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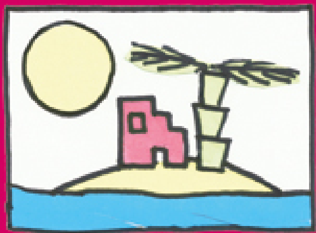
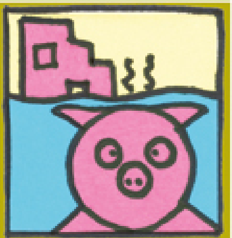
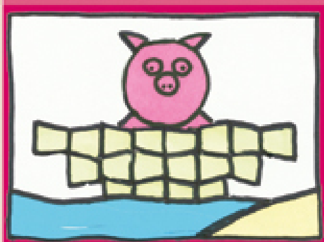




Innovation development for highly energy-efficient housing

Opportunities and challenges related to the adoption of passive houses



Erwin Mlecnik

TU Delft Delft University of Technology

Challenge the future

Innovation development for highly energy-efficient housing

Opportunities and challenges related to the adoption of passive houses

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. ir. K.Ch.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op woensdag 20 maart 2013 om 15.00 uur

door

Erwin MLECNIK
burgerlijk ingenieur-architect,
Vrije Universiteit Brussel

geboren te Genk, België

Dit proefschrift is goedgekeurd door de promotoren:
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Samenstelling promotiecommissie:
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The series **Sustainable Urban Areas**
is published by IOS Press under the imprint Delft University Press

IOS Press BV
Nieuwe Hemweg 6b
1013 BG Amsterdam
The Netherlands
Fax +31 20 6870019
E-mail: info@iospress.nl

Sustainable Urban Areas is edited by
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The Netherlands
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E-mail mailbox@otb.tudelft.nl
http://www.otb.tudelft.nl

Design: Cyril Strijdonk Ontwerpburo, Gaanderen
Printed in the Netherlands by Haveka, Alblasserdam

ISSN 1574-6410; 45 (print)
ISSN 1879-8330; 45 (online)
ISBN 978-1-61499-235-6 (print)
ISBN 978-1-61499-236-3 (online)
NUR 755

Contents

Acknowledgements

I would like to begin by thanking my supervisors, Professor Henk J. Visscher and Professor Anke (J.D.M.) van Hal for their continuous support, comments and suggestions for revisions. Without their continuous effort, this study would never have reached such a high standard. I would also particularly like to thank Sylvia J.T. Jansen (OTB), for her expertise on statistical analysis of end-user experiences, and Ger de Vries and Thorsten Schütze (Faculty of Civil Engineering) for providing Dutch research data for Chapter 6. Without their support and co-authorship, Chapter 6 would not have been realised. I am grateful to Dirk Dubbeling for his careful editing and to Evert Hasselaar for the continuous stream of ideas that he provided by organising events that explore challenges and opportunities of the market introduction of passive houses in the Netherlands. I would also like to thank my roommate, Ad Straub, for his timely advice on construction innovation theory and Dutch cases of enterprise innovation. Warm thanks are also due to all of my other colleagues from OTB-DWK, whose mailings and discussions have provided me with new ideas and research findings, as well as a clearer view of the research that remains to be done, with regard to both methodology and the achievement of practical results.

This work would not have been produced without the continuous support of the Passiefhuis-Platform vzw (PHP). I would like to thank the management board for allowing me the time off in which to focus on this work. Contributions by Christophe Marrecau, Stefan Van Loon, Irena Kondratenko, Wouter Hilderson, Johan Cré, Jeroen Poppe, Bart Cobbaert, Bart Deschoolmeester and several trainees led to co-authored articles and frequent discussions. Without the support of Peter Dellaert, Adriaan Baccaert, An Demaegd, Hilde Smets, Sandra Delaruelle, Astrid Strobbe and many others, the international passive house symposia, regional workshops and working groups would not have provided the continuous input that was needed for this research.

Much of the work that I have presented would not have been achieved without the research efforts and expertise of previous projects and activities (as well as that of the sources that supported them). Some of the data that I used could not have been developed without the thematic innovation stimulation project VIS-TIS 'Passiefhuis-Platform', which was funded by the Flemish Community (IWT) and co-funded by dozens of enterprises. I would like to thank all parties involved for their trust and contribution to this project. In particular, I would like to thank Cenergie cvba and Energie Duurzaam vzw for providing resources and a 'skunkworks' for starting up this project. The 'Promotion of European Passive Houses (PEP)' project within the Intelligent Energy Europe Programme (EIE/04/030/S07.39990) also provided some of the ideas that are used in this study, as well as an international forum of researchers studying the promotion of passive houses. Furthermore, I would like to thank the European Commission, who financed my contribution to the PEP project, as well as the Flemish Region, the Brussels Capital Region, the

Walloon Region and the FPS Economy, SMEs, Independent Professions and Energy, who co-financed under CONCERE-ENOVER agreement. The Transition Arena for Sustainable Living and Housing in Flanders also provided an excellent opportunity to discuss ideas in the ‘energy’ working group. I was able to develop ideas regarding renovation during the course of the ‘Low Energy Housing Retrofit (LEHR)’ project, which was supported by the Belgian Federal Science Policy. Some of the problems identified for renovation and suggestions for improvements were joint results that I generated in collaboration with three research teams (PHP/PMP, Architecture et Climat – UCL, CSTC-WTCB-BBRI). Furthermore, the LEHR project allowed a research contribution to the work meetings of IEA Solar Heating and Cooling Task 37 on ‘Advanced Housing Renovation with Solar and Conservation’ and provided connections to many international researchers. Amongst other benefits, the discussions held during this work generated valuable input and co-authorship of research reports and articles with Are Rødsjø, Trond Haavik, Edward Prendergast and Paul Parker. Furthermore, IWT also provided funding for my contribution to the ERANET-Eracobuild project ‘One Stop Shop’. I am grateful to all the Belgian, Danish, Norwegian and Finnish researchers who contributed to developing ideas, social experiments and research reports during this project. Special thanks are due to Trond Haavik for the many subsequent discussions we continued to have regarding the marketing of energy-efficient houses.

My decision to work in the Netherlands caused quite a stir, with many changes on the personal level. I would like to thank all partners, friends and family members for their continued support in these changing times. Special thanks are due to Mark-Jan and Lydia, who supported me every day with words of encouragement and relief from the stress of my studies. Furthermore, I would like to thank all of the interviewees for their contributions, particularly the owner-occupants, architects and enterprises involved. Some of them provided valuable feedback, information and an opportunity to do measurements. I hope that the results will benefit all present and future owner-occupants, in addition to contributing to future market development. I would also like to thank the many other people whose names I may have overlooked, but who have nonetheless provided me with inspiration.

Finally, I would like to thank professors and like-minded people from the period 1992-1996. Hendrik Hendrickx, José Depuydt and Marijke Mollaert, all from the Department of Architecture of the Vrije Universiteit Brussel (VUB), continuously inspired me to do research on a more holistic level, and to look beyond traditional engineering. I am grateful to my colleagues from the ‘Worldviews-Omega’ working group, which was initiated by the philosopher Leo Apostel. Furthermore, Professor F.P. La Mantia (University of Palermo) and Professor René Motro (Université of Montpellier) helped me to develop my first scientific rigor. Most of all, however, I am indebted to the late Professor Richard Vermuyten, who allowed me to develop an independent vision on construction research, and who always supported my research ideas (which were probably too advanced at that time), despite difficult circumstances. This study is dedicated to this visionary promoter of free research.

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Foreword

In 1992, I was appointed as the first officially employed full-time researcher in the Department of Architecture of the Vrije Universiteit Brussel. My official research topic was entitled 'domotics', my area of expertise was room acoustics, my promoter had given me a pile of research articles on low-energy housing and my colleagues tried to convince me to invest my time in either materials engineering, structural morphology or sustainable housing for the poor. I ended up working in a polymer lab investigating microstructural networks in new materials developed from household waste to build elements for developing dismountable energy-efficient low-cost housing to make it possible to manage our planet more effectively. This remains a great idea that calls for further research. At that point, however, I was confronted with reality: I had no researchers with whom to exchange ideas, I had insufficient expertise at the university, I was at the end of my contract and I had no funding from industry. The general advice that I received was, 'Find a network'.

I subsequently became unemployed, and I gradually became more patient and less anxious, realising that it can take a lifetime to achieve only one small part of an idea. I came to realise that, although connecting multiple disciplines can be a key to identifying innovative ideas, linking disciplines is far from daily practice at universities, especially when each professor is focused on only one small area of specialisation. This apparently cripples the process of innovation. It was only after considerable hesitation that I finally accepted a position in the Cenergie engineering firm, a spin-off of the University of Antwerp, focusing on research on energy efficiency. In this position, I was once again confronted with reality in the daily practice of energy consultancy. I experienced contractors who were incompetent, clients who lacked the resources needed in order to realise obvious savings, architects who lacked expertise and a general conservative attitude that always led towards business-as-usual. In 1999, I prepared a minor energy recommendation in which I combined all optimal energy-saving measures for a small community building. I reached the conclusion that, with a few minor changes in layout, this building could also easily do without space heating. Unfortunately, the client had no faith in such a solution. Fortunately, the people at Cenergie were visionaries and innovators. The recommendation revealed an important and much-needed internal shift from analysing energy-saving measures to delivering recommendations from the beginning of the design process. This observation in itself led to the development of many innovative engineering services, in addition to enhancing the effectiveness of communication with market actors.

Highly energy-efficient housing became visible during Cenergie's corporate visit to the World Expo in Hannover in 2000, where employees had the opportunity to sleep in a passive house. Although most of us had never experienced a passive house, they had apparently, been in existence in Germany since 1992, and hundreds of them had already been built. We wondered why our well-known university researchers had never told us anything about them. Consequently, three of us visited the Passivhaus Institut in Darmstadt, where Wolfgang Feist showed us the many passive house innovations that were already available on the German market, as well as an entire room filled with a library of research reports about passive houses. We realised that Belgian enterprises and universities were about ten years behind in research and technology development. In our spirit of innovation, we concluded that change was needed. Two of us decided to build the first passive houses in Belgium. For my part, I decided to focus on the dissemination of knowledge. Interested actors could be found through connections in daily engineering practice, and the opportunity arose to 'create a network'.

In 2002, after two years of preparation – and thanks to generous freedom provided by Cenergie and Energie Duurzaam – 'Passiefhuis-Platform' was born, which I would coordinate for many years to come, within the framework of an innovation study. The organisation survived after its initial subsidy, and it now counts more than 350 professional enterprise members representing a wide range of disciplines from the construction chain, all supporting the idea of realising passive houses and other forms of highly energy-efficient construction.

You might wonder why I would conduct studies on developing a market for highly energy-efficient housing, given that such a market already exists. The answer is that my choice is largely due to my observation that other networks, universities and policy actors still can and need to learn from our experience. Critical mass must be developed even if we wish to take even a small step forward in sustainable development. University researchers are particularly well positioned to set the tone of policy development. Moreover, the primary critique from various members at Passiefhuis-Platform is that many education arenas and universities have yet to integrate the available innovations into their curricula. At OTB, I found a multidisciplinary research environment that covers both sustainable construction and policy within which to conduct this series of studies. An interesting research question would have been why universities were so far behind in adopting this passive house innovation. Although I did not investigate this question, I hope that this work will ensure that one small aspect of sustainable housing (i.e. energy efficiency) can no longer be neglected in future innovation research.

1 Introduction

'We cannot solve our problems with the same thinking we used when we created them'.

Albert Einstein

1.1 The passive house market: an innovation research opportunity

Our world is facing enormous challenges created by a continuously increasing population of humans with increasing material and energy needs. In the latter decades of the twentieth century, insights developed in thinking about a way of 'managing' earth, particularly the built environment, in a more socially responsible and resource-efficient way. Design philosophy expressed a need for low-energy buildings that take account of the natural environment and a call emerged for 'integrated design' processes. A line of thinking developed that rejected the building skins which create an unfavourable indoor climate that constantly needs to be corrected with mechanical devices. The design along the lines of 'passive solar' criteria became a respected architectural approach, using the building skin as the primary climate control.

Furthermore, the oil crises in the 1970s were an important wake-up call regarding the limited availability of fossil energy and the social implications of a society's adherence to oil. Researchers put forward different approaches and technological options in a bid to significantly reduce the energy used by housing. The late 1970s saw the emergence of rudimentary ideas for integrated design concepts for minimum-energy dwellings. Researchers have been introducing various concepts ever since such as 'the autonomous house', 'the climate-responsive design', 'the passive house', 'the (net) zero-energy house', 'the zero-carbon house', 'the green building', 'the sustainability approach', 'the exergy-approach', 'the carbon-neutral city', and many more. These concepts put more or less emphasis on energy efficiency of various energy flows, the use of renewable energies as well as addressing a more responsible behaviour by users. As an important element in all these approaches energy efficiency of buildings has always figured as a main theme in research and engineering. Model projects were built as government money was freed up to promote energy efficiency. The energy crises of the 1970s led to the first statutory low-energy standards for new buildings in, for example, Sweden and Denmark. At that time, many innovations were developed to substantially reduce the energy used by buildings, including thick thermal insulation, minimised thermal bridges, air-tightness solutions, insulated glazing systems and heat recovery for ventilation. However, the innovators who proposed integrated designs for minimum-energy dwellings combining various innovations did not find a strong enough response in the mainstream construction industry. The market development of such buildings was not essentially a technological problem, but rather a social problem of adoption. The construction sector needed to change.

The construction of new homes and the renovation of existing homes currently offer opportunities to achieve considerable reductions in energy use, with the goal of decreasing CO_2 emissions, increasing energy security and combating climate change and energy poverty. To this end, energy policy programmes have been introduced in European countries with the goal of raising (and continuing to raise) the energy-performance standards for homes. For example, the European Energy Performance of Buildings Directive (EPBD, 2010) has been revised in such a way that member states must now introduce obligations for achieving nearly zero-energy newly built construction by 2020. Researchers and policymakers are now expected to provide valuable recommendations for how to interpret the requirements of the European Directive (EPBD, 2010) for introducing nearly zero-energy homes by 2020. At the same time, the construction sector must now prepare for a socio-technical transition towards a volume market of such highly energy-efficient housing.

Regarding the experience of limited diffusion of integrated design concepts in the previous decades, it is nonetheless logical to consider whether we can expect enterprises, users and policymakers to move smoothly into this required transition. Some researchers (Silvester, 1996; van Hal, 2000; Femenias, 2004) have noted that, if we are not careful, we might remain in a demonstration phase with regard to sustainable housing without ever progressing into the mainstream market. On the one hand, the state of the art regarding available energy efficient technology solutions is already relatively advanced. On the other hand, the implementation of highly-energy efficient buildings is still at an early market development stage in most European countries, and it is proving difficult to diffuse integrated concept solutions beyond the demonstration phase (IEA, 2006; Rødsjø *et al.*, 2010). The construction sector appears to be experiencing difficulty in moving integrated design concepts from demonstration projects to volume market and in introducing, adopting and diffusing related innovative technologies and systemic solutions.

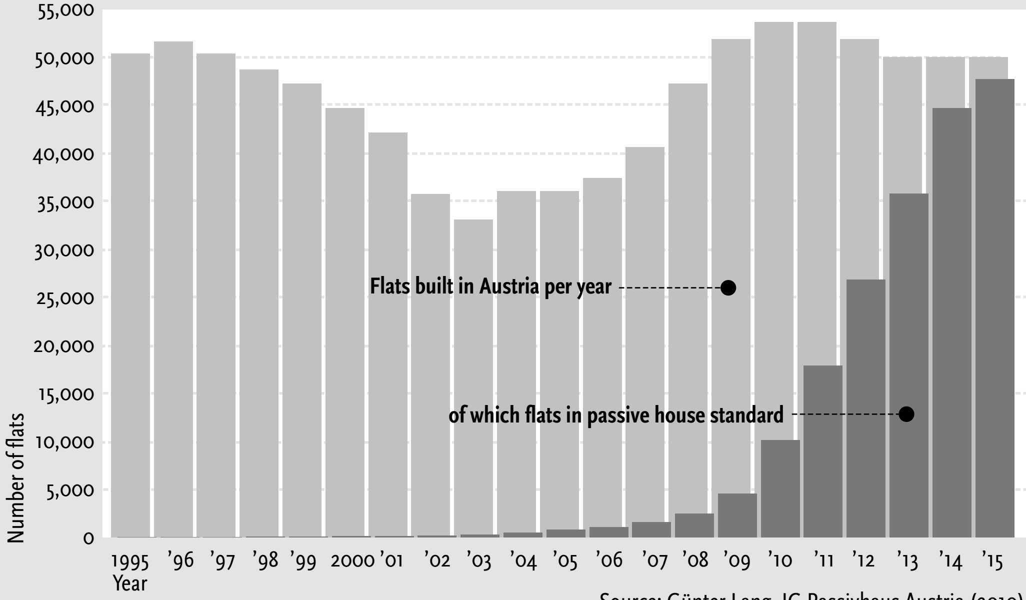
As previous explained, various concepts have already been introduced in research and engineering, and of these the ‘passive houses’, also known as ‘Passivhaus’ projects, appear to be very successful beyond the demonstration project and across various countries. Passive houses are therefore worth studying as an illustration of a successful market introduction of a concept and lessons can be learnt how various integrated design concepts could diffuse in the construction sector. Worldwide research by the International Energy Agency has revealed the strong influence of the passive house concept on the achievement of a market development of highly energy efficient housing (IEA, 2006; Rødsjø *et al.*, 2010; Haavik *et al.*, 2012). Authors are currently observing the emergence of a passive house market in almost all European countries, with variations in the rate of adoption across countries and market segments (e.g. new residential construction, home renovation and non-residential buildings; see Haavik *et al.*, 2012). In general, the numbers of renovated projects with high energy-efficiency performance are still limited in most countries, although a renovation market niche is emerging from experiences with newly built houses (Haavik *et al.*, 2012). In addition to differences in market segments, some countries and regions are faster than others are to adopt highly energy-efficient housing. Figure 1.1 illustrates how the passive house market is rapidly developing in Austria, and Figure 1.2 illustrates the current development of innovation.

Currently, the residential passive house market is more advanced in central European countries (PEP, 2008). The market introduction of passive houses started with newly built projects in Germany in the 1990s. Following these documented German examples, clients and supply-side actors built thousands of passive houses in Austria, Germany and Switzerland. The information gradually spread to other European countries as well. Passive house projects have recurred steadily in most European countries, although a majority of the market has yet to be reached. Regional differences also exist within countries. For example, in some frontrunner regions (e.g. social housing in Vorarlberg in Austria), passive house requirements have been introduced as obligatory, thus paving the way to reaching an early majority of the market (Haavik *et al.*, 2012).

While Austria, Germany and Switzerland started by developing a niche market for passive houses, other countries (e.g. the Netherlands and Belgium) did not realise their first passive houses until the beginning of this century (PEP, 2008). Countries that have been slower to develop the passive house market can learn from other countries and regions regarding processes that facilitate adoption by enterprises and users, as well as with regard to policies for stimulating innovation and deployment. The passive house experiences in 'frontrunners' are therefore an interesting topic of study for purposes of guiding energy and innovation policy development in Belgium, the Netherlands and other countries with a slower market development. For example, while the construction sectors in Germany, Austria, Switzerland and even Belgium have had considerable experience with the implementation of innovative passive house technologies and related business and policy innovation, the concept continues to be treated as an innovation in the Dutch market. This perception implies that the passive house concept still requires careful scientific validation, which could possibly result in market introduction, adoption by business and customers, and integration into policy (PEP, 2008).

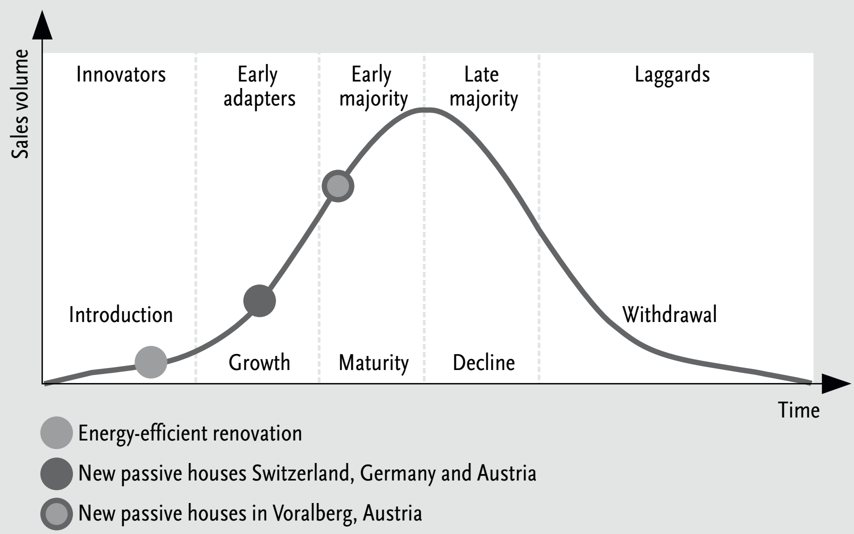
It might be interesting to draw generic lessons from the Belgian situation, where the market development for passive houses can be considered more advanced than in the Netherlands, and where a rapid adoption of the concept by businesses, end users and policymakers has been observed. For example, more than 350 companies are already supplying passive house solutions in Flanders, northern Belgium, and as a European frontrunner the Brussels

Figure 1.1 Follow-up and projection of the development of the passive house market in Austria



Source: Günter Lang, IG Passivhaus Austria (2010)

Figure 1.2 Product Life Cycle curve illustrated for passive house development



Source: Haavik *et al.* (2012)

Capital Region has pledged to introduce passive house requirements as a construction standard for newly built construction by 2015. On the other hand, research could also draw lessons from countries in which the market is even more developed (e.g. Austria, Germany and Switzerland).

The topic of adoption and diffusion of innovations (e.g. passive houses) provides an interesting research opportunity, and it can contribute to the development of innovation theory. From theory, scientists have found that the speed with which companies adopt innovation can be influenced by societal, technical, economical, geographical and policy circumstances (see e.g. Rogers, 2003). Such 'innovation-diffusion' processes have been studied for the introduction of various technologies (Rogers, 2003). In addition, strategic niche management scientists (Kemp, 1994; Kemp *et al.*, 1998; Rotmans *et al.*, 2000; Schot *et al.*, 1994; Vanden Belt and Rip, 1984) have developed models and pathways through which niche processes for innovation can emerge and bring about broader changes. Such broader changes occur in relation to expectations and visions (Kemp *et al.*, 1998), as well as in relation to a wider contextual 'landscape', which consists of societal factors (demographics, political culture, lifestyles and the economic system), which can change only slowly over time (Raven, 2005). In addition, marketing researchers highlighted the importance of key issues for innovation development, including the stimulation of enterprise collaboration (Porter, 1998), addressing specific user segments (IEA, 2006) and the use of approaches that target specific market phases (Rødsjø *et al.*, 2010). Even environmental behaviour scientists have contributed to the field of innovation-diffusion theory by showing models of how clients can be motivated to adopt innovations with an environmental benefit (Jones and De Meyere, 2011).

Scientific literature is nevertheless scarce with regard to the barriers and opportunities that can impede or stimulate the effective adoption of integrated design concepts and highly energy-efficient innovation in construction companies, as well as with regard to why enterprises and users decide to adopt and experience systemic solutions (e.g. passive houses). While scientists have described innovation-diffusion theory approaches and specific analyses to highlight the importance of processes, social factors and landscape factors, such theoretical approaches have only rarely been applied to the investigation of innovation barriers and opportunities with regard to highly energy-efficient housing. While marketing scientists acknowledge the presence of market-development gaps between various market phases for various technologies, factors influencing these gaps and the transition from one development phase to the next are also less well understood, and they are only rarely investigated for the construction sector. Theoretical approaches that can help leading the market to innovation deployment should therefore be studied in more detail – particularly for integrated design concepts for the segment of highly energy-efficient housing – in order to develop better and more scientific ways of guiding enterprises, users and policymakers towards the wider adoption of highly energy-efficient housing. The European passive house market development is widely acknowledged, and it can be used as a new source for scientific investigation.

As mentioned earlier the topic of passive houses is certainly of interest as an example of successful diffusion of an integrated design concept beyond the demonstration phase. With a German, Austrian and Swiss background, it is not 'brand new' as an innovation. Nevertheless increasing energy efficiency of buildings is key for a more sustainable development and entering new markets – such as Belgium and the Netherlands – is crucial to support the EU goals and the proposed innovation studies carry the potential to catalyse this process. The previous discussion shows that concepts and actors can promote innovation, and innovations (e.g. passive houses) can move into the mainstream. It is important to consider which lessons this development could provide for process and policy changes with regard to the delivery of highly energy-efficient homes and deployment of innovation in countries and regions, especially those with an emerging passive house development. It could also offer insights that could stimulate the development of a volume market in countries and regions in which the market is entering the mainstream.

To relate to both the practical and scientific challenges described earlier, the present work applied various theoretical approaches to investigate several research questions (see further) related to the adoption of passive houses by companies, customers and policymakers. A series of innovation studies have generated valuable generic lessons for developing innovation theory and the uptake of innovation for highly energy-efficient homes. The primary focus was on newly built houses and on passive houses, but many lessons apply to major renovations as well. Although research drew mainly on the development of the passive house market, the models used and lessons on theory can be applied by other scientists in the deployment of other energy-efficient integrated design concepts (most notably 'zero-carbon' homes, 'net zero-energy homes' and 'energy-plus homes'), as well as other concept approaches (e.g. based on sufficiency, renewale energy, sustainability criteria). At the same time, the lessons provided can nurture the further development of several theoretical frameworks, including innovation diffusion, systemic innovation and the marketing of housing.

In the following section of this introductory chapter, several overarching issues (combating climate change, securing energy supply, combating the economic crisis) are explained in order to provide insight into why enterprises, customers and particularly policymakers should focus on achieving high energy efficiency in homes. This section provides an overview of 'landscape' factors influencing the market development of highly energy-efficient homes. It also provides a concise overview of European and Dutch policy changes that are expected to influence the construction sector. Following this discussion, the research problem and goal are defined and research questions are developed with regard to adoption by enterprises, users and policymakers. This is followed by a brief introduction of the applied theories of innovation research and the research methods, along with an explanation of the limitations of the research. The chapter concludes with an overview of the structure of the entire study and how it can be read.

1.2 Drivers of high energy efficiency; opportunities for innovation

First, it is important to understand the most important expectations and landscape factors that can affect the construction sector's transition towards highly energy-efficient housing.

1.2.1 Combating climate change and reducing greenhouse gas emissions

The promotion of 'efficient energy use' (in short 'energy efficiency'), is an essential element in the achievement of the climate-change mitigation goals specified in the United Nations Framework Convention on Climate Change and its Protocols (Pachauri and Reisinger, 2007).

Greenhouse gas emissions lead to increasing global temperatures, which can have major implications on the global physical environment, influencing ecosystems, water supply and crop and animal productivity (Pachuari and Reisinger, 2007; Bresser *et al.*, 2005). Within the framework of the Kyoto Protocol, most developed countries have engaged in combating climate change by reducing emissions of six greenhouse gases[1] by an average of over 5%, as compared to 1990 levels (UNFCCC, 1998). According to the agreement, this reduction should already have been achieved between 2008 and 2012, but the global reduction of CO_2 emissions was not successful. Under the supervision of the European Community, the Netherlands was required to reduce CO_2 emissions by 6%. In 2007, the Bali Action Plan was adopted, stating that industrialised countries should have measurable, verifiable and comparable actions and percentages for reducing greenhouse gas emissions. International agreements to achieve the main objective of the UN Climate Convention have yet to be made for the post-2012 period (VROM, 2008).

An even more important driver appears to the European Council's 2007 agreement to establish deeper absolute emission-reduction commitments and to cut greenhouse gas emissions in the European Union (EU) by at least 20% by 2020 relative to current levels. The Council also endorsed a commitment to reduce emissions by 30%, as part of a comprehensive, global climate agreement beyond 2012, provided other developed countries adopt comparable reductions and provided that developing countries that are more eco-

1 CO_2, CH_4 and N_2O and the fluorine compounds HFK, PFK and SF_6.

nomically advanced contribute as well. As part of a decision by the European Commission's Environment Council (20 February 2007) and the Spring European Council (2007), an appropriate European framework was proposed to enhance efforts to address adaptation by increasing cooperation in the areas of technology, research, development, diffusion, deployment and transfer.

In addition, local authorities are increasingly placing climate issues high on their agendas. More regional authorities are demonstrating a high level of ambition with regard to ecological and climate protection. This can be observed in the increasing number of members of European initiatives (e.g. the 'Climate Alliance of European Cities' and 'Energy Cities'). Municipalities are also engaging in local Kyoto targets and CO_2 neutral community developments, and many have signed the European Covenant of Mayors for formalising energy-saving and climate-protection objectives.

Globally, around 65% of greenhouse gas emissions are energy related. The most important greenhouse gas is carbon dioxide (CO_2), accounting for 82% of total EU emissions in 2002 (Balaras *et al.*, 2007). A majority of global emissions are produced from power generation and distribution (24%; Williams, 2012). About 39% of total EU emissions of CO_2 originate from electricity and heat production (Balaras *et al.*, 2007).

Most climate researchers currently agree that a global temperature rise above 2 K would lead to serious difficulties with regard to maintaining current human settlements and safeguarding ecosystems. For example, present trends may accelerate sea-level rise and land subsidence, thereby leading to serious problems in the lower-lying regions (e.g. the Netherlands) in the second half of the 21^{st} century (Bresser *et al.*, 2005). The is a major challenge: with current atmosphere CO_2-equivalent concentrations, avoiding global warming in excess of 2 K would require reducing CO_2 emissions related to fossil fuel to almost zero by 2050 (Aitken *et al.*, 2004).

Buildings contribute significantly to global greenhouse gas emissions (8%, largely CO_2 emissions; Williams, 2012). Reducing CO_2 emissions from buildings, largely due to energy use related to fossil fuels[2] is an important focus within this debate on energy and climate. Buildings represent the largest end-energy use, accounting for approximately 40% of the world's total energy use (Laustsen, 2008). Europe's buildings are a large energy user as well, comprising 40% of final energy use and 36% of CO_2 emissions in the EU (EC, 2003;

2 The most polluting fuel (in terms of CO_2, SO_2, NO_x and particulate emissions) is coal, followed by oil (Balaras *et al.*, 2005). In the United States, buildings are estimated to account for about 35% of CO_2 emissions, 50% of sulphur dioxide emissions, 22% of nitrous oxide emissions and about 10% of particulate emissions (Vine, 2003). As a solution for reducing carbon emissions, nuclear energy is regarded as too easy and addictive, and it is considered likely to reduce pressure to develop innovations in terms of renewable energy sources, in addition to acting as a disincentive with regard to energy efficiency (Sunikka, 2006).

Itard *et al.*, 2008; ACE *et al.*, 2009). In 2000, energy use in residential buildings accounted for about 65% of the total final energy demand in the building sector (including all buildings in the residential and tertiary sectors), with households using 244.7 Mtoe in EU-15 and 279.1 Mtoe in EU-25 (Balaras *et al.*, 2005)[3]. In the Netherlands, the built environment currently accounts for approximately a third of the total primary energy use. According to Statistics Netherlands (CBS), most of this energy (largely of natural gas and electricity) is used for providing a comfortable indoor temperature and climate (heating, cooling and ventilation), producing hot water and operating electrical appliances.

Buildings have an estimated potential to reduce global greenhouse gas emissions by around 20-30% (1000-1100 MtCO_2,eq/yr) in the year 2020 (Pachauri and Reisinger, 2007). There is significant potential for cost-effective energy savings and CO_2-emission reductions in both new and existing buildings (McKinsey and Company, 2009).

1.2.2 Securing energy supply

The issue of energy efficiency is also directly related to energy security. European countries spend about 3% of their gross domestic product on oil and gas imports, thereby supporting Russian oligarchs and oil-exporting countries (e.g. Libya and Iran) through the purchase of oil and gas. In the 12 months from October 2010 to September 2011, import dependency has cost the 27 EU countries around €408 billion. During the same period, the account deficit of the EU 27 was about €119 billion (Liese, 2012). Reducing dependence on energy providers (and on uncertain future energy costs), as well as on resources from unstable regions is therefore an important policy issue at the European, national, regional and municipal levels. Some municipalities (e.g. Kristianstad in Sweden) and regions (e.g. Samsø in Denmark and Växjö in Sweden) already profile themselves as fossil-fuel-free communities. Energy imports affect the development of prices (up to economic instability) and the generation of political conflicts. Reductions in energy use help to reduce dependence on energy imports. For most countries, however, security of supply can be obtained only when energy imports are sufficiently low.

To eliminate problems of energy security, regions, nations or groups of nations must become more self-sufficient. To this end, the European Commission[4] has proposed a wide-ranging energy package that provides a new boost to energy security in Europe (e.g. by advancing a new strategy for building

3 Prior to the accession of ten candidate countries on 1 May 2004, there were 15 member countries in the European Union. On January 1st, 2007, two additional countries joined, thus resulting in the EU-27.

4 Discussion and policy documents available online: http://ec.europa.eu/energy/strategies/2008/2008_11_ser2_en.htm, accessed: 29 June 2012.

energy solidarity among member states and proposing an Energy Security and Solidarity Action Plan to secure sustainable energy supplies within the EU).

Against this background, in late 2006, the EU pledged to reduce its annual use of primary energy by 20% by 2020. In March 2007, the European Council formalised the following policy goals for 2020:

- Increase energy efficiency to achieve a reduction of 20% in total energy use (below 2005 levels).
- Achieve a 20% contribution of renewable energies to total energy use (11.5% above 2005 contribution).
- Achieve a 20% reduction of greenhouse gases below 1990 emissions (14% below 2005 emissions).[5]

On the one hand, this means that energy demand must be decreased through energy-efficiency measures. On the other hand, once demand is reduced, it becomes more feasible to replace finite sources of energy with renewable sources. In some cases involving new developments, it can even become feasible to eliminate the need for new energy sources[6] or fossil fuels.

Various studies have demonstrated the dominance of energy use for space heating in household energy use (ECN and RIVM, 1998; Van der Waals, 2001; De Jonge, 2005; Klunder, 2005; Itard *et al.*, 2008). For example, researchers from Enerdata (2003) demonstrated that household energy use by end-users in EU-15 member states is dominated by space heating (70%), followed by water heating (14%) and electrical appliances and lighting (12%)[7]. These results indicate that greater carbon-reduction potential – particularly the reduction of energy demand for space heating – could make a major contribution to achieving climate change and energy-security objectives.

Various researchers have called for improving energy efficiency by a factor of four on average (relative to current rates) over 25 years (Von Weizsäcker *et*

5 Targets elaborated within the document E2B Impact Assessment, Version 2, February 2009.

6 For example, IG Passivhaus Austria reports a case in which a new urban neighbourhood development in Austria was planned with a new power-generation plant for the district. Once the energy need was calculated for the district (if executed as passive houses), however, it appeared that the investment in new energy-production facilities could be avoided entirely (communication by Günter Lang, IG Passivhaus, 2008).

7 Research data can vary according to the research strategy used. However, the dominance of space heating has always been prevalent. For example, for European residential buildings, Chwieduk (2003) estimates that about 57% of all final energy use is used for space heating, 25% for domestic hot water and 11% for electricity. Itard and colleagues (2008) demonstrated that, on average, tap water and space heating are responsible for over 60% of final energy use in both residential and non-residential stocks. On average, the residential stock (comprising households) is responsible for 30% of total final energy use, with use proportional to the useful floor area (Itard *et al*., 2008). It can also be noted that household energy demand is expected to increase by 0.6% pa in 2000-2030, largely due to the increasing number of households (Balaras *et al*., 2005).

al., 1998; Raad voor het Milieubeheer, 1996; Reijnders, 1998). Von Weizsäcker and colleagues (1998) describe the example of the 'passive house' as an illustration of a possible system solution for residential buildings in order to achieve such targets, compared to newly built constructions realised according to current methods (von Weizsacker *et al.*, 1998). Today, thousands of passive house demonstration projects in many European countries have already provided convincing data suggesting that reducing the demand for non-renewable energy by a factor of four, relative to national building energy-performance standards is not only possible, but also realistic, while maintaining good comfort conditions during winter and summer (PEP, 2008; Schnieders, 2003; Schnieders and Hermelink, 2006; Mahdavi and Doppelbauer, 2010). In addition, compared to other highly energy-efficient housing concepts, the passive house appears to be robust with regard to behavioural influences (Schnieders 2003, Schnieders and Hermelink, 2006).

1.2.3 Combating the economic crisis

In order to combat the economic crisis, Europe will be focusing on economic savings and growth in the coming years. Creating jobs, providing cost-effective solutions and combating energy poverty will be important items on the policy agenda.

The shift in focus from energy production towards energy efficiency is expected to have a significant economic effect. According to FIEC (the European umbrella organisation of contractor federations), in 2007 the European construction sector accounted for 30% of industrial employment, contributing to about 10.4% of the gross domestic product, with three million enterprises, 95% of which are small and medium-sized enterprises (SMEs). In all, 48.9 million workers in the EU are dependent upon the construction sector (either directly or indirectly). Within the construction market, the industrial building sector (residential and non-residential) is the largest economic sector, as such construction and refurbishments accounted for 80% (€1,200 billion) of the total output of the construction sector (€1,519 billion) of EU27 in 2007.

The European Commission highlights opportunities for new investment, cost savings and jobs that a low-carbon economy would provide and presents a strategic plan for accelerating the development of such opportunities and the deployment of cost-effective low-carbon technologies.[8] According to calculations by the European Commission (COM (2005) 0265 final), around one million jobs could be created in Europe (mainly in national SMEs and European industries) through the direct and indirect effects of increasing energy

8 Discussion and policy documents available online: http://ec.europa.eu/energy/strategies/2008/2008_11_ser2_en.htm, accessed: 11 June 2012.

efficiency. In addition, calculations by the European Commission (COM (2008) 772) estimate that an average household could save at least €1,000 per year through energy efficiency measures.

The strategic plan of the European Commission therefore includes measures relating to planning, implementation, resources and international cooperation in the field of energy technology (EC, 2007). Various initiatives (including within the construction sector) are seeking to exchange and apply good practices to improve their energy efficiency and promote low-carbon business and economic development. For example, various EU programmes have been established to investigate, highlight or promote policy, economic, social and technological opportunities related to establishing higher energy efficiency in the building sector (e.g. Intelligent Energy Europe, SAVE, ALTENER, ERACOBUILD). Further, the Covenant of Mayors[9] is an ambitious Commission initiative that seeks to bring together the mayors of Europe's most pioneering cities in a permanent network in order to exchange and apply good practices aimed at improving their energy efficiency and promoting low-carbon business and economic development.

In addition, the awareness of possible future 'energy poverty' is on the political agenda of many countries. In the long term, energy prices are expected to rise due to decreasing resources, even to levels that would endanger the economic buying power of households and rental income from social housing enterprises (Rødsjø *et al.*, 2010). The most feasible way of combating energy poverty would be to reduce energy-related expenses. Energy-efficient buildings could reduce the energy bills of households and businesses.

1.2.4 European policy development

It is thus widely recognised that energy use in housing has a significant impact on the global production of greenhouse gases – particularly CO_2 emissions. Furthermore, energy-efficient housing provides opportunities for securing energy supply, creating jobs and assuring the purchasing power of occupants. Europe has therefore agreed a forward-looking political agenda in order to achieve its core objectives of combating climate change and ensuring competitiveness and security of supply. Improving energy efficiency is expected to prove decisive for competitiveness, security of supply and the ability to meet the commitments on climate change made under such agreements as the Kyoto Protocol. Meanwhile, with regard to the challenges that Europe will face between 2020 and 2050, a package of energy-efficiency policy proposals is being adopted, with the goal of realising energy savings in such key areas as buildings and energy-using products.

9 http://www.eumajors.eu, accessed: 11 June 2012.

The recent recast of the Directive on Energy Performance in Buildings (EPBD, 2010), which was approved 19 May 2010, can be seen a major legislative instrument affecting energy use and efficiency in the EU building sector, as it significantly increases the required energy-efficiency levels for EU buildings. In addition, the objectives of the European Community Competitiveness and Innovation Framework (2007 to 2013) include significant and demonstrable progress towards achieving a more efficient and responsible use of energy. In line with the European Economic Recovery Plan, further strategic targets affecting Energy Efficiency in Buildings and the associated innovation potential are also associated with the following policies (EeB, 2009): the EU Lisbon Strategy for Growth and Jobs; the Barcelona 3% RTD intensity objective; the Action Plan on Energy Efficiency in Europe (saving 20% by 2020); the Directive on End-use Energy Efficiency and Energy Services; the White Paper on Renewable Energy Sources (RES); the Action Plan on Energy Efficiency ('Doing More with Less'); the Directive on Electricity from Renewable Energy Sources; the Directive on eco-design of end-use energy using equipment; the Directive on energy labelling for appliances; the Directive on high-efficiency cogeneration based on heat demand; the European Strategic Energy Technology Plan; the Environmental Technology Action Plan; the EU Sustainable Development Strategy; the Green Paper Towards a European Strategy for the Security of Energy Supply; the EU leadership and mandate of the Kyoto Protocol internationally assumed in Bali and Poznan; and the i2010 Strategy and Communication.

European member states are expected to implement these Directives in their national policies and to take into account the Plans and Protocols in their policy development. This policy agenda is expected to lead to substantial change in Europe's energy system and construction sector in the coming years, with active involvement from public authorities, energy regulators, infrastructure operators, the energy industry, the construction industry and citizens. The 'landscape push' thus implies making choices for energy efficiency and investments in innovation during a time of economic crisis. Within these side conditions, capturing the energy-efficiency potential of residential buildings will be a major challenge. One of the most difficult problems in the coming decades will involve the decarbonisation of the built environment (Oreszczyn and Lowe, 2010). Nevertheless, significant potential exists to reduce the rate of future emissions in the building sector by promoting the more rapid uptake of energy efficiency in buildings (Wiel *et al.*, 1998; McKinsey and Company, 2009). Realising this potential will require change on a massive scale, strong global cross-sectoral action and commitment, in addition to a strong policy framework (McKinsey and Company, 2009). This transition will require the mobilisation of scientists, decision-makers and market operators.

1.2.5 The development of the policy framework in the Netherlands

As early as the 1990s, Dutch policy development acknowledged that both renewable energy sources and energy-efficiency measures have an important potential for reducing CO_2 emissions and securing the energy supply (Lysen, 1989). Dutch researchers (Lysen, 1996; Duijvestein, 1997) recommended integrating energy efficiency, renewables and the clean use of fossil fuels in energy policies in three consecutive steps (the Trias Energetica):[10]

1. Permanent increase in energy efficiency
2. Augmented use of renewables
3. Cleaner use of remaining fossil fuels.

The Dutch interpretation of the European Directive on Energy Performance in Buildings (EPBD, 2002) before its recast (EPBD, 2010) was officially approved in January 2008. Since then, several policy initiatives have been launched in order to improve the energy efficiency of housing. For example, the Dutch Platform Energy Transition in the Built Environment (PEGO)[11] was a cooperative effort of government, industry, knowledge institutes and non-governmental organisations. In January 2008, these actors committed themselves in a covenant entitled 'More with Less' ('Meer met Minder'), which involves realising energy savings of 30% in 2.4 million existing houses and other buildings by 2020. Pilot projects are currently being built (VROM, 2008). The redefined covenant, which was approved recently, emphasises the achievement of supply-chain collaboration and the development of quality assurance for improving 300,000 houses each year, through two energy-label steps.[12] The improvements in the energy efficiency of the existing housing stock are also supported by the social housing, rental and real estate sectors (see 'Convenant Energiebesparing Huursector').[13]

Specific policy targets and programmes for energy-efficient newly built

10 The term 'Trias Energetica' – also known as 'Trias Energica' - relates to the integration of the three elements described above (Lysen, 1996). This integration of major elements of all energy strategies is also known as the '3-step strategy' (Duijvestein, 1997), which Dutch researchers have expanded for passive houses towards the 'Kyoto pyramid' (PEP, 2008).

11 Note by A. van Hal: PEGO ceased to exist in spring 2012.

12 http://www.rijksoverheid.nl/onderwerpen/energielabel-woning/documenten-en-publicaties/convenanten/2012/06/28/convenant-energiebesparing-bestaande-woningen-en-gebouwen.html?ns_campaign=documenten-en-publicaties-over-het-onderwerp-energielabel-woning&ns_channel=att, accessed: 2 August 2012.

13 http://www.rijksoverheid.nl/onderwerpen/energielabel-woning/documenten-en-publicaties/convenanten/2012/06/28/convenant-huursector.html?ns_campaign=documenten-en-publicaties-over-het-onderwerp-energielabel-woning&ns_channel=att, accessed: 2 August 2012.

housing were also defined in collaboration with the housing sector.[14] In particular, the 'Spring Agreement' ('LenteAkkoord', 22 October 2008,[15] redefined 28 June 2012) initiated a framework for cooperation amongst several local initiatives and specified energy-reduction milestones for newly built houses: 25% in 2010, 50% in 2015,[16] and even more for pilot regions. The recently revised version[17] strengthens the pathway towards achieving energy-neutral newly built construction by 2020.

Parallel to energy policies, specific innovation policy programmes are also guiding the development of innovation. In particular, innovation in SMEs was facilitated by the Dutch innovation-voucher scheme (until 2011),[18] as well as by innovation-performance contracts that allowed 10 to 20 companies to work together on innovation strategies.[19] 'Energy' was also defined as a major sector for innovation in the Netherlands.[20] While the 'Clean and Efficient' programme primarily concentrated on breaking the social trend, the programme Entrepreneurial Innovation in the Netherlands ('Nederland Ondernemend Innovatieland')[21] aimed to make better use of current knowledge and innovative entrepreneurial skills. The main objective regarding Dutch innovation policy for achieving energy-neutral new construction and sustainable exist-

14 Under the previous administration (Balkenende IV), the Netherlands specified the goal of reducing energy use by 25% in 500,000 houses/buildings in the period 2008-2011, with another 300,000 houses/buildings each year, beginning in 2012. An agreement with the social housing board specified a 25% reduction in gas use by 2020, compared to 2008.

15 http://www.lente-akkoord.nl/, accessed: 11 June 2012.

16 For non-residential buildings, the reduction goal was 50% by 2017. On 28 June 2012, the Spring Agreement was redefined after four years, combining energy reduction with user wishes. Although the ambition level for energy reduction for newly-built construction remains the same, the government has now placed stronger emphasis on bringing the message of energy reduction to the end-user, by more directly appealing to perceived advantages (e.g. increased comfort, a healthy indoor climate, reduced energy costs and increased value).

17 http://www.rijksoverheid.nl/onderwerpen/energielabel-woning/documenten-en-publicaties/convenanten/2012/06/28/convenant-herijkt-lente-akkoord.html?ns_campaign=documenten-en-publicaties-over-het-onderwerp-energielabel-woning&ns_channel=att, accessed: 2 August 2012.

18 Source: http://www.kvoucher.eu, accessed: 11 June 2012.

19 Source: http://www.agentschapnl.nl/organisatie/divisies/divisie/NL%20Innovatie and https://zoek.officielebekendmakingen.nl/stcrt-2012-10598.html, accessed: 11 June 2012.

20 Source: https://zoek.officielebekendmakingen.nl/kst-32637-15.html, accessed: 11 June 2012.

21 NOI programme, Ministry of Economic Affairs, November 2007.

22 Innovation programme for Climate-neutral Cities (Innovatieprogramma Klimaatneutrale Steden, or IKS). AgencyNL received 43 demonstration project proposals from communities. In 2012, 12 communities received grants for developing their plans regarding sustainable energy production and energy saving, and eight communities received cheques for process costs related to the implementation of their plans. Source: http://www.agentschapnl.nl/programmas-regelingen/klimaatneutrale-steden, accessed: 11 June 2012.

ing buildings was to define initiatives to ensure the achievement of the 2020 targets. More specifically, with regard to the built environment, the Climate-Neutral Cities innovation programme[22] helps Dutch communities to realise process innovations and plans for achieving climate neutrality. The Energy Innovation Agenda combines innovation issues of both programmes ('Clean and Efficient' and 'Nederland Ondernemend Innovatieland'), generating a single agenda for energy innovation, thematically based on the work achieved by the Energy Transition Platforms (Hameetman *et al.*, 2009). The 'Built Environment Innovation Agenda' (IAGO) aims to encourage and realise the necessary activities and instruments, including innovative steps for existing buildings, as well as innovation in new buildings.

Recently, the Dutch Ministry of the Interior and Kingdom Relations (BZK) implemented the 'Energy Leap' ('Energiesprong') programme, which combines elements from innovation policy, as a follow-up to the PEGO programme. The Energy Leap programme aims to make a substantial contribution to the conditions under which the energy transition can be achieved effectively. It further aims to deliver and upscale market-proof concepts that are 80% more energy efficient than previous market developments had been. The starting point for the programme is embedded within the government objectives, as expressed in the Built Environment Innovation Agenda (IAGO). For new buildings, it aims to create the market conditions for (and examples of) market-ready concepts that can lead to a 100% reduction in the use of fossil energy for heating and cooling (amongst other goals). For the retrofitting of existing buildings, it aims to create the market conditions for (and examples of) market-ready concepts that can lead to reductions of between 50% and 75% in the use of fossil energy for heating and cooling.[23] Knowledge sharing, chain cooperation and value creation are now seen as necessary preconditions for developing experiments and a successful transition.

In the Netherlands, a combination of measures (e.g. market stimulation, target setting in covenants, legislation and support of innovation) is thus already being developed. If we are to meet the established goals, we must accelerate the transformation of the energy and housing market significantly (see also: Moniz, 2010; Rødsjø *et al.*, 2010), in addition to addressing barriers to innovation diffusion and early market development. Within this framework of urgency, it is useful to investigate the market introduction of highly energy-efficient housing concepts as an innovation, in order to contribute to the required transition and to eliminate innovation and energy policy barriers with identified opportunities, specifically for the home-construction sector.

23 Source: presentation by Ivo Opstelten (SEV): http://energiesprong.nl/wp-content/uploads/2011/12/ES-longtermplan-def.pdf, accessed: 3 July 2012.

1.2.6 The passive house potential in Belgium and the Netherlands

The focus of the passive house concept is on applying mandatory limits in terms of space heating demand to 15 kWh/m²a.[24] As space heating dominates energy use in homes located in northern, western, eastern and central European regions, the passive house concept has become a European wide accepted solution to reach a significant energy demand reduction in the built environment (Elswijk and Kaan, 2008). In 2006, the European research project 'Promotion of European Passive Houses – PEP' calculated that in Europe an average energy reduction of 50% to 65% can be obtained per house compared to the business as usual. This estimate was based on national calculations. For example, the following scenario[25] illustrates how the implementation of passive houses was commented to contribute to greenhouse gas emission reduction in Belgium.

In Flanders in 2006 every passive house was estimated to save about 2,000 kWh electricity use (5,000 kWh primary energy use); every newly built passive house would additionally save 19,718 kWh gas compared to business as usual; every renovation towards passive house would save about 27,590 kWh gas per family. Taking into account the national emission factors for electricity and gas, every newly built passive house saves more than 5 ton CO_2 emission and every major renovation towards a passive house more than 7 ton CO_2. In a very modest scenario of 2,500 newly built housing units per year and 1,500 passive house renovations per year this would already contribute to a saving of about 28,600 ton CO_2 per year. If 10% of the newly built houses and major renovations would have been realized as passive house, the government would have saved about €870,000 due to avoiding having to pay for emission rights. In practice, this money would have been better spent for allowing grants for passive houses.

Most European countries have made progress in reduction of energy use in the housing sector and the introduction of incentives since 2006 and most countries are still continuously reinforcing the energy efficiency obligations. However, the application of the passive house in newly built construction still can save a factor two to four in space heating energy demand, compared to current national obligations. The energy saving potential in major renovations is still of a similar magnitude.

Regional circumstances and conditions can influence the market progress.

24 The reader is referred to Chapter 2 for a detailed introduction to the particularities of the concept and to chapter 9 for the policy positioning of the passive house.

25 See http://pep.ecn.nl and http://pep.ecn.nl/fileadmin/pep/pdf/E1_Erwin_Mlecnik.pdf for a detailed discussion on energy and emission saving potential (in Dutch).

Table 1.1 Barriers for the market development of passive houses in Belgium and the Netherlands, as compiled by Elswijk and Kaan (2008)

Barriers	Belgium	The Netherlands
Technical/construction barriers	Local construction methods and technologies have to be adapted to the passive house concept (e.g. brick cavity wall tradition, window casing, small heat pumps)	
	Lack of quality guarantee can lead to bad examples and counter-effects	Specifications needed for balanced ventilation systems, otherwise problems regarding indoor air quality and poor electrical performance may occur
	Small companies have little time to spare to innovate and require special attention and guidance in the development of innovations	Limited knowledge of thermal bridges and airtightness
Market related barriers	Pull-market incentives needed	Push-market incentives needed
	Bringing the concept to candidate-builders, general public	Bringing the concept to real estate developers and municipalities
	Traditional construction is associated with quality, innovation is considered risky	
Building regulations barriers	Lack of grants for passive houses; regional differences in regulation	Passive house may not comply to voluntary guarantee schemes, which might weaken its position in the market

Though the physical principles of passive houses are valid in general, the building tradition differs from country to country. In Germany, for instance, outer wall plastering is quite common, whilst in Belgium and in the Netherlands brick cavity walls are mostly applied. Both in Belgium and in the Netherlands passive house as phenomena was until recently only known in a limited circle of specialists. Both countries have seen a recent market development for passive houses stimulated by learning organizations and enterprise networks that address the specificities of the national market. The market progress of passive houses is now being influenced by market drivers and barriers of all sorts at different levels of the society. The previous subsections illustrated various energy efficiency drivers regarding combating climate change, reducing greenhouse gases, securing energy supply and combating the economic crisis. However, the adoption and diffusion of the passive house cannot be considered as something that will happen by itself in Belgium and in the Netherlands. Table 1.1 illustrates some of the various barriers detected in these countries that have to be eliminated.

Furthermore, the passive house development is not a stand-alone market development. Besides energy efficiency, the use of renewable energies as well as the sufficiency approach – addressing a more responsible behaviour by owners and tenants – led to various concept approaches regarding energy-related issues. While these approaches may be considered as complementary, they also lead to scientific approaches that can shift the focus away from energy efficiency. For example, urban energy planning, low-exergy building, energy-autonomous houses and zero emission architecture do not necessarily call for maximum reduction in space heating demand using passive measures, although the passive house principles can aid in realizing energy efficiency objectives. Each approach has its own pros and cons and various approaches may encounter specific adoption problems. For example, there is a growing body of literature criticising the focus on individual behaviour change and the preoccupation with providing information as a means to change behaviour. It is now recognised by many in this field that people do not necessarily act 'rationally' and that providing information will not necessarily lead to the types of behaviour change we might expect. For example, a discourse on privation and illustrating needed sacrifice sometimes can have an adverse effect. Regarding the use of renewable energies it is recognized by many authors that on the one hand solutions are needed beyond the context of buildings on the neighbourhood level. On the other hand energy efficiency of buildings makes the application of renewable energy more feasible: smaller production units are needed and the energy load mismatch between produced and used energy will be lower.

Meanwhile, landscape factors also push for broader concept developments that include sustainability next to energy. Such development regards energy use as only one pillar to achieve environmental goals. For example, 'active houses'[26] call for indoor climate and environment as key principles next to energy. For example, Dutch building sustainability evaluation tools like 'GPR Gebouw'[27] call for the evaluation of energy, environment, health, quality of use and future value as key themes, whereby the user can define the priority of objectives for each key theme. Furthermore, prescriptive developments are on-going to set specific requirements regarding functionality (e.g. comfort), durability (e.g. life-cycle analyses), health (e.g. indoor air quality), material efficiency (e.g. recyclability).

Various other developments thus hinder, complement or aid the passive house development. On the one hand, the passive house developed smoothly alongside the increasing public interest in energy efficiency in the framework of sustainability. On the other hand, the passive house concept – by means of demonstration projects in various cultures and climates – had a strong influence on worldwide development and interpretation of sustainable housing (IEA, 2006; Rødsjø *et al*., 2010). After an introduction phase the passive house has shown the potential to grow beyond a singular focus on space heating demand and initiate structural changes in society. This holistic process of generating impact on companies, end-users and policy makers is worth exploring. Putting the passive house concept into the broader picture of innovation development, lessons can be learnt for a variety of energy-saving, environmental and sustainability approaches that do exist.

26 Specifications see: http://www.activehouse.info (consulted: 21 January 2012).

27 See for example: http://www.gprgebouw.nl (consulted: 21 January 2012). call for the evaluation of energy, environment, health, quality of use and future value as key themes, whereby the user can define the priority of objectives for each key theme. Furthermore, prescriptive developments are on-going to set specific requirements regarding functionality (e.g. comfort), durability (e.g. life-cycle analyses), health (e.g. indoor air quality), material efficiency (e.g. recyclability).

1.3 Problem definition

As illustrated in the preceding sections, it is important to improve our understanding of challenges and opportunities related to achieving high energy efficiency. debates concerning climate change, security of energy supply and new economic opportunities and policy developments have revived the interest in energy efficiency and related innovations. There is significant potential for reducing energy use, especially in energy-intensive sectors (e.g. residential buildings).

Research should address challenges and opportunities related to the adoption of highly energy-efficient houses. Reducing energy use by implementing energy-efficiency measures in residential and other buildings is more challenging than might be expected (Lomas, 2010: 9). Buildings, energy concepts and energy-efficiency measures can differ widely across countries and regions, as they depend upon the culture, climate, available construction materials, differing legal frameworks, available information and expertise, and level of economic development. The adoption of the passive house is certainly worth focusing on – as an example of an integrated design concept – since increasing energy efficiency of buildings is key for a more sustainable development.

The previous section illustrated the need to investigate innovation opportunities and challenges for stimulating innovation development for highly energy-efficient housing concepts, particularly passive houses, in order to develop recommendations for a more rapid introduction of highly energy-efficient housing. Such research is particularly needed in countries in which the development of the passive house market is lagging behind central European countries (PEP, 2008). Such recommendations can contribute directly to the achievement of policy goals, in addition to illustrating opportunities for other European countries. The timing of such research is right, as member states must revise their current energy policies in accordance with the recast of the European Energy Performance of Buildings Directive (EPBD, 2010) in order to achieve the introduction of nearly zero-energy homes by 2020.

Researching and implementing innovation related to highly energy-efficient housing concepts, particularly passive houses, is in itself a challenge. As shown in the previous section, household energy use is particularly dominated by space heating. Given that adequate heating remains a basic need in housing, and given that people are not expected to use appliances less in order to conserve energy (Sunikka, 2006), enterprises, end-users and policymakers are challenged to integrate home construction concepts that involve less intensive reliance on space heating. Low-energy space heating can be realised only if heating losses are avoided as much as possible, which results in systemic solutions that address very good building thermal insulation, building airtightness and ventilation-heat recovery systems. A theoretical problem that emerges is that current innovation research and policy usually relates to individual technologies (e.g. solar collectors) or services (e.g. sanitation systems). Innovation and energy policy actors and businesses are accustomed to focusing on the component level of promoting innovation (e.g. requiring thermal insulation levels of walls or promoting certain types of thermal insulation, requiring efficiency levels of heating systems or promoting heat pumps). Experience with the promotion of concepts is limited. Despite the existence of energy-performance standards for buildings, holistic innovation approaches based on overall building energy efficiency have not been well researched.

Research on challenges and opportunities related to innovation adoption of highly energy-efficient housing concepts, such as passive houses, should lead to identifying various recommendations. The implementation of energy-efficient innovations in the building industry requires new policies, improved regulations and reformed practices in the industry itself (see e.g. Beerepoot, 2007; Visscher 2008; Ryghaug and Sorensen, 2009; Guerra Santín, 2010; Tambach *et al.*, 2010).[28]

Numerous obstructions to process and technological innovation were identified in order to achieve energy-neutral construction. For example, the Dutch Built Environment Innovation Agenda (Hameetman *et al.*, 2009) observes the poor transfer of European climate and energy targets to the national and local levels and lack of harmonisation amongst various schemes. Furthermore, an excessive gap has been identified between trendsetters and the majority of actors in the building world, in addition to a lack of an 'early market' and weak and fragmented lobbying by innovators. Market development is also hampered by insufficient demand from end-users and insufficient incentives for integral collaboration, as well as by an excessive focus on costs instead of on benefits and values. With regard to technology, authors have identified the lack of examples of cohesive system concepts and criticised insufficient co-development by industrial and knowledge institutes, in addition to insufficient harmonisation of various technologies for integral building concepts (Hameetman *et al.*, 2009). Lack of education in the construction sector has also been identified as a significant obstruction.

Finally, research on challenges and opportunities related to innovation adoption of highly energy-efficient housing concepts, such as passive houses, should lead to improvement in innovation theory. There is a need to go beyond traditional technology-oriented research towards concept solutions and services (EeB, 2009; Hameetman *et al.*, 2009). This study therefore looks beyond purely technological innovations to address systemic innovation opportunities, e.g. by examining the systemic innovation-adoption process

28 According to some of these authors, energy-efficient construction has been seriously restrained by deficiencies in public policies designed to stimulate energy efficiency and by limited governmental efforts to regulate the conservative building industry.

by suppliers, the opportunities for enterprise collaboration and the development of market niches. The demand side is studied as well, through reflection on end-user experiences, and policy challenges are addressed through the investigation of opportunities for collaboration and promotion. The research is unique in this respect. It identifies systemic innovation opportunities and challenges of highly energy-efficient housing concepts on the supply side, the demand side and within the steering environment. Combining these key items results in recommendations for innovation deployment, user adoption and energy policy development, and in various insights regarding how a concept approach can contribute to the development of innovation theory.

1.4 Goal of the research

As defined in the previous subsection, research on challenges and opportunities related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, can be very useful for further market development of integrated design concepts and improvement of theory. The goal of this research is to review, identify and refine such challenges and opportunities, as well as to develop practical recommendations and improvements in theory. To this end, it will detect and reflect the experiences in the successful passive house market as a case study.

From a practical viewpoint, this research aims to provide a deeper understanding and conceptualisation of the various factors (opportunities and barriers) that can affect the market introduction and development of highly energy-efficient housing concepts. To accelerate the introduction of nearly zero-energy houses, it mainly studies the adoption of passive houses and low-energy home renovations. Within this framework, the current viewpoints and experiences of enterprises, end-users and policymakers were explained. As original research, ten studies were defined in order to explain how the passive house concept is perceived and used by actors on the supply side (businesses), the demand side (end-users) and within the steering environment (policymakers), given that these actors influence the introduction, adoption and diffusion of innovations (Rogers, 2003) and that the current passive house market development provided an innovation research opportunity. These studies identified possible solutions for achieving a rapid increase in the adoption of integrated design concepts such as passive houses through the development of supply and demand (business innovation) and factors that could influence the innovation environment (end-user experiences with innovations and factors related to innovation and energy policy), taking into account possible solutions involving a 'concept' approach and systemic collaboration opportunities.

Directly related to the practical studies, company experiences, user experiences and experiences of enterprise networks in different market phases helped to improve understanding regarding several key issues and hypotheses from theory. The various studies contributed to the improvement of innovation theory related to a concept approach (instead of individual technologies) and enhanced understanding of innovation opportunities related to the promotion of (highly energy-efficient housing) concepts, in order to define pathways for eliminating barriers to innovation.

The development of innovation theory focuses on the ways in which a concept approach can contribute to innovation deployment, user adoption and energy policy development. The practical research on challenges and opportunities related to innovation adoption provides a coherent framework within which to reflect on innovation-diffusion theory at the concept level. Although the technologies, systems and services associated with highly energy-efficient housing concepts are probably not new to various target groups, an integrated design concept such as the passive house might be considered an innovation by many enterprises, end users and policy makers. Highly energy-efficient housing concepts (specifically passive houses) and their associated technologies, systems and services are therefore studied in an integrated way as 'innovations'. This 'concept' approach challenges innovation-diffusion theory in order to allow more explicit consideration of experiences from construction-innovation theory and related theoretical fields (e.g. strategic niche management, marketing and environmental behaviour research). Elements from various theoretical frameworks are combined, and new research methods and tools are explored, specifically for studying highly energy-efficient housing as a concept or systemic innovation. Within the theoretical framework, the study thus provides a deeper understanding and conceptualisation of various issues that can lead to improvements in innovation theory, using practice-oriented research as a mirror.

Using these practical and theoretical study results, the work identifies opportunities and barriers, and it recommends ways of eliminating barriers to the adoption of innovation. To this end, technology innovation, business innovation and policy innovation are studied, and pathways are suggested for the integration of highly energy-efficient housing concepts as an innovation by analysing technological, societal and policy factors that can stimulate or hinder innovation diffusion. As such, this work introduces recommendations that can help to accelerate the adoption of highly energy-efficient housing concepts (e.g. passive houses) by businesses, customers and policymakers.

1.5 Main research question and sub-questions

Related to the identified research goal, the main research question in the present work is formulated as follows:

Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses?

This relates directly to the practical question:
Which challenges and opportunities exist with regard to eliminating barriers to market development for passive houses?

The main research question is further subdivided into three parts, as follows:
Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, as observed from the supply side (Part A), the demand side (Part B) and the policy side (Part C)?

The following research questions are introduced and addressed in Part A, in Chapters 2, 3, 4 and 5, respectively:
Q1. *Which innovations are likely to be adopted in accordance with the passive house concept?*
Q2. *Which opportunities exist for eliminating barriers to supplier–led innovation in highly energy-efficient housing?*
Q3. *Which collaboration opportunities exist with regard to highly energy-efficient housing renovation?*
Q4. *Which opportunities and barriers exist with regard to enterprise collaboration, particularly with regard to bridging the gap between innovation and early adoption?*

The following research questions are introduced and addressed in Part B, in Chapters 6, 7 and 8, respectively:
Q5. *What are the experiences of Dutch occupants with nearly zero-energy houses (e.g. passive houses)?*
Q6. *What are recommendations for the improvement of passive house certification, based on end-user experiences?*
Q7. *How were owner-occupants persuaded to apply highly energy-efficient renovation concepts in renovations of single-family houses?*

The following research questions are introduced and addressed in Part C, in Chapters 9, 10 and 11, respectively:
Q8. *Which definitions of nearly zero-energy housing are likely to be adopted in Belgian and Dutch policy?*
Q9. *Which barriers and opportunities exist with regard to the further diffusion of labels for highly energy-efficient houses?*
Q10. *What are the tactics and success factors for stimulating the adoption of project-based innovation, as determined from a study of the activities of an innovation-oriented passive house network?*

This subdivision is intended to allow each of the ten studies to be read independently, also according to the preference of the reader. Business professionals and innovation researchers might be more interested in Part A, Chapters 2 through 5. Commissioners, clients and user experience researchers might be more interested in Part B, Chapters 6 through 8. Policymakers and policy researchers might want to focus on Chapters 2 and 4, as well as on part C: Chapters 9 through 11. In general, researchers might want to analyse the whole work as a referential framework for research aimed at identifying challenges and opportunities related to the adoption and diffusion of innovation (in particular, energy-saving technologies, concepts and technology clusters), as well as for studies aimed at providing solutions to overcome such barriers and to support such opportunities.

1.6 Research method

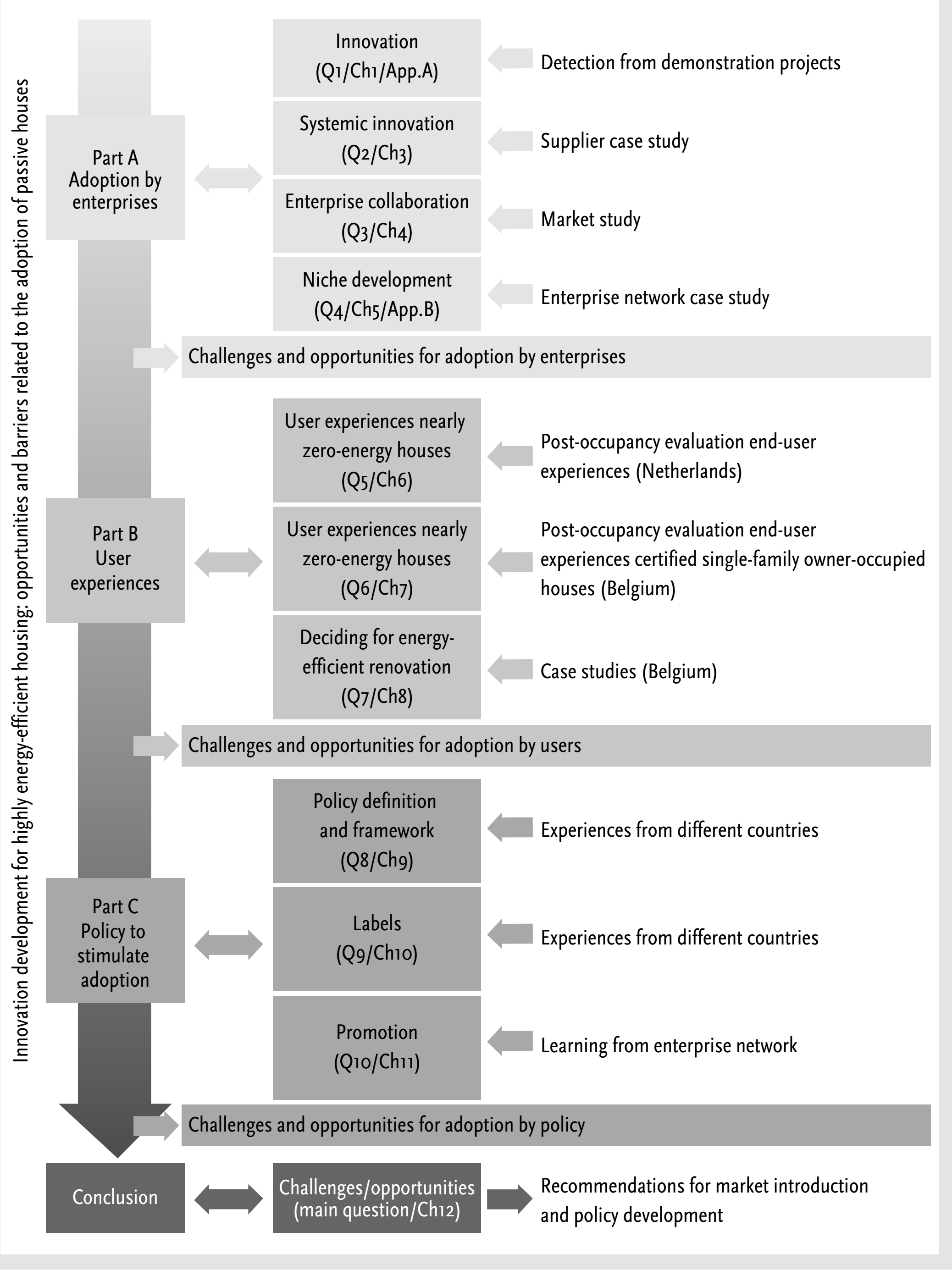
With regard to the supply side (Part A), the adoption of the passive house concept by individual enterprises and groups of enterprises is studied, as well as the adoption of highly energy-efficient housing renovation. With regard to the demand side (Part B), the research aims to learn from user experiences with highly energy-efficient homes, particularly by studying end-user experiences and user motivation to adopt concepts (e.g. passive houses and highly energy-efficient housing renovation). With regard to the policy side (Part C), the study defines opportunities for and barriers to the adoption of highly energy-efficient housing.

Figure 1.3 provides an overview of the main topics addressed in each chapter, the research input used in each chapter and the research output expected from each part. The research question and research methods used to investigate each question are explained in more detail in the introduction to each part (as well as in the associated chapters).

Following the studies discussed in Parts A, B and C, all results are cross reflected as recommendations for innovation deployment and policy development, with a particular focus on the market development for passive houses. This general approach is illustrated in Figure 1.4.

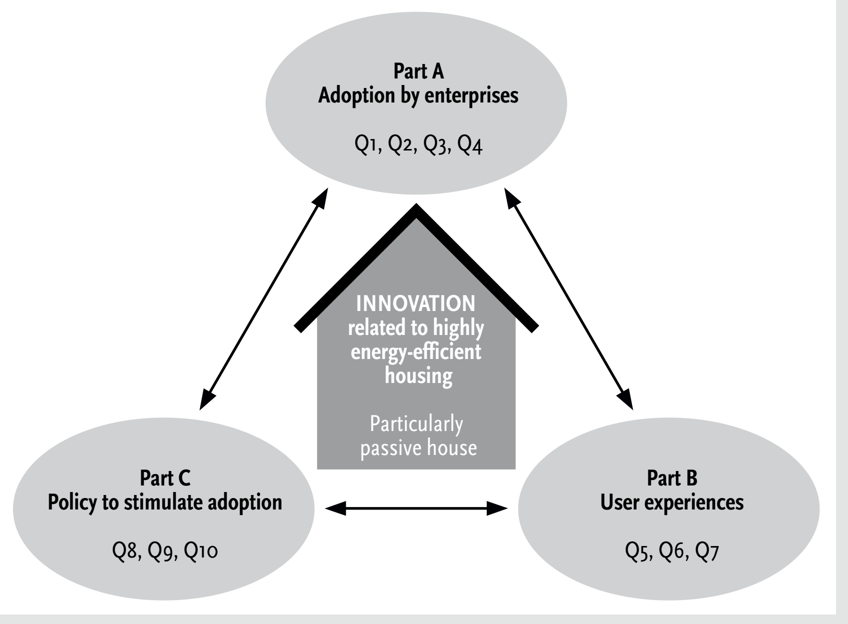
The study thus identifies and cross-reflects opportunities and challenges related to innovation adoption involving highly energy-efficient housing concepts (in particular, passive houses) on the supply side (Part A: research questions Q1, Q2, Q3 and Q4), the demand side (Part B: research questions Q5, Q6 and Q7) and the policy side (Part C: research questions Q8, Q9 and Q10). Although the research questions cover only a selection of problems for the defined research field, the simultaneous provision of empirical research in business innovation (Part A), user experiences (Part B) and stimulation by policy (Part C) provides a substantial foundation for answering the main research question.

Figure 1.3 The three main parts in the book, the main themes covered in the ten studies, the research input used in each chapter, and the research output expected from each part



Chapter 12 summarises and cross-links the major findings from the ten studies in order to provide recommendations for market introduction and

Figure 1.4 The research defined the 'innovation' and studied its adoption by enterprises (Part A), end-users (Part B) and policy (part C), defining multiple research questions in each part



development. It also provides recommendations for improving innovation-diffusion theory, using the conclusions from the various studies of adoption by enterprises (Part A), users (Part B) and policymakers (Part C). Based on the conclusions from these ten studies – all of which have been submitted to or published in scientific journals or books – the main research question is answered in the conclusion. The work closes by presenting opportunities for future research. The appendices provide additional useful information related to the study, in addition to a glossary of terms used in the study.

Given that the work covers a broad range of varying questions, various theoretical frameworks are used within the chapters in order to answer the questions. These frameworks are explained in detail in each chapter. The starting scientific framework for the entire study is innovation diffusion, as defined by Rogers (2003). The reader should nevertheless be aware of the existence of an additional extensive body of literature in the field of adoption of innovation. Conceptual frameworks in literature can differ when addressing various aspects (e.g. innovation diffusion, the role of networks, regional or sectoral business development and policy development). Each research question is therefore investigated with a slightly different take on the initial theoretical framework, as explained in the introductions to Parts A, B and C.

The following subsection describes the key approaches applied within the general framework of innovation theory – introducing several key elements from the theories used in the various studies to improve the reader's understanding of the general framework of innovation theory –, and the subsection thereafter describes several of the key ideas that have been borrowed from Rogers' theory.

1.7 Theoretical framework

1.7.1 General innovation framework

Innovation research is addressed in multiple ways by various authors. Most empirical literature begins by defining 'innovation' as some form of technological change, either in a product or in the production of goods or services (Blake and Hanson, 2005; Edquist, 2005)[29]. In general, the newness of the innovation is less relevant than is the fact that the ideas, practices or objects are new to the operational unit adopting them (Rogers, 2003; Bhaskaran, 2006). In order for an innovation to be effective, or even successful, it must result in a significant change, preferably an improvement in a real product, process or service compared with previous achievements (Amabile, 1997; Harper and Becker, 2004). The extent of change has most commonly been described in innovation literature as the difference between radical and incremental innovation (Henderson and Clark, 1990). Marquis (1988) introduces the terms 'incremental' and 'radical' innovation as opposites with which to distinguish small changes based on current knowledge and experience from scientific and technological breakthroughs that can change the very nature of an industry.

Since the 1950s, researchers have been working to develop a scientific framework for innovation. The innovation literature is typically concerned with understanding how innovations emerge, develop and grow, as well as in how they are displaced by other innovations (Hockerts, 2003). A general understanding emerges that a key success factor for innovation is the presence of an inherently social, interactive learning process (Lundvall, 1992). Lundvall (2005) therefore characterises innovation as a continuous, cumulative process involving radical and incremental innovation, as well as the diffusion, absorption and use of innovation.

The concept of 'systemic innovation' (which emphasises the need for coordination and cooperation in innovation processes) as opposed to 'autonomous' (independent) innovation was first introduced by Teece (1984, 1988). The

29 In Appendix C, a glossary is provided of the terms that are used in the various chapters; the listed terms related to innovation are based on the references introduced in this section. The terms related to energy and buildings are also listed in this appendix. These terms were sourced from the International Energy Agency, the European Economic and Social Committee and the Architects' Council of Europe.

30 This 'innovation-systems' approach encompasses individual firm dynamics, as well as particular technological characteristics and adoption mechanisms. Innovation systems have been developed as a heuristic attempt to analyse all societal subsystems, actors, and institutions contributing in some way (directly or indirectly, internationally or nationally) to the emergence or production of innovation (Nelson and Nelson, 2002). An innovation system is defined as any of these institutions and economic structures that affect the rate and direction of change in society (Edquist, 2005).

term 'systemic innovation' should not be confused with 'system innovations', which are characterised by the integration of multiple independent innovations that must work together to perform new functions or improve performance as a whole (Cainarca *et al.*, 1989), nor with 'innovation systems'.[30]

Rogers (1962, 2003), who is widely acknowledged as a leading scientist in innovation-diffusion research, defines diffusion of innovation as the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). Rogers defines the rate of adoption as the relative speed by which an innovation is adopted by members of a social system. Key ideas developed by Rogers (2003) that are used in this work include reflections on adopter categories, innovation characteristics and decision processes. The following subsection defines several of these key elements, which are borrowed from Rogers' innovation-diffusion theory.

A wide range of literature addresses innovation from a systemic perspective and introduces such terms as 'national', 'regional' or 'sectoral', 'innovation systems', 'technological innovation systems', 'socio-technical systems', 'innovation journeys', 'transition paths' and 'strategic niche management' (Coenen and Diaz Lopez, 2010; Cooke *et al.*, 2004; Edquist, 2005; Lundvall, 2005; Malerba, 2004; Sharif, 2006; Smith *et al.*, 2010; Verbong *et al.*, 2008). 'Niches' are defined as spaces in which radical innovations are tried out, varied and developed further, while they are sheltered from mainstream competition (Schot and Geels, 2008). They are considered highly important in socio-technical experiments for creating 'proto-markets' (Hoogma *et al.*, 2002) or 'socio-technical regime transitions' (Rotmans *et al.*, 2001; Schot *et al.*, 1994; Kemp *et al.*, 1998; Verheul and Vergragt, 1995).

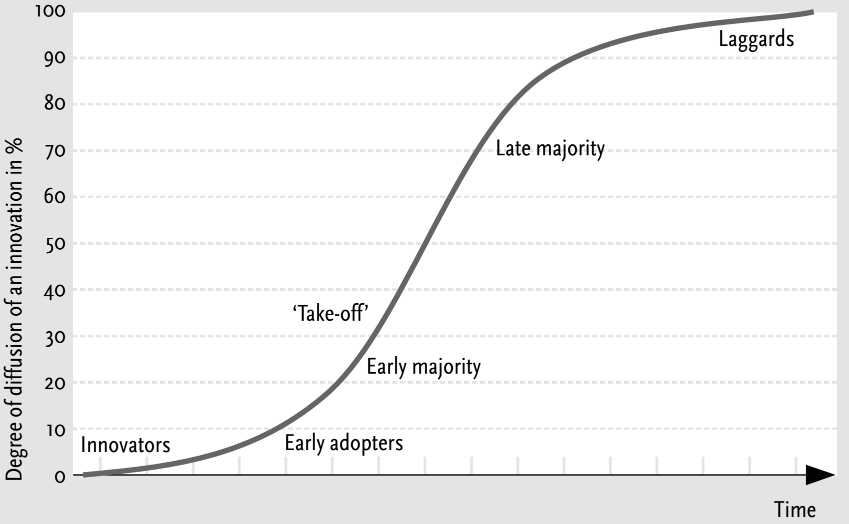
Given that the work of Rogers is widely considered the leading theory of innovation diffusion, this theoretical framework was chosen as a starting point in the search for theoretical reflection. Although numerous studies have addressed innovation diffusion with regard to individual technologies, the novelty of this research is expressed largely by grouping various technologies (including energy-saving technologies) into a single concept (as exemplified by the passive house). This is accomplished by exploring systemic innovation opportunities within the home-construction sector (businesses and networks), as well as by researching the adoption of an innovative concepts by businesses, end-users and policymakers. Because many of the chapters in this book rely upon terms and experiences from Rogers' innovation-diffusion theory, the following section explains several relevant key elements from this work.

1.7.2 Key elements borrowed from Rogers' innovation framework

Rogers' adopter categories

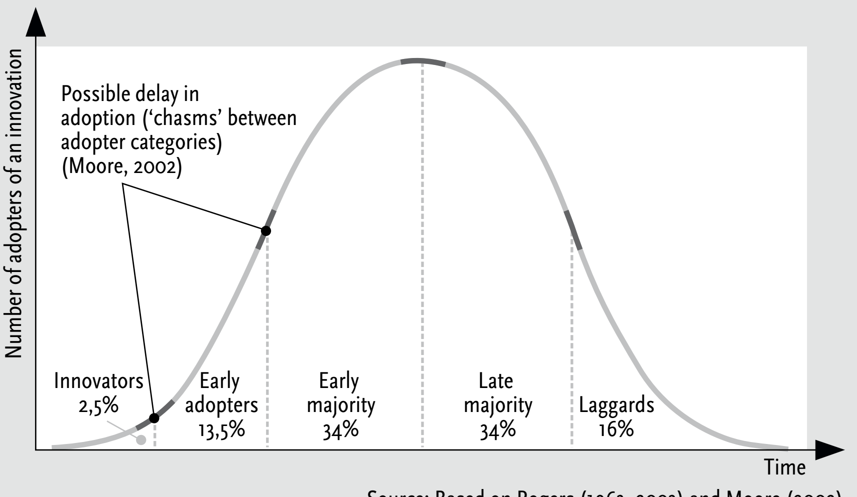
To explain diffusion processes, Rogers (2003) derived a model from hun-

Figure 1.5 Schematic representation of the typical S-curve of a diffusion process



Source: Based on Rogers (1962, 2003)

Figure 1.6 The technology adoption life cycle curve



Source: Based on Rogers (1963, 2003) and Moore (2002)

dreds of case studies on market penetration of any new technology product throughout its useful life, which is typically an S-curve (see Figure 1.5) or a bell curve[31] (see Figure 1.6). In marketing theory, this is also known as the 'technology-adoption life cycle' or 'product life cycle'.

These curves are divided into categories of adopters, which Rogers suggests

31 Originally proposed by Beal, Rogers and Bohlen (1957) to represent the diffusion of farm practices in Iowa.

Table 1.2 Adopter categories and basic characteristics of individuals in these categories

Adopter category	Dominant characteristics of adopting unit (e.g. business developer, customer, policy maker)
Innovators	• venturesome: first to adopt an innovation, willing to take risks • close contact to scientific sources and other innovators, complex technical knowledge
Early adopters	• respect: highest degree of opinion leadership, judicious choice of adoption • seek innovation to support own vision, highly connected and knowledge of innovation
Early majority	• deliberate: adopt an innovation after it is tried and tested • contact with early adopters
Late majority	• sceptical: adopt an innovation only after increasing peer/norm pressure or as economic necessity • mainly in contact with others in late majority and early majority
Laggards	• traditional: last to adopt an innovation, aversion to change and/or limited resources • near isolates in social networks

Source: Based on Rogers (2003) and Moore (2002)

in order to standardise their use in diffusion research. Dominant characteristics of these categories are listed in Table 1.2. As shown in Figure 1.6, early majority and late majority adopters fall within approximately one standard deviation of the mean, with early adopters and laggards falling within two standard deviations. Innovators are located at the very onset of a new technology, about three standard deviations from the mean.

Both Rogers (2003) and Moore (2002) argue that each group of adopters has a unique psychographic profile (a combination of psychology and demographics) that distinguishes its marketing responses from those of the other groups. Moore (2002) represents the dissociation between each adopter category as a 'gap' (or 'chasm') in the bell curve. Moore's research illustrates the difficulty each group is likely to experience in accepting a new product if it is presented in the same way as it was to the group to its immediate left. It uses several examples to illustrate how these gaps represent a possible loss of momentum, which can lead to missing the transition to the next segment, thereby preventing the innovation from ever reaching a mainstream market in the middle of the bell curve. Understanding each profile and its relationship to its neighbours (who might have different expectations) has been shown to be a critical component in the marketing of innovative technologies. Moore asserts that a small chasm exists between innovators and early adopters, with a larger gap between early adopters and the early majority. In describing how an innovation reaches critical mass, thus allowing the continued adoption of the innovation to be self-sustaining, Rogers (2003) and Moore (2002) outline several strategies for helping an innovation reach this stage. For example, Moore highlights the need to select a target market and related market strategies with care, using a whole-product concept.

Rogers' concept of innovation characteristics

Using numerous cases studies, Rogers (2003) demonstrates that the potential adopter's perception of the relative advantage, compatibility, complexity, observability (alternative term name: visibility) and trialability (alternative term name: demonstrability) of the innovation affect its rate of adoption (see Table 1.3).

Table 1.3 Innovation characteristics and influence on adoption rate

Innovation characteristics (attributes)	Influence on adoption rate (empirically detected)
Relative advantage The degree of which an innovation is experienced by the adopter as being better than the idea it supersedes (for example: lower price, less inconveniences, social prestige).	The higher the perceived relative advantage of an innovation, the higher the rate of adoption.
Compatibility The degree to which an innovation is perceived by members of a social system as consistent with the existing (socio-cultural) values, past experiences (and previously introduced ideas), and needs of potential adopters (according to culture/adopter category).	The higher the compatibility, the higher the rate of adoption (also: naming an innovation and positioning it relative to previous ideas and indigenous knowledge systems are important means of making an innovation more compatible).
Complexity The degree to which an innovation is perceived as relatively difficult to understand and to use.	The higher the complexity, the lower the rate of adoption.
Trialability (alternatively: demonstrability) The degree to which an innovation may be experimented with on a limited basis.	The higher the trialability, the higher the rate of adoption.
Observability (alternatively: visibility) The degree to which the results of an innovation are visible to other members in a social system.	The higher the observability, the higher the rate of adoption.

Source: Based on Rogers (2003), Moore (2002), van Hal (2000)

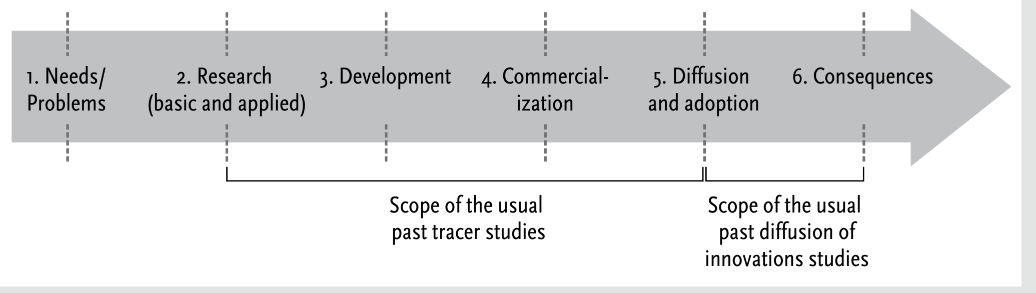
In addition to the attributes listed in Table 1.3, Rogers (2003) observes that the rate of adoption is influenced by the type of innovation-decision, the nature of communication channels diffusing the innovation at various stages in the innovation-decision process, the nature of the social system and the extent of effort exerted by change agents in diffusing the innovation.

Rogers' concept of decision processes

In order to understand the diffusion process, familiarity with the course of decision-making of the potentially adapting actor is essential. Part of the research presented here examines the decision-making of businesses, networks and end-users that adopt innovations first, in order to identify the most important elements that are needed to develop the market for highly energy-efficient housing. Rogers (2003) provides a model that is used in this research in order to investigate the innovation-decision process. The model in Figure 1.7 is often referenced with regard to tracer and diffusion studies. It shows six main stages in the innovation-decision process. These stages are somewhat arbitrary, as they do not always occur in exactly the order shown, and certain stages may be skipped in the case of certain innovations. Rogers criticises many of the past tracer studies as being limited to Stages 2-5, with the usual past diffusion of innovation studies often limited to Stages 5-6. To understand the generation of innovations, it is important to investigate the entire innovation-decision processes and to include serendipity and accidental aspects.

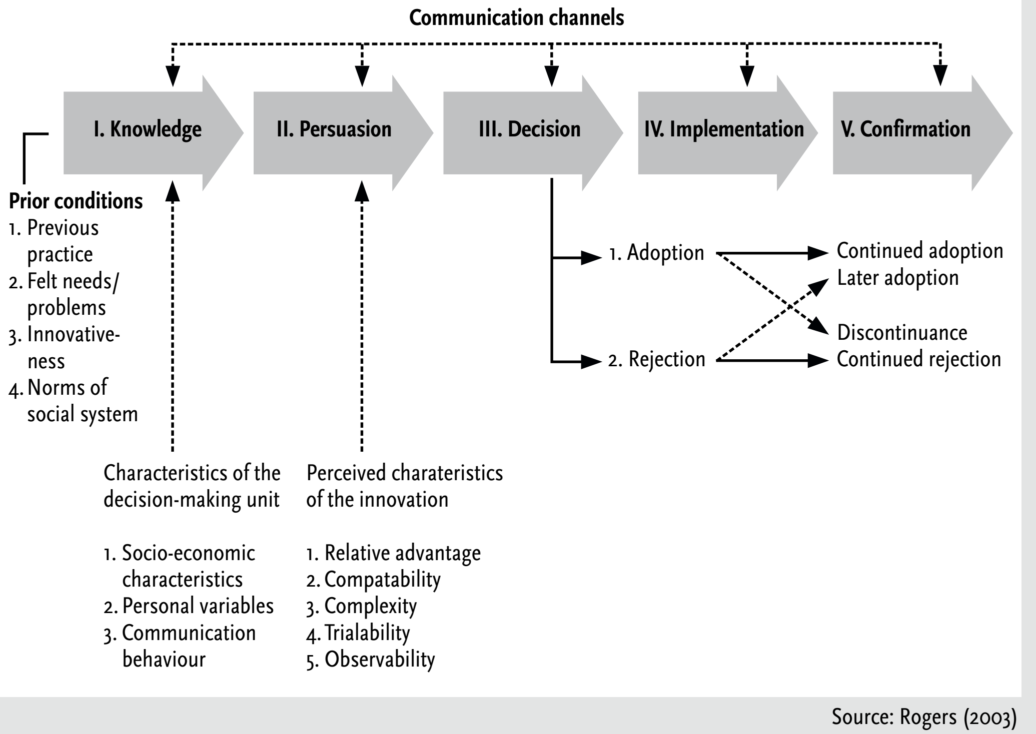
Rogers (2003) further defines the innovation-decision process as the process through which an individual (or other decision-making unit) passes from ini-

Figure 1.7 Six main stages in the innovation-decision process



Source: Rogers (2003)

Figure 1.8 A model of five stages in the innovation-decision process



Source: Rogers (2003)

tial knowledge of an innovation, to forming an attitude towards the innovation, to a decision to adopt or reject, to the implementation of the new idea and, ultimately, to the confirmation of this decision (see Figure 1.8).

1. Knowledge occurs when an individual (or other decision-making unit) is exposed to an innovation's existence and gains an understanding of how it functions.
2. Persuasion occurs when an individual (or other decision-making unit)

forms a favourable or unfavourable attitude towards the innovation.
3. Decision takes place when an individual (or other decision-making unit) engages in activities that lead to a choice to adopt or reject the innovation.
4. Implementation occurs when an individual (or other decision-making unit) puts a new idea into use.
5. Confirmation takes place when an individual seeks reinforcement of an innovation-decision already made, but the individual may reverse this previous decision if exposed to conflicting messages about the innovation.

Rogers' notion of adopter categories, innovation characteristics and innovation-decision processes is used in various chapters, particularly those in which questions relate directly to adoption by singular decision units. Using Rogers' scientific framework on innovation diffusion has implications for the possible scope of the research. For this reason, additional literature sources are analysed and applied in several chapters.

Possible critique of Rogers' scientific framework

Shove (1998) and other authors have expressed the critique that the 'classical' diffusion theory is excessively focused on the 'adopter' (or future user of the technology), with insufficient attention to the social and institutional context. General references exist that focus more on social, organisational and institutional aspects of market introduction and the diffusion of innovative technologies (e.g. Lundvall, (1988, 1992); Linstone, 1991; Lynn *et al*., 1996; and Kowol, 1998). Considering the market introduction of energy-efficient housing, the works of Blumstein and colleagues (1980), Lutzenhiser (1993, 1994), Mills (1995), Kasanen and Persson (1997) and Biermayr and colleagues (2001) consider the social and institutional context. These works demonstrate that mandatory regulations (e.g. in the present study the required introduction of nearly zero-energy housing in the framework of the recast EPBD; EPBD, 2010) might stimulate companies to accelerate market development. Also, good access to available knowledge can stimulate enterprises to introduce innovation.

Various authors (e.g. Jensen, 2005; Guy and Shove, 2000) have tried to explain the disinclination of property owners to close the gap between their current energy use and the level that is technically feasible. According to Guy and Shove (2000), technical or economic barriers are easy to overcome by using the appropriate means in research and development, demonstration and dissemination. The crucial barrier is not located within the realm of technology or economy, but within the realm of society and individuals. Jensen (2005) describes the experiences of the Danish Energy Authority with regard to convincing users to embrace energy-saving strategies in order to distinguish specific barriers (e.g. lack of interest, lack of knowledge, lack of solutions and lack of motion). Jensen stresses the importance of the final barrier – 'lack of motion' (or motivation), therefore attempting to study such barriers using an anthropological understanding of consumption.

Several authors have also argued that studies in building energy efficiency should look beyond the singular adopter. For example, the importance of considering different views from various parties involved in building processes has been argued by Janda (1999) for architects and installers. In addition, Rogers' concept of decision processes is only one possible way of looking at decision processes. Other authors highlight the importance of psychological factors in decision processes. For example, this is illustrated in studies by of Wortmann and Schuster (1999) and by Haghighat and Donnini (1999) with regard to the appreciation of air quality in mechanical ventilation. Other decision-making models have been proposed; Wilson and Dowlatabadi (2007) provide a good overview of available models when studying residential energy use, with each model highlighting advantages and disadvantages.

In times of economic crisis, considerable research is devoted to finding cost-optimal strategies. Economically focussed researchers (e.g. Verbeeck and Hens, 2005) prefer to use microeconomic theories of user choice based on the assumption that individuals seek to maximise utility given budget constraints. In utility-based decision models, users are assumed to behave as rational actors in a normative sense of having preferences that are ordered, known, invariant and consistent. Such microeconomic models can nevertheless fail to capture the importance of innovation characteristics beyond relative economic advantage, as heterogeneous preferences or adopter categories are sometimes poorly characterised. This theoretical background is not considered in this study for this reason, as well as because various researchers have criticised it as an overly narrow-minded approach, as explained further. Microeconomic models have been criticised for presenting decisions as losses or gains that can influence the innovation-decision outcome (Tversky and Kahneman, 1981). In addition, micro-economic studies often fail to consider the fact that budget decisions at the household level are assigned to different 'mental' accounts (Thaler, 1990; Shefrin and Thaler, 2004). For example, an individual's willingness to spend earned income, windfall income and saved income is rarely the same even though the money is fully interchangeable (Thaler, 1999).

The decisions and rationality of individuals can be further bounded by psychological and environmental constraints, including the cognitive burden of information gathering and processing (Conlisk, 1996). Individuals can make decisions or behave in such a way as to strive for internal consistency between their knowledge, attitudes and actions, given that inconsistency or dissonance produces discomfort (Festinger *et al.*, 1989). When making decisions, individuals also tend to 'anchor' on certain types of information, rather than searching for and processing all relevant information (Tversky and Kahneman, 1974; Ariely *et al.*, 2003; Ariely, 2009). Social psychologists have found that the most effective information for promoting residential energy efficiency is simple, salient, personally relevant and easily comparable, rather than technical, detailed, factual and comprehensive (Kempton and Montgomery, 1982; Yates and Aronson, 1983). For example, Knight and colleagues (2006) observe that selling comfort and fulfilled desires are more likely than the prospect of energy efficiency is to motivate homeowners to renovate their homes. The perceived trustworthiness and credibility of the information and/or service provider is also important (Craig and McCann, 1978; Farhar and Buhrmann, 1998).

1.8 General limitations of the research

The scientific framework developed by Rogers can be criticised in relation to the systemic approach towards innovation (see previous sections). The present work considers many of the previous theoretical concerns and critique, using Rogers' key observations regarding innovation-diffusion theory largely as a general guideline. It addresses an agenda of research priorities established within this scientific field set. The present study focuses largely on social and individual barriers (e.g. 'lack of motivation', 'lack of knowledge' and 'lack of competencies').

It examines the extent to which technological innovations are developed by 'lead users' rather than by R&D experts. It observes the role played by change agents in translating the needs and problems of enterprises, users and policymakers. It studies interrelationships amongst the various organisations and individuals involved in the innovation-development process.

This study is limited to highly energy-efficient housing and related innovations. In this work, demonstration projects are often used as an information source for learning and as instruments in the innovation-diffusion process. The learning effects from demonstration projects are limited to the experiences derived from the selected demonstration projects, particularly in the Netherlands and Belgium. Demonstration projects represent attempts to introduce new technologies or services on a scale bounded in space and time, driven by a long-term, large-scale vision of advancing the society's sustainability agenda. The author thus explicitly recognises the demonstration effort as an experiment, characterised by learning by doing, trying out new strategies and new technological solutions, and continuous course correction. When a demonstration project is being planned, it is still possible to gain insights from empirical observations analysed through the lens of a conceptual framework of learning processes. This becomes difficult, however, once a project is completed and inhabited.

The fact that several chapters focus on the situation in the Netherlands and in Belgium should be considered with caution. Given that building traditions and the uptake of innovation can differ across countries, the conclusions related to market development should be interpreted mainly in terms of the regional situation. Innovation-diffusion recommendations specified in response to the analysis of situations in some regions might not necessarily lead to market uptake in terms of supply and demand in other regions.

In addition, this work focuses primarily on concepts, technologies and services for the reduction of heating demand (particularly space heating), due to its importance regarding possible energy saving. The reduction of electricity demand (e.g. energy-saving household appliances) is not considered in detail, largely because the application of household appliances is assumed to differ from the construction of houses and to be uncontrollable by construction activity. The link with renewable energy production (e.g. smart grids) is not considered in detail.

In some chapters, the study of the demonstration projects and decision processes is limited to owner-occupants. The behaviour of occupants is recognised as an essential factor in real energy use (e.g. indoor temperature depends upon the occupant). The conclusions of these studies should therefore be interpreted primarily for this market segment. Conclusions could be very different when addressing other segments, e.g. private or social tenants, groups of owners instead of individual owner-occupants.

Because the research was conducted in 2007-2012 in the Netherlands and Belgium, the information presented in this study is time-sensitive and possibly affected by the availability of information in these countries. Given that several previously published articles are now chapters of the present work, these chapters may contain some repetition and time inconsistencies. Published or submitted articles were not edited, in order to allow each chapter to be read separately. Time inconsistencies might result partly from the development of the business and policy environments, which are strongly affected by the increased business activity, increasing resources for green business and political opinion leadership. New policies and energy-saving targets are constantly taking place in EU countries. The research was conducted within this continuously changing economic and policy framework. For example, during the study, EU objectives were formulated with regard to achieving energy savings of 20% by 2020, and the recast of the European Performance of Buildings Directive was proposed. In addition, certification procedures for passive houses were introduced in the Netherlands and adapted in Belgium during the research period. The regional focus on the Netherlands and Belgium should be considered a 'regional case study' aimed at improving innovation theory.

Further limitations are described in each chapter.

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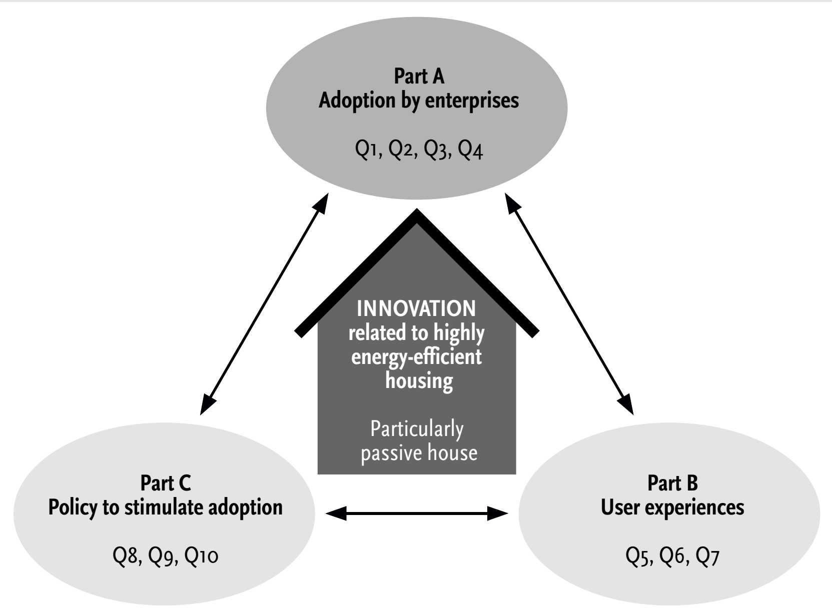
Introduction to Part A: Adoption by enterprises

Figure A.1 The research defined the 'innovation' and studied its adoption by enterprises in Part A, studying research questions Q1, Q2, Q3 and Q4



Part A focuses on highly energy-efficient housing concepts from the perspective of innovation adoption by enterprises and groups of enterprises. To study the adoption of highly energy-efficient housing concept by enterprises, the research focuses on small and medium-sized enterprises (SMEs), given that more than 90% of supply-side market players in the construction sector are SMEs (EeB, 2009). As observed by Bos-Brouwers (2010) in a study on sustainable innovation processes within SMEs (focusing on learning from the innovation-decision process), the socio-technical nature of innovation in highly energy-efficient houses is an important subject for further research.

Chapter 2 presents characteristics of the innovation based on demonstration projects

The realisation of highly energy-efficient housing concepts (e.g. passive houses) requires the implementation of several innovations. For example, a passive house typically involves several technological innovations (e.g. a high level of insulation with minimal thermal bridges and low infiltration, along with passive solar gains and ventilation heat recovery), in order to reduce the demand for heating and primary energy demand to a very low level (PHP, 2008, PEP, 2008). First, it is important to understand which innovations (including technologies, systems and services) enterprises associate with the passive house concept. The first research question addressed is therefore formulated as follows:

Q1. *Which innovations are likely to be adopted in accordance with the passive house concept?*

An empirical study investigated the adoption of innovation related to highly energy-efficient housing, by identifying innovations applied by enterprises in passive house projects. In Chapter 2, these innovations are identified within the context of realised passive house demonstration projects (some of these projects are exemplified in Appendix A), in order to demonstrate the type of innovations that are generally attributed to the European notion of a 'passive house', in addition to identifying companies that are likely to adopt such innovations. In relation to this topic, Chapter 2 introduces a general theoretical framework of innovation. With regard to the development of innovation theory, this empirical study aims to relate individual technologies and services to the concept level (in this case, the passive house concept) and to explain which innovations have been implemented in practice with regard to the acceptance of the concept. The results of this study provide a concept-innovation foundation for the further studies on enterprise innovation, user experiences and stimulation by policy. Based on the empirical findings from demonstration projects and the companies involved in them, the study defines the innovations currently available and discusses the opportunities available to companies for adopting these innovations.

Chapter 3 determines supplier-led systemic innovation opportunities
The empirical investigation of Q1 led to the identification of a multitude of technologies, services, systems and architectural innovations (possibly clustered) from demonstration projects. Evidence suggests that the construction industry offers a wide range of energy-efficient technologies and systems. There are many examples of technology enterprises engaged in the development of innovation for highly-energy efficient houses. In 'innovation journeys' these enterprises develop and implement new ideas in order to achieve desired outcomes by people engaged in transactions (relationships) with others within changing institutional and organisational contexts. The literature nevertheless contains few references to the innovation journeys of individual enterprises with regard to the adoption of highly energy-efficient house construction. To date, highly energy-efficient housing concepts (e.g. passive houses) have been implemented only in demonstration projects in certain countries (e.g. the Netherlands). Previous researchers (e.g. Silvester, 1996; van Hal, 2000; Femenias, 2004) have analysed demonstration projects in order to

examine opportunities for and barriers to the market introduction of sustainable housing in the Netherlands. According to their results, the diffusion of such projects and associated technologies requires making them systematically available. Enterprises play an important role in making innovations available. One major challenge for businesses (particularly SMEs) appears to involve handling systemic innovation opportunities. This process of adoption by enterprises is not well understood within the context of highly energy-efficient housing, particularly with regard to why enterprises do not systematically develop innovations. According to the findings of the study, suppliers of materials have the potential to be key players in the development of systemic innovation trajectories within the house-building sector. The second research question was therefore defined as follows:

Q2. Which opportunities exist for eliminating barriers to supplier-led innovation in highly energy-efficient housing?

This study investigates an innovation trajectory started by a supplier in the SME sector, in order to provide input for reflection on the theory. This part of the study highlights the need for systemic innovation research by introducing, discussing and developing the theoretical framework of systemic and construction innovation. The innovation journey described in this section demonstrates the validity of a new model for introducing radical innovation in the construction sector, reaching beyond the individual demonstration project.

Chapter 4 investigates opportunities for collaboration within an emerging market segment (highly energy-efficient renovation)

After studying a single enterprise, the following step in understanding the adoption of innovation by enterprises is to identify opportunities for collaboration amongst groups of enterprises, in order to stimulate joint market development for innovation. The Intelligent Energy Europe project involving the ‘e-retrofit-kit’ (2008) and international research work within the framework of the International Energy Agency Solar Heating & Cooling Programme (IEA SHC Task 37, 2010) have identified only a limited number of housing renovations targeting high energy efficiency. Nevertheless, improving energy efficiency in existing buildings is considered one of the most cost-effective ways of cutting carbon emissions (Ashford, 1999; Van der Waals, 2001). It is therefore useful to conduct further investigation into opportunities for highly energy-efficient renovations. It is of great importance to address the existing stock of buildings, in order to obtain large-scale energy reductions. Moreover, it will be impossible to reduce the level of greenhouse gas emissions without saving energy by retrofitting the present housing stock (Hens *et al.*, 2001). Taking the subsector of energy-efficient single-family house renovation as an example, and considering the need for additional research at the level of groups of enterprises, the third research question was defined as follows:

Q3. Which collaboration opportunities exist with regard to highly energy-efficient housing renovation?

In Chapter 4, this question is addressed using results from a collaborative ERANET-Eracobuild research project entitled 'One Stop Shop: From demonstration projects towards volume market: innovations for one stop shop in sustainable renovation' (One Stop Shop, 2012). Amongst other objectives, this project examined possibilities for improving collaboration in the supply chain for highly energy-efficient renovation, while stimulating customer demand for integrated renovations. The author coordinated the research efforts of collaborators in Belgium, Denmark, Finland and Norway in an investigation of the supply-side needs of architects and contractors with regard to developing integrated, highly energy-efficient housing renovations, based on interviews with demonstration project stakeholders and the results of a contractor questionnaire. These research results contributed to the definition of various opportunities and barriers related to process innovation designed to reduce the burden on clients and to achieve less fragmented single-family housing renovation processes (most of which have been described in various project reports). The results presented in this chapter are largely intended as practice-oriented, summarising several key results from the author's work. The chapter describes the identified needs of enterprises regarding collaborative development of the market for highly energy-efficient renovation, taking into account opportunities for improving the effectiveness of efforts to reach customers through joint supply. The study also draws upon results from collaboration experiments in order to improve understanding with regard to opportunities for and barriers to enterprise collaboration. In theoretical terms, it illustrates how the innovation diffusion theory developed by Rogers can be used to discuss and improve innovation-decision processes and specific communication tools (e.g. web tools).

Chapter 5 studies opportunities for enterprise collaboration in the early adoption phase

The following step in understanding the development of innovation is to identify innovation opportunities for groups of enterprises, in order to define pathways for the joint development of a market niche towards market transition. One persistent problem within the context of construction innovation is that innovations are not automatically diffused beyond a limited group of innovators or demonstration projects (Femenias, 2004). From theory, it is known that innovators and early adopters might have different characteristics (Rogers, 2003). The players needed (and thus the innovation policy strategies used) may differ when introducing innovations or when targeting the early-adoption market (Rødsjø *et al.*, 2010). Early adopters must somehow collaborate with innovators in order to gain experience and market share. For example, researchers have speculated that companies of different sizes (e.g. micro-enterprises and large enterprises) also adopt different innovation strategies (Rogers, 2003) and that different actors collaborate in different market phases (Rødsjø *et al.*, 2010). Such issues are not well understood within the niche of highly energy-efficient housing. The following research question was therefore formulated in order to study opportunities for and barriers to enterprise collaboration in the transition from innovation to early adoption, in order to improve understanding with regard to the facilitation of market development from innovation to early adoption:

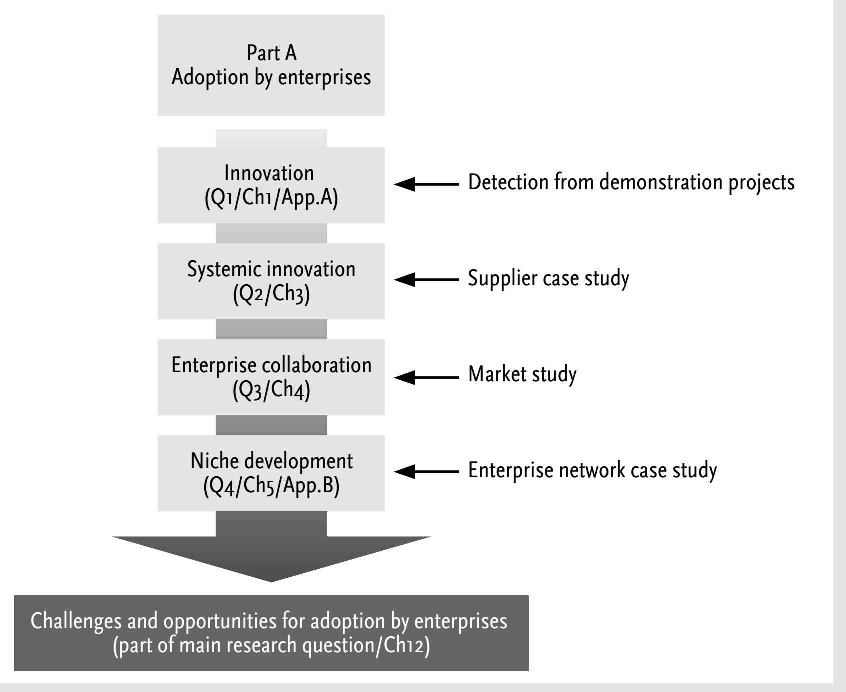
Q4. Which opportunities and barriers exist with regard to enterprise collaboration, particularly with regard to bridging the gap between innovation and early adoption?

The emergence of an enterprise network involved in the passive house market niche is illustrated in Appendix B, briefly exploring the theoretical framework of 'strategic niche management' (SNM), as pioneered by several Dutch authors (see e.g. Kemp, 1994; Kemp *et al.*, 1998; Rotmans *et al.*, 2000; Schot *et al.*, 1994; Van den Belt and Rip, 1984). Further development of the enterprise network described in Appendix B towards an early-adoption market is analysed in Chapter 5, which explores differences in innovation adoption in different market development phases. The chapter examines the experiences of enterprises that have adopted innovations in highly energy-efficient construction, as well as the opportunities and barriers they encountered. It also considers which enterprises are likely to adopt innovations sooner. Chapter 5 contributes to theory development by building upon the experiences of the enterprise network, relating them to the experiences described in innovation diffusion theory, along with limited findings from marketing theory and enterprise network theory. In particular, this study contributes to theory development with regard to explorations of the relevance of innovation phases and the relevance of company size to innovation, in addition to the need for enterprise collaboration.

General overview of Part A (Figure A.2)

Using information from demonstration projects, Chapter 2 aims to identify the innovations that enterprises associate with highly energy-efficient housing concepts (e.g. passive houses). Innovation theory is developed further in Chapter 3, which also contains an exploration of systemic innovation opportunities involving the examination of the systemic innovation-adoption process of a supplier. Chapter 4 examines collaboration opportunities in advanced housing renovation. The chapter consists of an executive summary of

Figure A.2 The main topics covered in the four studies addressed in Part A, the research input used in each chapter and the research output expected for the conclusions



a study, led by the author, which was performed in collaboration with various research partners. Chapter 5 examines opportunities for and barriers to market niche development with an enterprise network (the emergence of which is described in Appendix B).

With regard to highly energy-efficient housing concepts, these studies identify the innovations, opportunities for eliminating barriers standing in the way of supplier-led innovation and opportunities for and barriers to enterprise collaboration in the innovation development phase, within the context of highly energy-efficient renovation and in the early market-development phase (e.g. for newly built passive houses).

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2 Innovations in passive house projects

*Revised version of the publication: Mlecnik, E., 2011, Technological Innovations in Passive House Projects, in: M.J. Acosta (Ed.), **Advances in Energy Research Vol. 8,** Hauppauge, N.Y. (Nova Science Publishers Inc.), pp. 295-314, https://www.novapublishers.com/catalog/product_info.php?products_id=19881*

Abstract
The adoption of innovative concepts – such as that of the passive house – can be effective in restricting the demand for space heating in houses. This has been shown in demonstration projects introducing various innovations that significantly reduce the energy use of houses.

This study examines the innovations that can be expected when promoting the passive house concept, splitting it into easily recognisable principles and specific technological criteria. Data were collected from residential demonstration projects, using company interviews, in order to examine the innovations introduced in passive house demonstration projects in the Flemish Region (northern Belgium). The study thus provides a technological review of product, system, service and architectural innovations as they actually appear in new-built passive houses and renovations.

In the analysis, insights from companies are used to examine the opportunities for and barriers to the introduction of passive house innovations, as well as solutions to some of the barriers.

The present work shows how energy-efficiency targets have been translated into various technological opportunities resulting from the specific requirements of passive houses and related technologies. Many innovations can be expected to emerge from the promotion of passive houses. In addition to those of a technological nature, these innovations are likely to involve systems, services and architecture. The introduction of innovations related to passive houses can be hindered by lack of demand or market infrastructure. The findings of this study nevertheless show that change agents could facilitate the adoption of innovation by clients, as well as by enterprises.

2.1 Introduction

The ultimate goal of energy reduction is to mitigate climate change. Energy reduction in the building sector is considered one of the most important and affordable means to this end (IPCC, 2007). Amongst other studies, the Working Group III of the Fourth Assessment Report of the IPCC (Levine *et al.*, 2007) outlines the need for strategies to reduce energy use in buildings, identifying major technologies and systems that can be used, as well as policies that could help to achieve large-scale energy savings.

In Europe, the European Energy Performance of Buildings Directive (in short, EPBD; EPBD, 2002) introduced the framework to be used by European countries in order to develop regulations for the energy efficiency of buildings. Energy performance standards and certificates are important instruments in this Directive. The European Performance of Buildings Directive was recently reformulated (EPBD, 2010). It now requires all European member states to develop a framework for the introduction of nearly zero-energy buildings, based on the concept of energy performance. It has established 2021 as the target date for achieving such housing (EPBD, 2010).

Relative to local conditions, researchers have acknowledged the feasibility of reducing energy intensity to such levels. In a review of the literature, Harvey (2009) shows that the annual energy use per unit of floor area could be reduced by a factor of 3-4 for new buildings and by a factor of 2-3 for comprehensive renovations. In dozens of demonstration projects (e.g. the Brussels Capital Region, where a specific target value has been established for subsidised projects), the specific heating demand is typically about 15 kWh/m²a for new houses, with values for renovations reduced from 150-280 kWh/m²a to about 30 kWh/m²a. Various European researchers (Hastings *et al.*, 2010; Mlecnik *et al.*, 2010) have shown that calculated and/or observed energy savings after renovation can be achieved up to 80 to 95%, depending upon the type of building.

In recent years, many countries have developed methods for the definition of houses with very low energy usage, including the widespread concept of passive housing, which is particularly popular in some frontrunner regions in Europe. The passive house concept specifies a maximum heating-energy usage of 15 kWh/m²a. By comparison, the heating load for new residential buildings complying with the EPBD (2002) is typically 65-120 kWh/m²a, depending upon the policy criteria in specific countries. Given that space heating accounts for the majority of the total energy usage of households in the European Community, focusing innovation efforts on concepts representing major reductions in the demand for space heating is compatible with the desire to reduce primary energy demand and achieve political ambitions.

This development creates opportunities within the present market for introducing innovation within the construction sector in member states, in order to achieve substantial improvements in energy performance in housing. The outcomes of research aimed at understanding barriers to and drivers of innovation are expected to accelerate the necessary transformation of the housing sector (EeB, 2009). Before examining these barriers and drivers, however, it is important to understand the types of innovation that can be expected from the introduction of the passive house concept.

2.2 Research framework

2.2.1 Research goal

The goal of this research is to enhance understanding of the types of innovations that can be generally attributed to the European notion of 'passive houses' and the companies that can be expected to adopt such innovations. Rogers (2003) defines an innovation as any idea, practice, or material artefact perceived to be new to the relevant adopting unit. This research explicitly identifies companies as the adopting unit.[1] Although various studies have been conducted on the innovation diffusion of individual technologies (e.g. environmental technologies), the novelty of this research lies in the fact that it addresses various types of companies in the housing sector and that various – mostly incremental – innovations for higher energy efficiency are related to an integrated highly energy-efficient housing concept, particularly the passive house. Based on the empirical findings from demonstration projects and the companies involved in them, this study defines the innovations that are currently perceived by companies and the opportunities that companies identify for adopting these innovations, as well as several measures that can be taken to eliminate barriers to adoption.

2.2.2 Research question and approach

The main research question of the present study addresses companies as innovation adopters and is as follows:
Which innovations are likely to be adopted in accordance with the passive house concept?

Given that building traditions and practices can vary according to climate and country, this research focuses on Western Europe. In particular, the study focuses on the Flemish Region in Belgium, as the introduction of the passive house concept is well advanced in this region (PEP, 2008). After Belgium introduced the passive house concept in 2002 and subsequently introduced grants and tax reduction schemes, a niche market emerged for demonstration projects aiming to obtain a passive house label. This allows for the analysis of a pool of 'certified' and well-documented passive houses in Belgium (PHP, 2010: project database), in addition to the actors involved in introducing innovations.

1 This means that the innovation has to be perceived as new by the enterprise. This perception of newness might differ for example from the perception of the interviewer/ researcher, who can be more accustomed to some ideas, practices and artefacts.

This question is analysed according to the following sub-questions:
1. *How does the passive house concept relate to specifications for individual technologies?*
2. *Which innovations have been adopted in passive houses, both in new-built houses and in renovations?*
3. *What do innovator companies perceive as opportunities for and barriers to the further adoption of innovation, and what solutions do they perceive for eliminating barriers?*

To address the first sub-question, this study provides a list of specifications focused specifically on housing. Definitions and technology requirements – specifically designed to stimulate innovation in companies with regard to passive housing (IWT, 2007) – were provided by the Flemish passive-house company network PHP (PHP, 2010).

To answer the second sub-question, enterprise experiences were collected during previous research projects from existing Flemish residential demonstration projects. Data were collected regarding the first new-built passive houses from the period 2002-2007 (IWT, 2007), and regarding the first passive and nearly-passive housing renovations from the period 2007-2010 (Mlecnik *et al.*, 2010). The data were collected through project database searches, company literature searches and interviews with corporate representatives, either at building fairs or during individual visits. The companies were selected from their stated involvement in passive houses, using the Flemish project database as a reference. While full research reports are available (IWT, 2007, Mlecnik *et al.*, 2010), here the experiences within these research projects are evaluated in order to detect product, system and service breakthrough innovations in new-built and renovated passive houses. Using short, focused interviews and requests for information, the companies were additionally encouraged to express their views on the adoption of the passive house concept and their experiences with innovation activities in this field.

To answer the third sub-question, the results of Questions 1 and 2 were regularly structured and presented for discussion, thus allowing input, particularly from companies engaged in innovation follow-up committees (IWT, 2007; Mlecnik *et al.*, 2010). This made it possible to analyse barriers and opportunities, as perceived by the companies, in addition to identifying possible activity changes and the extent to which they have adopted innovation.

The following section begins by discussing related literature and framing the research according to findings from innovation studies. The subsequent section provides answers to research Sub-questions 1 (Section 2.4.1) and 2 (Section 2.4.2). This is followed by a discussion of the results in relation to Question 3, leading to a discussion of perceived opportunities (Section 2.5.1), barriers (Section 2.5.2) and solutions (Section 2.5.3). The main research question is answered in the concluding section.

2.2.3 Limitations of the research

This study is limited to innovations related to the construction of owner-occupant single-family or two-family houses in a region dominated by heating demand. For this reason, it might not be suitable as a reference for innovations related to large residential buildings or buildings dominated by a demand for cooling (e.g. houses in warmer and/or humid climates, or office buildings). In addition, the research does not specifically address innovation opportunities for energy-efficient or energy-positive districts or communities or non-residential buildings. Research in these fields could entail the discussion of different issues and derive different conclusions.

2.3 Theoretical framework

Researchers have been working to develop a scientific framework for innovation since the 1950s (Rogers, 1962). Innovation is not only related to technological products. Empirical literature generally takes 'innovation' to mean some form of technological change, either in a product or in the production of a good or service (Blake and Hanson, 2005). More comprehensively, Rogers (2003) defines innovation as any idea, practice, or material artefact perceived to be new to a relevant adopting unit. In addition to products, therefore, it also refers to systems, services, techniques, methodologies, concepts and more or less abstract ideas.

A 'system' notion of innovation is particularly important when addressing buildings and energy conservation. On the one hand, within the context of buildings, it is understood that 'architectural innovation' (Henderson and Clark, 1990) – alternatively coined as 'system integration innovation' (Jochem, 2009) – can even include developments in which the component level remains more or less untouched, with the source of novelty being the knowledge of how to integrate components into a product. On the other hand, energy saving in buildings depends to a significant extent upon the ways in which various energy-using devices (e.g. heaters, pumps, fans, chillers) are put together as indoor climate systems and energy concepts. The savings opportunities at the system level generally amount to many times what can be achieved at the device level, and they can often be implemented at net investment-cost savings (Harvey, 2009). In particular, passive houses require such a system approach, as their realisation relies on integrated design processes that optimise the building-energy performance to a certain level.

Compared to single technologies and other developments, innovation in passive houses has received only limited attention in literature. For example, Dieperink and colleagues (2004) cluster variables to provide an analytical framework for the diffusion of energy-saving innovations in industry and the built environment. Egmond and colleagues (2006) describe a strategy for increasing the diffusion of energy-related innovations into the mainstream of housing associations, and Alkemade and Hekkert (2009) develop theoretical patterns with which to assess technological innovation systems concerning environmental technologies. None of these contributions, however, specifically addresses the achievement of high energy-efficiency targets up to the level offered by passive houses.

Several researchers in Germany and Austria have conducted studies focusing on passive houses. For example, Feist (2001) presents several general trends and technological developments. Biermayr and colleagues (2001) observe that the introduction of innovative concepts and technologies in the building sector (e.g. high-efficiency insulation, the use of solar energy, ventilation systems and ensuring indoor air quality) can be strongly influenced by various obstacles and supporting factors related to technical, legal, sociological, psychological, ecological and economic factors. More recently, Jochem (2009) conducted research on patent dynamics for various passive house components and passive house market development. Guschlbauer-Hronek and colleagues (2003) compiled data about the use of passive house components in renovations in order to diffuse information about such innovations in Austria.

Enterprises are understood to play a key role in bringing innovations (e.g. new products, processes and forms of organisation) to economic life (Mytelka, 2000). The construction industry is characterised by inter-organisational collaboration, which involves the practice of constructing unique projects (Harty, 2005). Innovations in construction are usually not implemented by any one firm alone, but as aspects of larger projects in which several firms are engaged (Miozzo and Dewick, 2002). With respect to achieving highly energy-efficient housing, demonstration projects have shown that the introduction of innovations is usually negotiated between two or more parties comprising project coalitions and based on the joint goal of attaining a certain level of energy performance (Silvester, 1996; van Hal, 2000). Demonstration projects have also been acknowledged as providing enterprises with a variety of opportunities for innovation learning (Femenias, 2004).

For these reasons, demonstration projects and the experiences of firms involved are of particular interest for studying the adoption of technological innovation in construction. In this context, it is interesting to examine the ways in which companies have introduced innovations in passive house demonstration projects.

Box 2.1 The commonly used definition of the 'passive house' as defined in the European project 'Promotion of European Passive Houses' and used in Belgium and other countries

The term passive house refers to a specific standard for the construction of residential buildings that offer good comfort conditions during winter and summer, without the need for traditional heating systems or active cooling. Typically this includes very good insulation levels and very good building air tightness, as well as the guarantee of good indoor air quality by a mechanical ventilation system that has a highly efficient heat recovery capacity. Thereby, the design heat load is limited to that which can be transported by the minimum level of required ventilation air. However, space heating does not have to be carried through the ventilation system. For 40-60 degree northern latitudes, under conditions specified in the PHPP* calculation model:

- the total annual energy demand for space heating and cooling is limited to 15 kWh/m² of treated floor area;
- the total annual primary energy use for all appliances, domestic hot water and space heating and cooling is limited to 120 kWh/m².

A Passive House has a high level of insulation with minimal thermal bridges and low infiltration and utilises passive solar gains and heat recovery to guarantee these characteristics. Consequently, renewable energy sources can be used to meet the resulting energy demand.

Source: PEP, 2008

Note that the m² of treated floor area refers to the net heated surface according to national standards.

* The PHPP or 'Passive House Planning Package' is a software tool designed by the Passive House Institute in Darmstadt for the evaluation of passive houses.

2.4 Innovations in passive houses

2.4.1 Definitions and technology criteria

Thousands of 'passive house' demonstration projects have been realised in Europe, the majority of them in German-speaking countries and regions (Pass-net, 2010). In Belgium, the German notion of the 'passivhaus' was adopted at the beginning of the 21st century and was referred to as 'passive house', 'passivehouse', 'passivhaus', 'maison passive' and 'passiefhuis'. In Flanders, the promotion of the passive house concept by regional companies was initiated by a cluster consisting primarily of small and medium-sized enterprises under a Flemish grant programme for 'thematic innovation stimulation' (IWT, 2007). The Flemish passive house company network (PHP) adopted a specific definition of a passive house (see Box 2.1) and specified criteria related to the technologies available for realising passive houses (see Table 2.1).

In one European project (PEP, 2008), the passive house definition from Box 2.1 has been translated into 'basic', 'often applied' or 'optional' technology measures, using different sets of specifications:

- Specifications for superior thermal insulation
- Specifications for the heating and ventilation system
- Requirements regarding the control of solar gains

Table 2.1 Basic principles, technology solutions and recommended technical values for the development of innovative passive house technologies in Belgium

***Basic principle*/technology solution**	**Recommended technical values**
1. *Reduction of transmission losses*	
Thermal insulation of walls, roofs and floors	Thermal transmittance $U \leq 0.15$ W/m²K
Thermal insulation of transparent parts	Thermal transmittance $U_g \leq 0.8$ W/m²K
Thermal insulation of window frames	Thermal transmittance $U_f \leq 0.8$ W/m²K
Avoidance of thermal bridges	Linear heat coefficient $\Psi \leq 0.01$ W/mK
2. *Avoidance of air leakages*	
Building air tightness value to be measured with fan pressurization method	$n_{50} \leq 0.6$ h^{-1}
3. *Improved solar gains*	
Required solar energy transmittance glazing	Solar energy transmittance glazing $g \geq 50\%$
Avoidance of overheating	Annual overheating hours (indoor temperature over 25°C) ≤ 10%
4. *Comfort ventilation with heat recovery*	
Air quality through controlled ventilation	min. 0.4 ach^{-1} or 30 m³/pers/h or national regulation if higher
Efficient air-to-air heat exchanger	Heat recovery $\eta_{HR} \geq 75\%$
Minimal air heating	Space heating load ≤ 10 W/m²
Efficient fans	Specific Fan Power SFP ≤ 0.45 W/m³h (transported air)
Examine the possibility of earth-air heat exchangers	Fresh air after sub-soil heat exchanger ≥ 8°C
Examine avoidance of active cooling	Specific space cooling demand ≤ 15 kWh/m²a
5. *Reduction of household energy demand*	Primary energy use for all appliances, domestic hot water and space heating and cooling ≤ 120 kWh/m²
6. *Application of renewable energy*	

Source: PEP(2008)

- Criteria considering electrical efficiency (e.g. household equipment)
- Considerations regarding renewable energy
- Considerations regarding cost efficiency.

The project (PEP, 2008) defined criteria for individual components, focusing on effectively reaching the defined set of specifications. A strong focus was placed on measures involving building skin and HVAC. In practice, the use of renewable energy was regarded as the 'icing on the cake': once the energy demand is sufficiently low, it becomes easier and more cost-efficient to cover the low remaining energy demand with renewable energy.

In order to promote the passive house concept effectively, the specifications defined in the European project were translated into six energy-saving principles (see Table 2.1): reduced transmission losses, increased building air tightness, improved solar gains, comfort ventilation with heat recovery, the reduction of household energy demand and the application of renewable energy sources. These principles were observed to be easier to communicate to both companies and potential clients. Specific recommended technical values were promoted within companies in accordance with the above-mentioned principles, thus stimulating the development of specific technology solutions (see Table 2.1).

Further, after their success had been demonstrated for new-built houses, the actors involved in the project also promoted these principles and technical values for use in renovation projects as well. In many cases, however, the space heating demand criterion proved too stringent for the renovation of certain (e.g. highly ornamented) types of buildings. In a later stage, a Flemish project defined a 'low energy housing retrofit' as a 'thorough retrofit of a building towards a building with improved comfort, taking into account substantial thermal insulation, the avoidance of thermal bridges, and the provision of air tightness in the building and mechanical ventilation with heat recovery' (Mlecnik *et al.*, 2010). Within the context of low-energy housing retrofitting, the passive house principles tended to take a more important lead than the strict passive house definition.

2.4.2 Adoption of innovations in demonstration projects

The regional promotion of the passive house principles led to innovative solutions, specifically in the Flemish market. Compared to other passive house enterprise networks, PHP had the relative advantage that it was necessary for the corporate members of this non-profit organisation to engage formally in innovation in their business in order to achieve the passive house concept. In addition, PHP received funding to create synergies for stimulating innovation within companies, particularly SMEs (Mlecnik, 2008).

The most important innovation actors were thus SMEs and PHP, along with a few large companies, non-profit organisations and universities. Comparable to the findings reported by Jochem (2009), the actors involved in developing passive house innovation in Flanders were also active in the realisation of low-energy buildings. In particular, supplier SMEs were engaged in marketing efforts to introduce technological innovations into the regional market. Innovative architects had an important impact on the adoption of architectural innovation. While enterprises invested considerable effort in convincing clients to adopt innovation in some cases, the innovations were led by clients in other cases[2] In particular, several renovation[3] clients reported greater difficulty with the adoption of innovations by architects and contractors. Many architects stated that they regularly had to control the work of relatively inexperienced contractors and installers. Some contractors were unfamiliar with architect's proposals (in some cases, relatively simple measures, such as extending a roof to connect to future wall insulation), and contractors were

2 For example, three of the projects identified had owner-occupants who were motivated to achieve the best energy-efficiency solution, although they had difficulty finding suitable architects or contractors. In one case, the owner had even commissioned a specialised consulting agent instead of an architect to find the best available technologies.

3 Adoption problems by professionals occurred in passive house renovations, although 'easier' low-energy renovations were also experienced as cumbersome in some cases.

particularly likely to learn by doing, through a process of trial-and-error.

Companies introduced their own typical innovations into demonstration projects (the first projects were documented in Mlecnik and Marrecau, 2008). The following tables show how the promotion of passive house principles (see Table 2.1) led to the introduction of certain types of innovation. The following tables present examples developed by some of the companies involved, as they appeared in realised Flemish demonstration projects. The pictures show the innovation as it was implemented after the described innovation barrier (on the right side of the picture) had been eliminated. During the first years that PHP promoted the passive house concept, the focus of promotional activities was on the first four principles listed in Table 2.1. This explains the introduction of many innovations in these areas. For example, Table 2.2 shows typical innovation challenges that were identified as relating to the principle of 'reduction of transmission losses'. The data show that innovations also include building systems. Some micro-enterprises were able to redirect their activities towards the passive house market very quickly. For example, one micro-enterpise – a space heating installer – radically transformed his business to sell passive house windows.

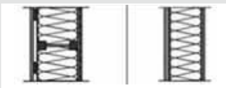
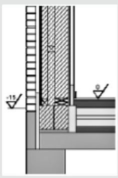
In addition, novel insulation materials were regularly being used in passive house projects (both new construction and retrofit), including improved carbon-filled polystyrene, polyisocyanurate, wood-fibre insulation and cellulose insulation. Outside facade-insulation systems (a well-known building method in other countries, but not very widespread in Belgium) was used in several demonstration projects, especially for the insulation of the usually single-brick facades. In some renovation cases, inside thermal insulation was applied (also behind protected facades) although this required careful planning and the investigation of possible risks, thus leading to additional architectural innovation. For example, innovations concerning inside insulation include the use of cladding systems with cellulose filling and vapour barrier with moisture control. More recently, quadruple glazing has also been introduced in Belgium within the market for inclined roof windows.

The renovation market further posed specific challenges. For example, intrusion into the habitat area is usually experienced when workers need to be able to reach the back facades, usually through the building. One opportunity that was identified therefore involved providing quick solutions for renovation of inhabited buildings, based on minor outdoor intervention only. In this field, innovations were observed for prefabricated integrated solutions for thermal insulation (see also IEA ECBCS Annex 50).

Table 2.3 shows typical innovations related to the principle of 'reduction of air leakage'. The fact that a performance criterion for building air tightness was specified as obligatory for passive houses was particularly influential in leading to the development of careful attention and new services in this field.

The principal of allowing solar gains while avoiding overheating mainly led

Table 2.2 Innovations related to the principle of avoiding energy loss through transmission, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

Typical innovations	Description of the company innovation/challenge (Flemish Region)
Solutions for placement of thick thermal insulation in roofs, floors and walls	
	A large company that specialised in the production of cellular glass products developed high thickness insulation solutions. The challenge was to gain experience in laying pressure-proof insulation under a basement floor, or to convince renovation clients to undercut their walls to avoid thermal bridges.
Advanced wood skeleton systems	
	An SME developed their first passive house from their experience with low-energy houses. The challenge was to increase the thickness of the timber skeleton system in a cost-efficient way and to include high thermal insulation thicknesses and excellent airtightness.
Advanced brick façade systems	
	A section of a large company developed a building system using a traditional brick façade which included high thermal insulation thicknesses. The challenge was to redesign an earlier development that had been used for the construction of low-energy buildings.
Advanced glazing systems with better thermal performance	
	An SME started marketing their innovative triple glazing to the passive house market. In this system the intermediate glazing panel is replaced by a polymer film to substantially reduce weight. The challenge was to provide scientific details related to the recommended technical values for passive house technologies.
Advanced window systems with better thermal performance	
	An SME initially involved in HVAC maintenance redirected its activity to the delivery of passive house window systems. The challenge was to reach an agreement with an Austrian manufacturer to deliver the required know-how and products to the Flemish market and to interpret and translate all the technical data.
Solutions to avoid thermal bridges	
	A large company produced cellular glass-based building blocks that reduced thermal bridging, which could be used in connection with wall and floor insulation. The challenge was to introduce this product into the passive house market by explaining the need to reduce thermal bridges and providing adequate details on increased wall thickness.

Source: IWT (2007). Source pictures: Passiefhuis-Platform vzw

to more cautious attention in the design of passive houses and architectural innovation. In particular, architects introduced new solar shading design

Table 2.3 Innovations related to the principle of avoiding energy loss through air leakage, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

Typical innovations	Description of the company innovation/challenge (Flemish Region)
Advanced building airtightness products	
	An SME initially providing cellulose insulation to the Flemish market expanded its activity to include the import and delivery of several specialised building airtightness products. The challenge was to gain experience with these products while using Belgian building methods.
Building pressurisation equipment	
	The above-mentioned SME also started importing equipment to verify building airtightness. The challenge was to develop educational tools permitting potential customers to use this equipment adequately on building sites.
Building pressurisation services	
	An SME initially specialising in the detection of HVAC leaks redirected its activity to include services to evaluate building airtightness, also to be combined with infrared thermography services to detect deficiencies in the placement of thermal insulation and air barriers. The challenge was to gain experience with this equipment and to evaluate results on demonstration projects.
Infrared thermography services	
	An SME initially specialising in the detection of HVAC water leaks by means of infrared thermography redirected its activity to include services to detect thermal insulation leaks.

Source: IWT (2007). Source pictures: Passiefhuis-Platform vzw

and passive cooling systems (see Table 2.4). For example, in one renovation project, it was observed that the architect had proposed triple-glazed window frames with integrated solar shading, including two different tilt positions for ventilation in the winter and in the summer.

Business-as-usual in Flanders involves natural ventilation strategies (in most existing houses, uncontrolled). The principle of 'comfort ventilation with heat recovery' therefore led to many innovations, shown in Table 2.5. For example, one company that was specialised in sales of air conditioning transformed its business to sell ventilation with heat recovery systems.

Instead of traditional central heating systems, indoor climate systems were used that integrate space heating, hot water production, ventilation and heat

Table 2.4 Innovations related to the principle of using solar gains while avoiding overheating, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

Typical innovations	Description of the company innovation/challenge (Flemish Region)
Solar shading design	
	SME architecture firms were creative in providing horizontal or vertical window-shading systems, roof overhangs, balconies, greenery or special constructions. The challenge was to integrate these solutions at the design level: some clients opted to wait before making such an investment, preferring to first experience summer comfort levels without shading devices.
Passive cooling design	
	SME architecture firms regularly proposed the use of ground/air heat exchangers. The challenge was to gain experience with the product in a total design context: all connections must be waterproof, tubing should have adequate dimensions and be laid out for housing ventilation, and the contractor must know how to lay the system in difficult soils, possibly below groundwater level.

Source: IWT (2007). Source pictures: Passiefhuis-Platform vzw

recovery, and connection to renewable energy systems. Such integrated units were commercialised by suppliers as being much more compact and requiring less space and maintenance.

The analysis of demonstration projects shows that, for low-energy housing retrofits, clients tend to prefer new types of post-heating, adapted to lower power requirements. Space gain is an important issue in most renovation projects. Novel post-heating systems were chosen in some cases, as they require no boiler and no chimney.

In some cases involving the renovation of the central heating system, conversion to low temperature and the elimination of several radiators generated new design ideas. In some projects, radiators were removed in locations where triple glazing and passive house level insulation had been installed. Some companies reasoned that surface temperatures would be high enough on those walls and windows. In some cases, companies were very creative with integrating mechanical ventilation into existing shaft or chimneys.

Room-based decentralised ventilation with heat recovery had not yet been used, although companies were aware of experiences in other countries showing that such systems could offer the advantage of avoiding large ductworks and reducing nuisance to inhabitants (e.g. in renovations). Companies were aware of solutions that could be placed only by drilling a hole in the wall or through integration during window replacement.

Although attention regarding renewable energy and electricity savings was relatively low, the promotion of the passive house concept also led to innovations in these fields (see Table 2.6). If the client wanted solar renewable energy or biomass fired system, the architect sometimes considered attaching a water-based storage boiler or ventilation post-heating system.

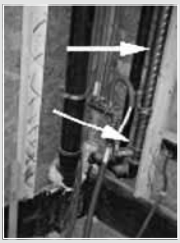
In general, the emergence of various clustered technology solutions was

Table 2.5 Innovations related to the adoption of comfort ventilation with heat recovery, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

Typical innovations	Description of the company innovation/challenge (Flemish Region)
High-efficiency air/air heat exchangers	
	An SME specialising in air-conditioning systems started importing and distributing a balanced ventilation system with heat recovery, especially for use in passive houses. The challenge was to reach an agreement with a Danish producer and to interpret technical data in such a way as to compete with cheaper systems from the Dutch market.
Low-power heating to provide remaining space heating demand	
An SME installer investigated the opportunity to integrate a pellet oven in a passive house. The challenge was to import and install a low-power system with visible flame that could use the surplus heat for the production of sanitary hot water.	
Ground/air heat exchangers for preheating and precooling ventilation air	
	A large company specialising in tube systems developed a ground tube system to be used for ventilation purposes. The challenge was to coat the plastic tubing with an internal antibacterial layer.
HVAC design tools	
A university developed a design tool for ground-covered tubing to be coupled to the ventilation system, on the basis of previous positive experiences with such devices in preheating winter ventilation air above freezing temperature and cooling summer ventilation air without the need for extra energy. The main challenge was to have adequate dimensions for the tubing for housing ventilation and to avoid internal condensation.	
Air-flow control systems	
	An SME distributor of ventilation systems and air conditioning expanded its range to include products and systems from the Finnish market, including air-flow control systems based on temperature, relative humidity and CO_2 levels. The challenge was to gain experience with possible air-flow control settings and customer wishes in the context of the Belgian building tradition and climate.

observed, resulting from the combination of several principles (also in renovation projects). Examples include the combination of thermal insulation with air tightness, mechanical ventilation with heat recovery, heat production with renewable energy and glazing with frames and airtight connections or prefabricated façades. One company identified solutions for combining the principles of 'avoiding energy loss through transmission' and 'comfort ventilation with heat recovery' by integrating ventilation ductwork into a prefabricated wall system. Another company expressed similar ideas for prefabricat-

Table 2.6 Innovations related to reducing electrical energy consumption and using renewable energy, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

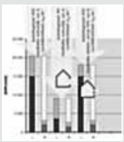
Typical innovations	Description of the company innovation/challenge (Flemish Region)
Energy-saving lighting	
Groen Licht Vlaanderen	The concern for energy-efficient lighting led to the development of an independent SME-based consortium and thematic innovation platform specialised in lighting. An important challenge was to reveal the facts and fables about the energy efficiency of LED lighting.
Electricity-saving household equipment and appliances	
	An SME specialised in energy audits in houses expanded its activity to include the sale of energy-efficient household equipment and energy-saving appliances. The SME was challenged by the slow uptake of end-products and tried to stimulate the market with web-based services.
Energy saving in hot water production	
	An SME introduced energy-saving devices to recover heat from hot sanitary waste water from the shower. The challenge was to be able to demonstrate realistic energy savings to argument inclusion in the Energy Performance of Buildings Directive.
Compact integrated units for hot water production, ventilation, heating and solar assistance	
	After gaining experience with mechanical ventilation in relation to heat recovery, an SME started importing and distributing a compact heat-pump unit especially for use in passive houses. The challenge was to gain experience with such a system in local demonstration projects.
Renewable energy systems	
	An SME and a large company already active in the import of renewable energy systems tried to link up with the passive house market.

Source: IWT (2007). Source pictures: Passiefhuis-Platform vzw

ed renovation. One architect developed a specific company providing thermal insulation and air tightness services.

Surprisingly, innovations were not only identified in relation to the princi-

Table 2.7 Service innovations related to the definition of the passive house concept, as detected in companies involved in Belgian passive house demonstration projects between 2002 and 2007

Typical innovations	Description of the company innovation/challenge (Flemish Region)
Passive house consultancy	
	An SME specialising in sustainable design services expanded its services to include the design of passive houses, also in the non-residential sector. The challenge was to gain experience from demonstration projects.
Courses for professionals	
	The passive house SME network developed a training course for professionals. The challenge was to gather and interpret material from all demonstration projects and to collaborate with other industrial associations.
Information sessions for candidate-builders	
	Two non-profit organisations that already provided information sessions for candidate-builders of low-energy houses, expanded their information material towards passive houses. The challenge was to gather material from experts.
Passive house calculation tool	
	The passive house network and an engeneering office developed a passive house design and calculation tool to ensure that the technical targets of the passive house definition are met. The challenge was to interpret an available German tool and to adapt the calculation procedures to include the regional climate zones and Belgian building traditions.
Passive house certificates	
	The passive house network developed a passive house quality assurance form. The challenge was to develop an associated quality assurance system and to develop detailed procedures for the provision of coupled grants.

Source: IWT (2007). Source pictures: Passiefhuis-Platform vzw

ples listed in Table 2.1. Innovations were also introduced that directly focused on control of the definition presented in Box 2.1. These service innovations are illustrated in Table 2.7.

As demonstrated by the data and examples presented above, the application of the passive house concept generated innovation within many fields in the form enhancing the energy efficiency of technologies or the associated comfort parameters. Innovations always related directly to the defined principles or the definition of the passive house. In addition to technological innovations, SMEs also provided system and service innovations. In many cases, it was necessary to investigate the application of new materials, as well as new designs that were capable of providing better energy efficiency. This also led to significant architectural innovation.

Many energy-efficient technologies that were already available on the market required further research and development in order to attain the passive house standard or a regional interpretation in the local building tradition. Some innovations were developed in response to a perceived need to develop specific passive systems that would enable the replacement of conventional heating, ventilation and cooling systems, combined with new design and technologies in order to provide higher heat transfer efficiency.

2.5 Opportunities and barriers

2.5.1 Supporting factors in the adoption of innovation

The data show that the implemented innovations were related to the passive house principles that had been promoted. Several companies noticed that a high level of identification of their own products, systems and services with the passive house principles supported the adoption of innovation. One essential supporting factor concerning the market introduction of the passive house concept was thus its translation into recognisable principles that would allow companies and single, technically and/or ecologically motivated actors to place their own products, systems and services within the passive house framework. This subsequently led them to convince their peers to push for involvement in demonstration projects and/or to test or develop an innovation. Although only technological innovation was expected initially, the innovation stimulation project also led to innovations in systems, services and architecture.

Several companies argued that a further supporting factor in relation to achieving the development of innovation was the fact that, from the beginning (i.e. upon becoming a member of the passive house network), companies were expected to express a high degree of personal commitment. In order to be fully acknowledged as ‘passive house’ companies, they were obliged to provide written statements of their commitment to the concept in their marketing and further business development. When comparing these statements to the results in the different tables, it could also be demonstrated that most of the companies making such declarations showed results after four years in new-built passive houses. Apparently, committed enterprises were prepared to champion the passive house concept despite resistance, in addition to accepting the setbacks that accompany innovation.

Some companies argued that it was important for their own activities to be recognised within PHP (or its activities) or within the passive house concept. Low recognition led to less innovation. For example, because the network focused on small residential houses in its first two years of promotional activity, two companies that were mainly expecting spin-offs in non-residential projects left the cluster and thus provided no innovation. In contrast, the companies that were elected to the management board of PHP were highly active in the development of innovations. A few companies stated that their innovation development was directed neither primarily nor exclusively towards the passive house market, but that they had also benefited from the market for low-energy housing. In particular, companies with a tradition of participation at the planning and building stages appeared better able to introduce innovations into demonstration projects.

The importance of the role of the innovation facilitators was confirmed by innovating companies. Innovation was stimulated because the network agents generated useful information that encouraged clients to adopt principles and companies to adopt innovation. In particular, the facilitators assisted companies that were already intending to adopt innovation (e.g. by providing support in obtaining industrial grants and establishing research partnerships). The network even developed its own accompanying innovations, including calculation tools, professional courses and a certification system. These innovations further boosted the passive house market (and the visibility thereof).

Many innovations have been identified in demonstration projects, and enterprises confirmed that owner-occupants have commented on perceived benefits, including energy savings, air quality, thermal comfort in winter and in summer, and health advantages. Upon careful examination, such end-user experiences can provide arguments for marketing passive house innovations.

As with most substantial retrofitting projects, the protection and renewal of construction was the most important technological driving force for low-energy housing retrofitting projects, and the passive house principles proved quite marketable within this framework. For example, thermal insulation and the implementation of ventilation measures can protect the construction from internal condensation, thereby increasing its life span. The minimisation of thermal bridges and improved air tightness also reduces structural damages. Mechanical ventilation with heat recovery can contribute to improvements in air quality and the reduction of moisture problems, while reducing ventilation losses.

2.5.2 Factors impeding the adoption of innovation

One of the most important barriers perceived was a possible lack of market demand. Although many technologies could be provided, it is necessary for the client to ask for such solutions. In the current Belgian situation, owner-clients are often expected to initiate new house or renovation projects, although they often have no experience. Although architects can act as intermediaries providing information, they must be aware and convinced of the relevance of the passive house solutions. In addition, clients often receive information and impulses directly from contractors, media or do-it-yourself shops. In many cases, these actors are also poorly informed about energy efficiency and the available innovations, and clients are often left with many questions concerning the execution of their own projects. It is therefore important for owner-clients to be able to find independent and trusted information sources.

Peer-to-peer contacts between passive house owners were observed to be particularly important triggers that could stimulate potential clients to consider passive house innovations. The experiences of companies suggest that clients prefer to consult other clients through peer-to-peer contacts and to compare offers and information with other companies in order to evaluate information. Furthermore, many clients asked for independent appraisals of technological solutions, information about costs and similar matters. Most notably, many companies observed that clients did not require any specific technology, but were looking for solutions in order to realise a passive house or low-energy home. Once they decided to adopt the passive house, many clients wanted some form of guarantee that they would indeed receive a passive house that functioned properly. This guarantee could not be provided by the individual companies, who were already struggling to implement technological innovation.

On the one hand, the market infrastructure was in need of improvement. A lack of information about passive houses and the visibility of passive house demonstration projects initially led to a very low demand for passive house and innovative passive house technologies. On the other hand, enterprises needed to develop their own strategies and activities related to passive houses. The shift to passive houses also had major implications for the knowledge base required by both clients and enterprises. During meetings with the innovating companies, questions were also raised concerning the opportunities for disseminating innovation through the demonstration projects. Deficiencies in contemporary demonstration projects are often attributed to the lack of incentives and interest in learning, deficiencies in the production of reliable and useful information, and the lack of institutions for information dissemination (Femenias, 2004). One detected obstacle to the further application of currently applied innovations could involve a lack of education on the part of professionals or a lack of access to information.

Enterprises also became aware that, in order to realise passive houses, they could not isolate themselves from one another, as the integrated design and construction of passive houses requires the interaction of a number of heterogeneous actors. In particular, gaining knowledge about system integration was perceived to require project specific collaboration in order to combine several types of expertise.

2.5.3 Solutions identified

Enterprises perceived possible solutions when innovators who had contributed to demonstration projects also helped to spread information, skills and competencies. Existing demonstration projects could serve as a starting point of information in order to reach partners for projects, other innovating businesses, opinion leaders and new motivated clients. In order to develop market infrastructure, companies perceived that their key information need concerned help in order to achieve ambitious energy-savings targets and to understand the whole system approach for realising passive houses. According to the companies, integrated architectural innovation (e.g. integrating bioclimatic conceptions, solar supply and protection, thermal insulation, air tightness and ventilation, systems, techniques, and renewable energies) was crucial, including for process issues (e.g. the problems identified with regard to the building process, quality and control). They expected PHP to guide them by providing them with neutral information and some form of quality control, particularly for demonstration projects.

The lack of available information on passive house demonstration projects and related innovations was further perceived as an essential impediment to reaching potential clients. Companies stated that most clients have a remarkably low level of specific knowledge concerning building (particularly energy-efficient building) and that many clients are still unaware of the success of such energy-saving concepts as the passive house and associated technologies. For this reason, clients do not demand passive houses or related innovations. The companies perceived that information about passive houses should originate from neutral organisations. Most companies thus relied on PHP to provide solutions to stimulate both client demand as well as company adoption, as its independent status would allow the credibility of neutral information.

Using this as a starting point, PHP gradually adopted the independent role of that to which Rogers (2003) refers as an innovation 'change agent'. A change agent has the task of guiding adopters – in this case, potential clients and innovating companies (particularly SMEs) – throughout various innovation-decision stages. These stages are part of a process in which the client or enterprise passes from initial knowledge (of the passive house concept), to forming an attitude (towards the concept), to a decision to adopt or reject, to implement and, finally, to confirm this decision (Rogers, 2003).

For example, in the period 2002-2007, the network developed several activities regarding new-built passive houses, using the following means to provide clients and enterprises with the necessary information:

- Individual advice explaining the passive house concept and principles.
- A detailed website providing further information on technologies, reference projects, experiences available and related events.

- Creating a market infrastructure through a technology fair in order to allow clients to contact individual enterprises.
- Directing clients to individual companies in order to gain more information about specific technological solutions.
- Organising site visits to demonstration projects in order to establish peer-to-peer contacts with other clients.
- Knowledge exchange through symposia and information sessions.
- Scientific evaluation of demonstration projects and data collection.
- Establishing quality assurance with a passive house certificate.

These efforts were later followed by specific activities covering renovation.

2.6 Conclusion

The analysis shows that many innovations are likely to be adopted in accordance with the passive house concept. Through its breakdown into passive house principles, the concept proved highly marketable for owner-occupied single-family houses, both for new built construction and for renovation, thus giving rise to innovation in a traditionally very conservative building sector. Breakthrough technology innovations were associated with the passive house concept in such fields as thermal insulation, building airtightness and high-efficiency mechanical ventilation with heat recovery, as well as passive solar and light gains, and additional heating and renewable energy systems (and combinations thereof). System, service and architectural innovations were also introduced, and the definition itself led to service innovations.

The adoption of the passive house innovation was strongly supported by a high level of company identification with their own products, systems and services within the passive house principles. Moreover, the personal commitment of companies played a role. Innovation facilitators appear to be quite important for identifying potential innovating companies, stimulating innovation decisions and creating synergies.

The introduction of innovations related to passive houses can be hindered by low demand or by the lack of a market infrastructure. In particular, demonstration projects can serve as a basis for demonstrating the availability of innovation and client opportunity, and the continued peer-to-peer networking surrounding projects with demonstrated quality can be expected to bridge the gap between future clients and innovating companies. This could be facilitated by change agents. Given that clients may be less well informed and somewhat reluctant, the development of specific communication channels or activities is needed in order to increase adoption, as along with a confirmation system in order to guarantee the quality of further projects.

An integrated architectural approach is needed in order to introduce innovation related to housing concepts. There is a particular need for the definition of a standard that could be translated easily into generally recognised principles. Addressing scientific limit values to such principles would allow the development of a multitude of technologies, services, systems and architectural innovations (possibly clustered). In addition, the integration of new technologies in existing housing and the development of standard protocols can be expected as a result. In particular, the passive house definition offers excellent opportunities for concept innovation in the construction sector.

Although demonstration projects offer several innovations, the increased adoption of innovation requires further research. In particular, the socio-technical nature of system and architectural innovation in passive houses and renovation calls for increased research attention to the social component.

Acknowledgements

The research on new-built houses, which was conducted between 2002 and 2007, was financed in part by the Flemish Government (IWT, within in the framework of the thematic innovation-stimulation project 'Passiefhuis-Platform'), as well as by the European Commission, the Flemish Region, the Walloon Region, the Brussels Capital Region and the FPS Economy, SMEs, Middle Classes and Energy within the framework of the IEE project, 'Promotion of European Passive Houses (PEP)'. Research on renovation was performed during the 'Low Energy Housing Retrofit – LEHR' project (Mlecnik *et al.*, 2010), which was financed by Belgian Federal Science Policy, as part of the implementation of the 'Programme to stimulate knowledge transfer in areas of strategic importance'.

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3 Opportunities for supplier-led systemic innovation in highly energy-efficient housing

In press as: Mlecnik, E., 2012, Opportunities for supplier-led systemic innovation in highly energy-efficient housing, ***Journal of Cleaner Production,*** *doi:10.1016/j.jclepro.2012.03.009,*

http://www.sciencedirect.com/science/article/pii/S0959652612001436

Abstract

The construction of highly energy-efficient buildings is more than an emerging business opportunity, it is also a major challenge in systemic innovation, particularly for SMEs, which are more accustomed to incremental innovation. Accordingly, this study searches for new innovation opportunities for supplier-led innovation in highly energy-efficient housing by examining the innovation journey and analysing the innovation opportunities and barriers encountered by a successful innovator in Flanders.

Existing innovation models and innovation barriers and opportunities in the construction of highly energy-efficient housing are discussed within the framework of the theory on systemic innovation. The successful innovation journey of a supplier illustrates how coordinated collaboration can help an incremental (technological) innovation idea to develop into modular, system and even radical innovation.

The study highlighted the importance of suppliers as players in the development of innovation. To successfully introduce innovation (even incremental innovation) suppliers need to join forces with other organisations and respond to the challenges of systemic innovation. Demonstration projects and collaboration between SMEs are key to achieving the modular and architectural innovation needed for highly energy-efficient housing. Given the specificity of both the construction sector and highly energy-efficient housing, the supplier should be given explicit guidance on how to link modular innovation to architectural and system innovation. Finally, the study also showed that players in dedicated radical innovations such as passive house networks can contribute to the market uptake of innovation.

3.1 Introduction

Changes to energy and environmental policy, societal factors, and a keen awareness of rapidly developing technology are putting mounting pressure on businesses to innovate. New-built houses can be regarded as a specific area of interest for innovation by small and medium-sized enterprises (SMEs). Several studies within a European context have confirmed the existence of vibrant business opportunities for sustainable and highly energy-efficient housing (see for example: IEA SHC Task 28, 2006). The original version (EPBD, 2002) and the recast of the European Energy Performance of Buildings Directive (EPBD, 2010) require all European member states to develop a framework for high energy efficiency in new housing with the ultimate aim of realising nearly zero-energy buildings. This will mean innovations at building (system) level. It is hoped that the outcome of research on innovation barriers and drivers will give the housing sector some much-needed momentum along the path to sustainability, particularly in energy efficiency (European Commission, 2010).

SMEs in the housing sector will be sorely challenged to implement such innovations. Innovation at building level invariably implies collaboration with other players and comes with high management and coordination costs. That is why most SMEs introduce only minor innovations. It would be interesting, against this background, to examine successful systemic innovations by SMEs (Teece, 1984) since the lessons learned might give us a better understanding of coordinated collaboration geared to highly energy-efficient housing and, at the same time, enhance our knowledge of innovation mechanisms in the construction industry. Suppliers of materials could be key players in the development of systemic innovation trajectories in the house-building sector. This study investigates an innovation trajectory started by a supplier in the SME sector and connects it with the theoretical framework of systemic and construction innovation.

3.2 Research strategy

The aim of this study was to identify innovation opportunities for suppliers of materials for highly energy-efficient homes by applying construction innovation theory to reflections on a successful process of innovation adoption by a supplier in the SME sector. The study retraces a supplier's innovation journey in Flanders (Belgium). The company in question applied for and received a grant for an innovation study from an SME innovation support programme under the auspices of the Flemish Agency for Innovation by Science and Technology (IWT). The initial innovation was introduced in 2003-2004[1] in collaboration with different partners. The research during the first part of the journey (2003-2004) consisted of a dialectic process of group facilitation, collecting information about (possible and real) collaboration efforts in task group meetings, and reflecting on the learning cycles every three months with (a growing number of) partners. An innovation project facilitator (from the Flemish Passive House Platform) helped the collaborating enterprises in

1 It should be noted that a study on market transformation can be limited in scope and highly time-dependent. The legal context for highly energy-efficient housing is changing rapidly. The study is further limited in scope as it addresses innovations in the construction of single- or two-family dwellings in a region dominated by heating demand.

this group to reach a work goal by applying the principles and processes of group dynamics. Section 3.4 therefore reflects on how the innovation journey proceeded from an idea conceived by a supplier to the meshing and shaping of a broader innovation network that supports the innovation process. Project outcomes have been described in detail in previous references (IWT, 2004, 2007). The analysis in this paper (Section 3.4) retraces the innovation journey with the aid of a chronological narrative which provides a more selective analytical focus for theoretical reflection on innovation in the construction business. Additionally, interviews were held with some of the key players in 2009-2010 to evaluate the consequences of the innovation (results described in Section 3.4, last paragraph).

Section 3.4 describes the supplier's innovation journey in a qualitative manner so that it can serve as input for reflection on the theory. Afterwards, in Section 3.5, elements of the innovation process are considered in relation to the literature on systemic innovation and construction innovation models. The conclusion (Section 3.6) contains a summary of new opportunities to eliminate barriers that stand in the way of supplier-led innovation in highly energy-efficient housing.

The next section begins with a review of the literature on innovation (Section 3.3). After a brief introduction to systemic innovation, the section presents some of the current models of construction innovation.

3.3 Theoretical framework

Slaughter (1998) defined innovation[2] as the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the organisation that developed it. First, this definition implies that innovation stands for more than just the development of knowledge; in effect, the knowledge that is developed is to be implemented. Second, the innovation is the entire route from the development of the knowledge to the market launch. Finally, products, processes and organisational structures are new for the organisation itself (see also Cobbenhagen, 1999).

The concept of 'systemic innovation' (which emphasises the need for coordination and cooperation in innovation processes) as opposed to 'autonomous' (independent) innovation was first introduced by Teece (1984, 1988). The term 'systemic innovation' should not be confused with 'system innovations', which are characterised by the integration of multiple independent innovations that must work together to perform new functions or improve

2 Empirical literature usually defines 'innovation' as some form of technological change, either in a product or in the production of goods or services (Blake and Hanson, 2005; Edquist, 2005).

performance as a whole (Cainarca *et al*., 1989).

There is a wide range of additional literature which addresses innovation from a systemic perspective and introduces terms such as 'national', 'regional' or 'sectoral', 'innovation systems', 'technological innovation systems', 'socio-technical systems', 'innovation journeys', 'transition paths' and 'strategic niche management' (Coenen and Diaz Lopez, 2010; Cooke *et al*., 2004; Edquist, 2005; Lundvall, 2005; Malerba, 2004; Sharif, 2006; Smith *et al*., 2010; Verbong *et al*., 2008). Also, Marquis (1988) introduced a difference between 'incremental' and 'radical' innovation, as an opposition to distinguish small changes based on current knowledge and experience from scientific and technological breakthroughs that can change the very nature of an industry. Since radical innovations require high levels of learning and communication they often take place in the domain of systemic innovation. But incremental innovations can also have consequences for systemic innovation. For example, technological innovation, business innovation and social innovation are often systemically interconnected (Kaivo-Oja, 2011).

It is widely recognised in the field of innovation studies that sectoral features play a significant role in innovation processes (Reichstein *et al*., 2005). The main differences between buildings and most manufactured products are that buildings are comparatively large and complex, they have a long life span and they are constructed in a specific social and political context with temporary alliances (Slaughter, 1998). Consequently, innovation usually occurs more slowly in the construction industry than in other sectors (Gann, 1994). While manufacturers and suppliers are accustomed to fairly linear trajectories from new knowledge to a new product or service, construction trajectories are usually systemic, non-autonomous and complex. The need for systemic innovation arises, amongst others, from interactions between the operating environments of the suppliers and the construction. A shift towards more systemic innovation on the part of suppliers would help to prevent systemic failures and quality problems, amongst other things, as it would involve more adequate enterprise resource planning, service design thinking and the prefabrication of product/service component systems (Kaivo-Oja, 2011).

Another challenge lies in the fact that the part of the construction sector that focuses on housing involves different market players with different types of expertise, such as design, engineering, project development, construction and the supply of materials – often SMEs which are not usually interconnected through the different phases of the construction process (European Commission, 2010). Another prominent feature of the construction industry, which has implications for the diffusion of innovation, is its project-based structure. Innovations in this sector are not usually implemented by one firm but rather within the project in which the firm is engaged (Miozzo and Dewick, 2002). A project-based structure creates opportunities for inter-company collaboration (Harty, 2005), but it also imposes constraints on the closure of learning loops

Table 3.1 Five categories of 'construction innovation' arranged according to the degree of required change and linking, with the most frequent source of construction innovation and the usual timing of commitment

Categories of construction innovation	Assessment with respect to advancement of the state of knowledge and links to other components or systems	Proposed most frequent source of construction innovation	Usual timing of commitment within construction project phases
Incremental innovation (Marquis, 1988)	Small improvement in current practice (based upon current knowledge and experience), minimal impacts on other components and systems	Within the organization that has the knowledge base on which to develop improvements (can include all parties in the value chain)	Any time
Modular innovation (Henderson & Clark, 1990)	Significant improvement in concept (or new concept), requires no changes in other components or systems	Within organizations that have control over and responsibility for a module; or through new entrants	Design/selection
Architectural innovation (Henderson & Clark, 1990)	Small improvement within a specific area or core concept, major changes in other components or systems in order to function	In the field (for example general and specialty contractors)	Design-to-implementation
System innovation (Cainarca *et al.*, 1989; Slaughter, 1998)	Set of complementary innovations which work together to provide new attributes or functions, together they can significantly advance the state of knowledge or practice	Entities that do not have a vested interest in current configurations and (sub)systems; often coordinators (technically competent and responsible for project performance)	Conceptual design
Radical innovation (Nelson & Winter, 1977)	Completely new concept or approach, including interdependent components or systems (often renders previous solutions obsolete)	From outside an existing industry, often based upon scientific or engineering research (often new companies and organizations)	Technical feasibility

Based on Slaughter (1998, 2000)

and the management and transfer of knowledge which is necessary for innovation. Moreover, cooperation that is based on temporary contracts between changing constellations of players complicates the learning process and tends to slow down innovation (Goverse *et al.*, 2001). Before suppliers can introduce construction-related innovation, specific management needs for dealing with loosely connected SMEs and project-based challenges must be addressed.

Slaughter identified five possible categories of 'construction innovation' on the basis of current management and economic theories of innovations. These five categories reflect the unique conditions of construction projects (Slaughter, 1998). Slaughter placed 'modular innovation' and 'architectural innovation' (Henderson and Clark, 1990) as models between 'incremental' and 'system' innovation, and suggested that 'radical' innovation needs even higher linking than system innovation. 'Modular innovation' entails a significant change in concept within a component, while 'architectural innovation' can even leave the component level more or less untouched, with the source of innovation being the knowledge of how to integrate components into a product (Henderson and Clark, 1990). The five regularly used 'construction innovation' models are thus incremental, modular, architectural, system and radical innovation. Some of their characteristics are listed in Table 3.1. Slaughter also offers proposals for the usual timing for the commitment of these different types of innovation, based on the phases in construction projects (see Table 3.1).

Table 3.1 suggests that market players such as suppliers might engage in more than just incremental innovation. This is highly unlikely to occur, however, if suppliers do not link with other components or systems and other players in the construction chain. They need to decide at which stage in the construction process they will commit in an innovation journey. Literature on systemic innovation further illustrates that innovating enterprises need to interact with professional contacts, agents,[3] industry associations, innovation centres, standard-setting bodies, universities and training centres, and banking and other funding mechanisms, and that such complementary players have an important role in the innovation(-decision) processes.

Though opportunities for systemic innovation have rarely been studied from the viewpoint of suppliers in the house-building sector, researchers see manufacturers and suppliers as key players in this domain (Quigley, 1982; Jacobs *et al.*, 1992; Pries and Janszen, 1995). Indeed, it is often the suppliers who educate and inform the different players in the house-building sector of manufactured innovations. Suppliers therefore have an important role to play in the adoption of innovations. Secondly, when different SMEs in the construction business enter temporary coalitions and collaborate on unique projects, suppliers acquire opportunities to learn from different successive projects, where the innovation and learning environment are centred in the company rather than in the project itself.

Highly energy-efficient housing has received very little attention in the literature on innovation, which tends to focus on individual technologies and/or general sectoral innovation challenges (for example: Jacobs *et al.*, 1992; Bossink, 2004; Dieperink *et al.*, 2004; Egmond *et al.*, 2006). That said, the introduction of nearly zero-energy housing, particularly passive housing, has already led to system innovations (Jochem, 2009; Mlecnik, 2011) and radical innovations (Mlecnik, 2011). The energy-saving opportunities at system level are generally many times greater than at device level (Harvey, 2009). System innovation is perceived as key to realising energy performance at building level.

Summarising, recent literature on innovation analyses innovation journeys as (continuous) social processes that involve organisational learning and collaboration. Specific empirical experience of highly energy-efficient housing is limited. Many companies in the housing sector are small and have neither the competences nor the resources to innovate independently. Collaboration for innovation purposes is being challenged by high levels of management and coordination and the realisation of organisational learning

3 Agents can provide a knowledge base, technologies and input, and can identify and (help) create potential and existing demand (Malerba, 2004).

in a project-based sector that is used to the ad hoc generation of knowledge and networking. The literature suggests different categories of innovation in the construction sector (incremental, modular, architectural, system, radical) and relates them to systemic linking and the phases in a project when innovation is most likely to occur. The literature shows that suppliers can be in an excellent position to eliminate some of the above-mentioned challenges and to diffuse innovation. It is therefore relevant to connect the theory with the lessons learned from the innovation journeys of suppliers. Retracing a successful innovation journey undertaken by a supplier of materials for highly energy-efficient housing will help to clarify innovation issues in this field and point the way to the collaborative structures that are important for the attainment of systemic innovation. The findings will pave the way for a better understanding of innovation opportunities for suppliers and of innovation models for the development of highly energy-efficient homes.

3.4 The innovation journey of a supplier in the context of highly energy-efficient housing

3.4.1 Initiating the innovation journey

The focus of the study was the innovation process in a company involved in wood-based construction, a supply material which already helps to reduce CO_2 emissions directly.[4]

The corporate profile and the intended innovation are shown in Table 3.2 along with initially perceived barriers and opportunities. The company spotted an opening to develop a niche market in sustainable construction[5] using the products and machinery at its disposal.

Table 3.2 shows that the supplier was not driven by radical invention. This

4 Various studies have shown that CO_2 emissions from the use of construction materials can be reduced by 30-80% (Buchanan and Honey, 1996; Goverse *et al*., 2001; Koch, 1992; Suzuki *et al*., 1995). Given the need to balance the positive CO_2 characteristics of wood on the one hand with the maintenance of wood consumption within the regeneration capacity of forests on the other, one can argue for an increase in the number of timber-frame buildings (Goverse *et al*., 2001). Also, timber building materials usually require less energy to manufacture and they generate fewer greenhouse gases than alternative materials in similar applications (Eriksson, 2003; Petersen and Solberg, 2005; Sathre and O'Connor, 2008; Werner and Richter, 2007). At the same time, researchers acknowledge that the intensive use of wood has the potential to create a significantly negative carbon footprint for a house up to the point of occupancy and even offset a portion of its heating and cooling energy use and carbon emissions (Salazar and Meil, 2009). In this framework, Rimmler *et al.* (2006: 179) also proposed that technological process innovation and the development of customer-supplier relationships and supply-chain management for the wood-product industry be prioritised in policy action and further research.

Table 3.2 Selected innovating supplier, scope for innovation, and initially perceived opportunities and barriers

Corporate profile	The company was a supplier of wood-based materials in the SME sector in Flanders (Belgium). It was founded in 1977 and, when it was selected for the study, it occupied approximately 10,000 m^2 of workspace (also for prefabricated construction) and storage. The company designed and produced timber elements, such as roof trusses, timber-frame walls and roof panels, for the construction industry. It also had a department for processing timber: sawing, shaving, vacuum pressurisation etc. The products were applied in housing (new-building and renovation), project engineering, small-scale service buildings, sheds and so on in the Benelux, Germany and France. Its core activities included design and production based on structural timber products from the Finjoist (FJI)* range, mainly using Canadian-type skeleton truss construction.
Scope for innovation	The FJI trusses were mostly used in floor construction, to prevent floor movement and associated problems. The company learned that FJI products were being used in passive houses in other countries: an FJI-based wall system could replace labour-intensive timber frame or masonry façade systems. However, the company had only limited experience of the use of FJI products in walls and no design knowledge of highly energy-efficient projects such as passive housing. It therefore needed special know-how on the requirements for thermal insulation, air tightness, costs and so on.
Opportunities	Users positively associate timber with well-being, aesthetics and ecofriendliness (Gold & Rubik, 2009). Single-family and two-family timber dwellings were already a target market for the company, which had state of-the-art machinery that could cut to size on demand, thus reducing waste. The building method could be highly standardised and prefabricated, possibly leading to excellent thermal and air-tightness performance. When the company first considered innovation, more than 3,500 passive houses had already been built in Germany, so there was potential for a volume market.
Potential obstacles	It was thought that potential clients would be put off the product by the strong Flemish tradition of masonry walls. Also, there were persistent prejudices in relation to perceived deficiencies of wood constructions in relation to fire resistance, durability and stability (see also: Gold & Rubik, 2009).

*FJI is a fully engineered timber I-Joist, manufactured from high quality OSB3 web, with flanges made from the company's structural timber product, Kerto (LVL), which delivered less dimensional change over time.

Source: IWT (2004)

was good for the study since the direct impact of 'bioneers' (Schaltegger and Wagner, 2008) is usually minor and has no effect on the majority of customers or the main flow of products, services, materials and energy in the mass market.[6] The company's main concern at first was to address fire resistance and stability prejudices by acquiring product certification and accreditation that proved compliance with the relevant regulations and standards.

5 In neighbouring Germany, where the company was also operational, wholesalers, retailers, property developers and other building professionals such as engineers and architects expressed unequivocal sympathy for timber as a construction material (Järvinen *et al.*, 2001). The company thus recognised an opportunity to increase its wood production for housing. The average share of general timber-frame construction methods in total housing production in Europe is indeed relatively low (below 5%), with large differences between countries (Rimmler *et al.*, 2006). In the UK the quality of modern timber frames is now generally accepted and perceived as equivalent to other forms of construction by property valuers, mortgage providers and insurers (Rimmler *et al.*, 2006).

6 The literature on technology management also suggests that new entrants often fail to deliver radical innovations due to low legitimacy, lack of political clout, limited resources or insufficient competences (Geels *et al.*, 2008: 533).

One key motive behind the company's pursuit of an energy-efficiency innovation was a demand-side business case in the form of a potential highly energy-efficient housing project and the scope for further projects. This made the supplier aware that drivers of sustainability innovations, especially with regard to the benefits of highly energy-efficient housing, were already being used by managers, authorities, clients, architects, consultants and contractors.

Initial knowledge about highly energy-efficient housing solutions was generated by an important stakeholder in the field, a non-profit organisation. The Passive House Platform (PHP, 2011) – a group of innovative companies in highly energy-efficient housing – had been established in the Flemish building sector in 2002 with funding from the Flemish Agency for Innovation by Science and Technology (IWT, 2007). At the time of the study, user demand for highly energy-efficient housing revolved mainly around so-called 'passive houses'. A demand for passive houses was generated by the then highly active Passive House Platform and its members. It was not until later, when the price of oil rose and governments introduced subsidies and tax relief for energy-saving measures, that people became more generally aware of the potential of more energy-efficient homes.

PHP consisted of network agents who carried out innovation studies and engaged in non-market interactions in order to stimulate research and innovation for the passive house concept. It was through contact with a member of this network that the general manager of the supply company became aware of opportunities for developing and promoting concepts like the passive house and the potential market for his product. Consequently, a representative from PHP (henceforth called the 'agent'), whom the company knew to be specialised in energy-efficient innovation, was invited to help the company embark on an innovation journey and to discuss ways to define the innovation and remove barriers. A meeting was scheduled with the agent, who was contractually accorded the specific role of creating synergies for innovation in passive houses.

"We are interested to know how our products can contribute to building passive houses." (PHP field note from first meeting, statement by the general manager, translated from Dutch). The idea to embark on an innovation journey was thus triggered primarily by visible market pressure (for passive houses), a lack of know-how on how to achieve (standardised) highly energy-efficient houses and an awareness that the base materials and machinery for producing suitable components were available in the company and would be appreciated by the customer (see also Table 3.2). However, the SME found it difficult to define the system innovation because it was used to incremental innovation. Also, the competences and resources for attracting research partners were limited.

The literature stresses the importance of consistent and stable policy frameworks and social embedding in innovation journeys (Geels *et al.*, 2008:

531). In 2004 there was no supportive policy framework for system innovation in passive housing – neither in the innovation policy for SMEs, which focused primarily on technological innovation with no distinction between sectors, nor in the energy policy, which suggested only limited energy performance targets. However, as described below, the agent exercised a significant influence on the gradual uptake of system innovation.

3.4.2 From incremental to system innovation

The different viewpoints of the supplier (targeting small product innovation) and of the players in the construction industry (targeting whole house performance as system innovation) had to be connected. At first, in the eyes of the company, the innovation seemed incremental in nature: after all, it was all about developing a walling system from an established flooring system (see Table 3.2).

However, in the Low Countries, the substitution of a traditional masonry house with a timber-frame building would be perceived as a radical innovation and would therefore be difficult to implement. Sustainability cases often require radical innovation (Schaltegger and Wagner, 2008) but this was not the immediate aim of this company – it needed encouragement to commit to system innovation.

The PHP agent began by conducting a constructive review of the perception of various aspects of innovation (relative advantage, complexity, compatibility, demonstrability, visibility; see also: Rogers, 2003). The agent explained the relative advantage of integrated floor/wall systems to the supplier, who easily recognised this as an in-house opportunity for modular innovation. Brainstorming on compatibility with energy performance standards and passive house criteria exposed some gaps in the company's knowledge of system innovation. The agent further explained that energy saving in buildings depends to a large extent on how various innovative components (not only wood, but also thermal insulation, sun shading, layers of air tightness, heating and ventilation systems, and so on) are put together and thus presented opportunities for system innovation. The general manager responded by saying that he lacked the architectural know-how to achieve this. The agent then clarified the perceived complexity of providing architectural solutions for sufficient thermal insulation and air tightness and solving thermal bridges, thereby showing the manager how to gain the know-how for architectural innovation. Paths were set out that could enhance the visibility of the company as a service player in the design of passive houses. A demonstration project was discussed as a means of gaining supplier experience.

Freely available information in leaflets and on websites provided examples of different innovation ideas from other enterprises and potential competitors and systematically legitimised a move from incremental to modular, architectural, system innovation. The supplier and the agent finally agreed to pursue more than just incremental innovation, largely because the general manager had spotted openings for exploiting prefabrication potential, experience, contacts and knowledge of existing production and applications. The agent knew about the availability of innovation grants for SMEs and together they prepared an application. As a result, the company gained a better understanding of the total innovation. It could then use this to determine the complementary know-how that was needed, how to attract complementary players, and whether to do this with or without a grant from a Flemish agency.[7]

The agent convinced the company by presenting it with examples of opportunities for modular, architectural and system innovation as a step towards the higher goal of radical innovation (marketing a passive house). This would require coordinated collaboration with different innovation players, which could then be optimised and multiplied in subsequent construction projects. The journey is further described in the next paragraphs.

3.4.3 From autonomous idea to systemic coordination and cooperation

The following statement illustrates how the supplier initially perceived the need for systemic cooperation: *"the proposal is for a passive house to cost no more than an energy-efficient house. The targets can only be achieved by continuously evaluating the programme of requirements within the building team after each phase of construction. This creates side conditions for reflecting fundamentally on all the problems in the construction in order to reach a cost-efficient solution."* (statement by the general manager, field note in intermediate report, 4 November 2003, translated from Dutch).

During the process the company realised that it should not only focus on supply, but also investigate design and building processes and get involved in building teams so that it could learn from other players. Tacit knowledge of an initial demonstration project was considered particularly important (see also: Gann and Salter, 2000; Femenias, 2004), especially with regard to cost-efficiency.

At first, the supplier saw potential in involving a stability calculator and a contractor. This was tied in with the fact that the company had already been thinking about how to solve product certification barriers and that the contractor would have useful information about the costs in low-energy housing projects. These parties worked with the supplier on a regular project basis and provided valuable input on the economic and technical implications of

7 In Flanders, public funding for innovation in SMEs has focused on providing financial support and expertise for companies participating in research and development projects with high technological and business risks.

new construction methods. It was through the involvement of these players that the supplier saw opportunities for 'modular' innovation: the need to focus on determining cost-effective and stable solutions for the prefabricated assembly of wall, floor and roof products.

To support architectural innovation, the agent insisted on involving more contributors, particularly those with expertise in energy efficiency and the design of innovative energy-saving construction details. One key supporting factor in attracting these players was the agent's translation of system innovation (the passive house concept) into the needed architectural innovation for the realisation of passive houses. The agent urged the company to search for additional partners by drawing its attention to entrepreneurs with complementary knowledge (an engineering firm specialised in building physics and an architect). The agent knew enterprises that were vision-driven innovators who could redirect their activities very quickly towards the specific gaps in the company's knowledge. These additional partners then recommended the inclusion of an expert on air tightness and a foreign subcontractor who specialised in timber-built passive houses. Eventually, this process led to the research partnership shown in Table 3.3. After the agent had introduced all potential partners at formal meetings, the group of entrepreneurs, led by the supplier, co-developed and submitted a grant proposal. The leading player/supplier engaged a young engineer to coordinate the innovation journey. The learning cycle involving all partners got off to a start by building the know-how of the different partners and by participation in learning activities that contributed to trust-building. A study trip to Germany, a second visit to a passive house in Germany, and a detailing workshop led by the foreign SME provided insight into possible construction methods. A groupware environment was created where the partners could exchange ideas and study results. The partners further engaged in extracting and exchanging information from building fairs, specialised technical journals and potential clients, and from the hands-on production of a prototype wall and subsequent air-tightness testing. Innovation work packages were set up for all partners, which reflect the progressive character of the innovation journey (see Table 3.4). The execution of this innovation study involving all research partners led to a final report confirming the 'pack' action.

In the long run, most players benefited from the coordinated collaboration effort. The supplier acquired the necessary complementary knowledge on costs, performance and execution. The contractor obtained information about the design and execution details of a demonstration project and thus gained the know-how to reproduce the effort. The architect gained experience which improved his know-how on execution and services, and so on. Innovation was achieved, but the supplier still had to find customers. There was still a gap between his product and service offerings and the market demand for passive houses.

Table 3.3 Partners in the innovation study and their contribution

Partners	Skills, competences, contributed know-how
Supplier SME/leading player	Supply of timber construction and materials; project coordination; prototype modular construction
Architect	Passive house design
Contractor SME	Previous experience of a demonstration project: financial know-how and project details
Consultant SME	Timber stability calculations
Consultant SME	Hygrothermal and building physics simulations
Consultant SME	Expertise in construction of air tightness
'Agent' passive house network	Inventory of competing construction systems and setting up passive house requirements
Subcontractor SME	Hands-on workshop on building system details

Source: IWT (2004)

Table 3.4 Project innovation journey, reflected in work packages in the innovation study

Subsequent work packages	Task specifications for the partners
Know-how retrieval	Literature study and general programme of requirements for passive houses and similar innovations, visits to companies and demonstration projects, technology watch, search for strategic alliances.
Programme of requirements	Detailed requirements for the building system and its certification (stability, fire, thermal, acoustic, hygric and air-tightness behaviour). Scenario analysis of different configurations and parameters (different building typologies and components).
Design testing	Design of building system details (demonstration project/prototype) reflecting programme of requirements.
Implementation testing	Detailed scientific evaluation of construction details (hygrothermal, financial, etc.).
Confirmation	Final report for valorisation (for internal use, delineation of further research and market strategy definition).

Source: IWT (2004)

3.4.4 Further collaboration with the passive house network

When it came to marketing the timber-frame construction method, the supplier found an important ally in the Passive House Platform. The involvement of the company in dissemination initiatives organised by the platform attracted a pool of potential customers, such as designers and other companies who were interested in adopting the innovation. Eventually, the company formed a broader coalition with new players by becoming a formal member of the network.

In the years that followed, the company's decision to join the passive house network bore fruit, as the efforts of the independent network continued to exert an influence. The construction details that were worked out during the innovation study were revised by the independent passive house network during a supported project. The revised construction details were made publicly available for dissemination to all architects in Flanders and pushed up the demand for passive house solutions and for the company's services.

The company benefited from constant growth in the market for passive houses from 2003 until 2010, with the demand doubling each year. The partners in the innovation study also saw a rise in the demand for their services. The engineer who coordinated the study set up his own construction company, specialising as an independent contractor in the market for passive and low-energy home construction projects.[8]

The supplier benefited from this development as he still provided all the partners with many of the building products. Good social relationships were also maintained. The scope of single-family housing (in the innovation study) and the SME's corporate embedding have since shifted to a larger market, involving residential and non-residential low-energy and passive building, including renovation: *"Now we are being challenged by new innovation opportunities, such as prefabricated solutions for the renovation of schools and office buildings. The application of new materials must be investigated along with new designs that can provide even higher energy efficiency."* (2009, personal interview on-site with sales manager at the company that took over supplier's activities, translated from Dutch).

3.5 Discussion and reflection on theory

The above innovation journey provides an opening for a discussion of the innovation theory, which could help to unravel the opportunities and barriers to systemic innovation in highly energy-efficient housing and explain how they relate to processes for suppliers in the SME sector.

The supplier's journey confirms that a tension exists between the concept of autonomous incremental innovation – which assumes that an innovation can be developed solely by the supplier – and the need in the construction sector for system innovation and project-based collaboration. There appeared to be a problem with the application of autonomous innovation to innovation processes in the complex socio-technological networks that are needed to realise buildings. The journey illustrates that the definition of an innovation can develop beyond an initially intended product-based technological innovation when new players become involved in a search for architectural, modular or system innovation. It therefore confirms the need for a systemic approach of coordinated collaboration to innovation in the construction of highly energy-efficient housing, all the more so, given that the realisation of this kind of housing relies on integrated design processes in which the costs and energy

8 From an interview with the general manager at the 2009 Passive House building fair (Brussels).

performance of the building are optimised to a certain level. Systemic innovation requires substantial management and coordination, tacit knowledge, regular informal communication and organisational learning processes (see for example: Teece, 1984; Taylor and Levitt, 2010; Milway and Saxton, 2011), all of which is confirmed in the example. Additionally, the study found that explicit attention should be paid to the gradual generation of a collaborative knowledge base, a supplier/sector connection in innovation teams, learning from demonstration projects and prototypes, and strategic alliances with dedicated networks.

The study confirms that suppliers and manufacturers of materials can be key players in innovation (Quigley, 1982; Jacobs *et al.*, 1992; Pries and Janszen, 1995), but intensive knowledge transfer between different players in the construction chain is essential in order to achieve more than just incremental innovation. Even so, the supplier found himself in a better position to introduce incremental innovations while engaging with players that focused on the required modular, architectural or system innovation. The lack of coordinated collaboration can be seen as a general obstacle to the diffusion of modular, architectural and system innovation, or: systemic innovation can pave the way for higher categories of innovation in construction. While the supplier could easily recognise opportunities for modular innovation, the challenges of architectural and system innovation in achieving high energy efficiency needed to be explained in detail and it was necessary to attract complementary innovation players. Furthermore, the road to marketing a system innovation entailed engaging different players and joining forces across an extended network.

The innovation journey illustrated that specific types of players – suppliers, contractors, architects, consultants, passive house network – contributed to the realisation of system innovation for highly energy-efficient housing, although their own perspective might have been incremental, modular, architectural or system innovation (Slaughter, 1998), as illustrated in Table 3.5.

Given the logic and structure of the housing industry, the importance of learning at (demonstration) project level (Femenias, 2004) was acknowledged. The project-based nature of building projects is often seen as an obstacle to systemic innovation and closed learning loops (Goverse *et al.*, 2001), but in this example it was identified as an opportunity for developing a formal innovation journey leading to modular innovation and paving the way for architectural and system innovation. It is important to note that Slaughter (1998, 2000) placed a strong emphasis on relating different categories of construction innovation to the timing of commitment in different phases of a project (see Table 3.1), but the study found that engagement in construction innovation does not have to 'follow' project phases and that, in contrast, it might be more beneficial to involve all the players at the concept design stage (see Table 3.5).

Table 3.5 Contributions of different players in the innovation journey

Contributor to innovation	Main contribution to the innovation	In-company intended innovation	Timing of innovation project commitment
Materials manufacturer/ materials supplier	New performance definition of existing products (from floors to walls)	Incremental	After contact with initiator (evaluation of innovation feasibility)
Assembly factory/stability calculator	Assembling existing floor products in new wall frames	Modular	At conceptual design
Architect/contractor	Major change in the links to housing projects (using wall systems for buildings)	Architectural	At conceptual design
Building services engineer/ air-tightness specialist	Integration of multiple passive house innovations (air-tightness layers, more thermal insulation, ventilation equipment)	System	At conceptual design
Passive House Platform	Breakthrough whole concept offer	Radical	Initiator/coordinator

The study showed that an agent (see also: Rogers, 2003: 'change agent') dedicated to promoting system innovation continuously facilitated the innovation uptake during the journey. The agent had a significant influence on the decision-making processes on innovation, he stimulated the 'packing' of innovators as a solution, and even contributed to the effective market launch of the supplier's innovation. In the framework of highly energy-efficient housing, passive house networks are thus emerging as novel institutions which can play a key role in facilitating system innovations. Detected market opportunities and the regional demand for demonstration projects turned out to be important drivers that helped to push the supplier towards system innovation, even when – as in this case – there was no national or European policy framework. Hence, the implications of the study for innovation policy appear to be instrumental (awareness raising and facilitating system innovation) rather than environmental regulation, although the (prospect of) European Performance of Buildings Directive (EPBD, 2010) can now also be considered as a facilitator of a rising demand for highly energy-efficient houses.

The study thus highlighted the need for suppliers in the construction sector to look beyond single technology incremental innovation. Exploring opportunities for coordinated collaboration is key to successful innovation journeys and to bridging the gaps from incremental to modular, architectural and system innovation. One possible barrier is that SMEs need to be able to identify their own products and services with the (passive house) system level, but this can be eliminated by specialised agents who explain the links with the intermediate steps of architectural and modular innovation. These agents can further facilitate the 'packing' of entrepreneurs, involving different SMEs in the construction chain in win-win innovation journeys.

3.6 Conclusion

The study searched for opportunities to eliminate barriers that prevent suppliers from engaging in innovation processes geared to highly energy-efficient housing. It did so by analysing the innovation adoption process of a supplier in the SME sector. In general, suppliers in the house-building sector lack the competences, knowhow and resources that are required for systemic innovation. They have specific innovation management needs for dealing with different SMEs and for integrating innovation in building projects. Suppliers that do engage in innovation may find players in the construction sector inhibited because they favour loose collaboration and a project-based approach with the ad hoc generation of knowledge. The study showed that it is nevertheless possible for suppliers to lead systemic innovation and offer a coordinated collaborative approach that allows risk-sharing between the different stakeholders.

The study found that, in order to eliminate these barriers, the supplier had to move away from an incremental vision of innovation and embrace a system-based vision, possibly by accepting modular innovation as a vehicle for incorporating architectural and system innovation. The study illustrated that an innovative idea can gradually change in the course of an innovation journey. It can grow from a notion of an incremental innovation to ideas for modular innovation, for architectural innovation when design and building are integrated, for system innovation when the performance for whole buildings is included, and it can even contribute to the realisation of a market for radical innovation that supports the system innovation. This in itself is an important insight and model for supplier-led innovation. Suppliers should embrace the added value of changing an idea about incremental technological innovation to systemic innovation when several organisations are involved, since this can contribute to market success.

If guided properly, innovation journeys can lead to cooperation and learning, and formal innovation collaboration structures can increase competences and resources for innovation processes. When engaging on an innovation journey, it is essential to develop and grow a network around the (proposed) innovation. There are various mechanisms for developing such networks. For example, one can identify a modular, architectural and system innovation (with the help of an agent), formalise the journey for obtaining a grant, increase the range of know-how by involving complementary players or share information with possible innovation allies. Different enterprises in the innovation chain in the construction sector have different frames of reference and different kinds of knowledge and competences (see Table 3.3) which might be useful to suppliers embarking on an architectural or system innovation journey. Suppliers need to realise that they can be the source of such innovation journeys and that they do not need to wait for policy directives before committing to innovation. Moreover, their innovation journey is not necessarily subject to specific phases in the demonstration project, since coordinated collaboration can be planned as far ahead as the conceptual design phase.

A continuous effort appears to be needed in the construction sector to consult SMEs on coordinated collaboration opportunities for highly energy-efficient housing and to facilitate innovation learning, and the 'packing' of SMEs in innovation journeys. Demonstration projects are usually key to facilitating innovation journeys and packing. Using emerging ideas of (possibly modular) supplier innovation, specialised agents can point the way to collaborative approaches to architectural and system innovation. Given the specificity of the construction sector and the required system innovation for achieving high energy performance, it would be worthwhile to cultivate and develop change agents as intermediaries between suppliers and other players in the construction chain, as well as passive house networks that support innovation journeys from incremental innovation towards system and radical innovation.

Acknowledgements

The innovation journey was realised thanks to funding by the Flemish Government – IWT within the framework of the thematic innovation stimulation project 'Passiefhuis-Platform' (IWT, 2007) and the related SME innovation project 030527 (IWT, 2004). The author wishes to thank the three anonymous reviewers for their valuable comments and reflections.

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4 Collaboration opportunities in advanced housing renovation[1]

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http://www.sciencedirect.com/science/article/pii/S1876610212016682

Abstract
In theory, there is huge potential for reducing the energy used by existing single-family houses by thoroughly renovating them. For the successful market development of highly energy-efficient integrated renovations, supply chain collaboration is very important, while at the same time customer demand for integrated renovations has to be stimulated. A research and networking methodology was developed within the framework of the One Stop Shop project to identify and develop collaboration opportunities for advanced housing renovation in Belgium, Denmark, Finland and Norway. The research identified key supply-side needs through interviews and questionnaires, and analysed important elements for the development of a web-based portal that can connect supply and demand. The project further developed ideas and methods for collaboration and business model generation between different players on the renovation market. These different research results contributed to defining new business opportunities related to process innovation to unburden the homeowner and to achieve less fragmented renovation processes.

4.1 Introduction

Today's new-build housing market focuses on higher energy performances. While a market niche is emerging for highly energy-efficient new-built hous-

1 This chapter is very practice-oriented and does not provide a full review of all the studies related to this subject to which the author contributed. For more information about collaboration opportunities related to low energy housing renovation – full research reports, scientific papers, illustrated case studies, and so on – the reader is kindly referred to the web site of the ERANET Eracobuild project 'From demonstration projects towards volume market: innovations for one stop shop in sustainable renovation', http://www.one-stop-shop.org. This specific paper was written by the main author and revised by various listed international partners and peer-reviewers as an executive summary of the project. It was chosen for inclusion in the present study to illustrate how communication channels (for example web platforms) can be studied in the framework of innovation theory and to show how key elements from innovation theory can be used to facilitate the emergence of collaborations (for example in networking events).

es – such as passive houses – improving the existing building stock is proving more difficult. For renovations to remain competitive with future newbuild houses, the awareness is growing that renovation work will need to go beyond implementing single energy-saving measures and towards integrated energy renovations. There is huge potential to reduce the energy used by the existing building stock, especially when the aim is high energy efficiency in individual integrated renovation, but in most countries this issue is still mainly being dealt with at the demonstration project level (Haavik *et al.*, 2006). But how do we make the leap from demonstration projects to a volume market for this kind of energy renovations? This subject has been dealt with in different IEA SHC Tasks, for example, resulting in reports such as *Business Opportunities in Sustainable Housing* (Haavik *et al.*, 2006) and, for advanced housing renovation: *From Demonstration Project to Volume Market* (Rødsjø *et al.*, 2010). While these reports provide useful reflections and define key actors, innovation phases and exemplary processes, an important challenge remains to shape (regional) integrated supply and customer demand to increase the number of such renovations taking place effectively. To develop the market successfully, it will be necessary for different actors to cooperate to stimulate supply and demand.

To provide a better understanding of what drives the market development for advanced housing renovation, research activities were designed as a follow-up of the IEA Tasks, such as the international research project *One Stop Shop. From demonstration projects towards volume market: Innovations for sustainable renovation* (One Stop Shop, 2012) which was set up under the European ERANET Eracobuild programme and involves researchers from Belgium, Denmark, Finland, and Norway. The overall aim of this One Stop Shop project was to facilitate the development of (mainly owner-occupied) whole house renovations for the volume market. The project focused on renovating single-family houses to a very high energy standard while providing superior comfort and sustainability for occupants. As a starting point for the research, the situation in Flanders, Belgium, was taken to reflect on.

4.2 Research approach

The research in the One Stop Shop project gathered together and structured previously fragmented information on building stock analyses and demonstration projects in Belgium, Denmark, Finland and Norway (see One Stop Shop (2012) for national descriptions). Further technological innovations for housing renovation were listed in a catalogue (see One Stop Shop, 2012), and demonstration projects and experiences of related market actors were examined in detail. This research found that particularly systemic and architectural innovation and supply side collaborations between SMEs (small and medium-sized enterprises) are needed in order to achieve a higher standard of integrated energy renovations and integrate the technological innovations into daily practice. Research was therefore set up to identify the supply-side needs for systematic collaboration between different market actors. Research strategies were also developed to detect supply chain collaboration opportunities for advanced housing renovation, while at the same time reflecting on how to stimulate customer demand for energy-saving renovations. During this process, the project initiated some innovation in the sector, particularly web-based collaboration, to reduce the burden on homeowners and achieve a less fragmented single-family housing renovation processes (so-called 'One Stop Shops').

In this paper the results from three specific research approaches within the One Stop Shop project are presented and related to innovation adoption. The first research approach specifically aimed to detect key supply-side concerns regarding the need for a One Stop Shop for renovation work on single-family housing, as observed by supply-side actors in Belgium. Experiences from Belgian demonstration projects were collected during interviews with key stakeholders (architects, homeowners, contractors) and a questionnaire was sent out to actors on the supply side. This information was used to provide input for a model that can be used to develop a web-based portal that links innovations on the supply side with potential customers. The second research approach focused on analysing the strengths and weaknesses of the different existing web-based collaborations. This led to recommendations for a new web-based portal on how to better connect the supply side with the demand side. The third research approach was designed to identify business opportunities through collaboration between different supply-side actors, and potential clients. After developing an actor categorisation in each partner country, a networking event produced additional research results.

4.3 Key concerns on the supply side

An initial step in supporting the supply side is to describe existing opportunities and key concerns. This was done using two parallel approaches. Firstly, experience from model projects in Belgium were used to identify difficulties and bottlenecks in real-life cases. Secondly, a questionnaire was used to record the ideas of all supply-side actors, even those without actual experience on very ambitious projects. The experiences of Belgian model renovation projects have been described in a separate paper (Mlecnik *et al.*, 2011) and the results of the questionnaire have been discussed in a research report (One Stop Shop, 2012). Here we present the following general observation from this part of the research in order to understand the supply side need related to One Stop Shop.

Firstly, we detected a possible reduction in energy use of about four to ten after renovation, depending on the building typologies. Reaching the ‘passive house’ goal (space heating demand of 15 kWh/m^{2}a) was found in practice to be quite a challenge for architects and homeowners, and in practice many major renovations ended up with a space heating demand of about 25-30 kWh/m^{2}a after renovation. If the energy reduction target was set clearly from the beginning, it was more likely that the renovation would achieve better end results.

Demonstration projects illustrated several technological innovations – including combined technologies and even passive house concepts. It was also shown that increased speed, cost guarantee, low hindrance and an energy performance guarantee for the final renovation all provide innovation opportunities to respond to customer demand better. Innovation in integrated energy renovations is socio-technological in nature and the social component is currently often neglected. Quicker high-quality renovations with fewer technical compromises and energy performance guarantees are in demand from homeowners.

Interviewees saw the following issues as particularly problematic, requiring process solutions where another actor might play a role:

- many traditional craftsmen are unfamiliar with the latest innovations;
- many craftsmen are not used to working together on whole building solutions;
- many craftsmen are involved, often resulting in problematic coordination on site which can result in lower quality and unclear lines of command and responsibility;
- the effort required from and disruption caused for occupants and owners should be reduced.

To overcome these socio-technical barriers, one option would be to improve the level of knowledge of the craftsmen. Another option might be to involve an additional actor with expertise of how to integrate innovative technologies to provide reliable information and play a coordinating role. The systemic use of innovative whole building concepts should be considered, since this can lead to well-coordinated renovation modules with fewer separate companies involved. Finally, it was observed that homeowners would like one single responsible person and a One Stop Shop solution in order to reduce the burden before and during the renovation.

Secondly, regarding the questionnaire, a survey was issued within the construction sector to consider the viewpoint of the companies involved and the willingness to cooperate with such a One Stop Shop idea. It was sent to selected categories of professional members of VCB, PHP and BBRI[2], thus giv-

2 Flemish Construction Federation, Passive House Platform and Belgium Building Research Institute.

Table 4.1 Preferences for collaboration: enterprise activity versus preferred partner activity

Enterprise activity	Preferred alliance					
	Structural works	Installation	Finishing	Design	Not interested	Total
Structural works	26.32 %	10.53 %	10.53 %	26.32 %	26.32 %	100 %
Installation	11.11 %	41.67 %	2.78 %	27.78 %	16.67 %	100 %
Finishing	5.88 %	11.76 %	44.12 %	17.65 %	20.59 %	100 %
Full buildings	8.33 %	8.33 %	25.00 %	25.00 %	33.33 %	100 %
Others	10.00 %	20.00 %	20.00 %	30.00 %	20.00 %	100 %

ing a broad perspective from the regional housing construction sector in Flanders. A total of 139 completed surveys was received; almost 70% of them from companies with less than five employees.

About one third of the respondents claimed that they already provided highly energy-efficient renovations that were frequently demanded. The share of such renovations within companies' turnover is still small to average. Respondents stated that they expected a large increase in this market within the next five years.

Table 4.1 shows some results regarding preferences for construction chain collaboration. It shows that each type of company is most willing to cooperate with a company within the same sector. For example, about 26% of all companies involved in structural works prefer an alliance with other companies in the same sector. Another 26% have no interest in working together at all. Sharing ideas or teaming up with companies in other sectors is only a second preference. Installation companies offering building services appear most willing to cooperate. Only 17% of them show no interest where as 83% would like to join forces. Companies that already renovate full buildings have the least interest in collaboration.

Aside from peer-to-peer contacts, most professionals prefer the designer as a second option for collaboration: the designer is second for a preferred alliance for all groups. More in detail, when asked what exactly the respondents meant by 'a designer', up to 54% chose an architect. Another 32% opted for a guiding engineer. These companies might in fact just have been looking for a coordinator to supervise the whole project. Another possible explanation can be found in discussions on responsibility. With the presence of an architect, responsibility can be shifted. Ssome companies had reservations about the efficiency and transparency of such cooperation. A badly organised alliance could, in the worst case, even work counterproductively and create additional problems.

Most of the participants in the questionnaire were micro-enterprises, which reflects the fact that most of the enterprises in the Belgian renovation market are small or micro-enterprises. In conclusion, to develop the One Stop Shop idea further, it would probably be best to concentrate on companies who are active in the finishing and/or technical issues within the regional housing market. Many of these companies are very much aware of the trend towards highly energy-efficient renovation and expect a share in this market development. A general contractor, on the other hand, may have more experience in different activities and be better placed to carry out their own coordination, which could reduce the need for cooperation with other enterprises.

The study observed that most companies wanted some form of collaboration. Their preference for cooperating within their own field of activity or with an architect could have important implications for the diffusion of knowledge, skills and innovations: it implies a preference for peer-to-peer education and stronger collaboration with the architect. The physical clustering of SMEs was not a popular option, maybe companies are still unfamiliar with this idea. On the other hand, professionals did expect awareness to increase through education and knowledge transfer. They recognised the value of seminars, workshops and a website for knowledge transfer. They also appreciated specific project information, listing of market players, better information on technical innovations and improving quality and cost control.

Regarding the preferences of the respondents, the concept of a web platform was considered as a source for the One Stop Shop, where possible techniques and innovations could be assembled with links to while coupling seminars and workshops, project brochures, listing market players, and so on. The questionnaire also confirmed the importance of linking this website with the demand side: the homeowner also needs to be able to access information, which was perceived by the supply side as a most important barrier. It can thus be imagined that such a website could even serve as a portal for the customer to gain knowledge about several firms.

4.4 Research on web-based portals

Following up on the results of the questionnaire, the research looked more closely at what a website for knowledge transfer between the supply side and the demand side could look like. We investigated already existing web platforms with the goal of providing a better understanding on how enterprises collaborate and how homeowners' innovation-decisions can be steered. This research was presented and discussed in a separate paper (Mlecnik, Paiho, Cré *et al.*, 2011). Some of the opportunities identified are presented below.

The use of innovation-decision models can significantly contribute to a better understanding of what drives decision processes in both customers and SMEs to adopt innovation and how this relates to possible solutions in order to increase the uptake of highly energy-efficient renovation. In this research we focused on research methods regarding the diffusion of innovations, as exemplified by the work of Rogers (2003). According to Rogers' concept of innovation-decision processes, communication channels can influence each step of the decision-making process. Rogers divided these steps in the innovation-decision process into five levels: first knowledge of an innovation; second forming an attitude towards the innovation; third making a decision to adopt or reject it; fourth implementing the new idea; and fifth confirma-

Table 4.2 Guiding questions that homeowners would expect to be addressed on a web platform, in order to guide them through each step of the innovation-decision to adopt integrated/deep renovation

Step of the innovation-decision	Guiding questions that homeowners would expect to be solved from a web platform to adopt integrated/deep renovation
1. Knowledge	What counts as integrated/deep renovation? What solutions are available? (concepts, technologies, innovation)
2. Persuasion	Why should I undertake integrated/deep renovation? (long-term savings, ecological motivation, energy savings, avoiding future works or long-term renovation, combining different grants and tax benefits, and so on) Why should I choose integrated/deep renovation compared to what I had in mind? (awareness-raising based on own situation: kitchen/bathroom renovation, desire for extension, improvement of comfort or air quality of certain rooms, improving downgrading roof or façade, ...) What are the experiences of other homeowners that chose integrated/deep renovation? (process, actors, cost-benefit, achieved quality)
3. Decision	Where can I ask for price quotations? (suppliers, financing, consultants) How can I compare, choose, reject offers? For example, what needs to be specified in a contract proposal?
4. Implementation	How should I plan the intervention of actors? What questions do I have to ask during the works to check the quality?
5. Confirmation	How can I express positive/negative experiences?

tion of this decision. In each step of the decision process potential adopters can decide to give up on the innovation, so communication channels need to provide the right information at each step and guide the potential adopter through the whole process.

The research found twenty existing web platforms in seven countries providing a housing renovation oriented portal aimed at suppliers and homeowners. By comparing these websites, it detected that different actors could lead such websites: public actors, vendors, consumer organisations, non-profit organisations, architect organisations, contractor federations, and so on. The content of the existing websites was found to vary from simple text communication and selection tools to multi-level interfaces or user toolkits where the customer can manipulate the final product or desired outcome.

In order to analyse the websites' strengths and weaknesses systematically, five levels of information were defined, as illustrated in Table 4.2, according to Rogers' concept of innovation-decision processes. This Table gives an idea of the questions that the homeowners would expect to be answered from a web platform in order to guide them from one level to the next.

4.5 Research on actor collaboration

The next step in researching actor collaboration was to determine which supply-side actors need to collaborate. Further research identified important actors regarding supply chain collaboration in four different countries (Belgium, Denmark, Finland and Norway). As such the research aimed to learn which actors need to cooperate and who plays what role in the innovation adoption process. For this reason, the logic of Rogers' innovation adoption process was continued when categorising actors and defined actors for each country in actor categories as: informing, convincing, deciding, implementing, and/or confirming.

Informing actors (information) – A very large group of possible actors in each country can be found in the informing branch. This role can be fulfilled by federations, policy supporting actors, non-profit organisations, research organisations, energy distribution net managers, manufacturers of products, and so on.

Convincing actors (persuasion) – In all country reports, persuasion was related to financial support, since this encourages homeowners to choose renovation. Persuading actors are therefore mostly those actors that provide financial support, such as governments, banks or energy distribution companies.

Responsible actors (decision-makers) – Practically, major renovation needs strong coordination and well-informed decision-making. We found that in the partner countries for the market of owner-occupied single-family houses, owner-occupiers are still often responsible for their choices despite having very limited knowledge of the technical issues involved in innovations. The decisions made by the homeowners depend heavily on the advisor they choose. Occasionally, an advisor such as an architect takes over (part of) the decision process. A number of different actors were identified who provide such guidance on the subject of renovation. In the case of minor renovation work, the homeowner will rarely hire a consultant, but instead make a decision based on the advice of the contractors or craftsmen hired to carry out the renovation. In case of major renovation work, we found that the homeowner may hire an energy consultant to help guide the process and make the right decisions. Energy consultants were engineers, architects, turnkey suppliers or building contractors, for example. Advanced energy performance certificate advisors do not currently act as responsible actors, although such opportunities were detected in Belgium. In Norway, emerging opportunities were detected for project managers as the decision-making actors, working directly for homeowners.

Implementing actors (implementation) – In order for an energy renovation to be effective, it is important that solutions are implemented appropriately. Although many SMEs claim to have some experience with integrated renovation, the previous questionnaire established that individual craftsmen still need to be educated on the specifics of deep renovation. There is shortage of training courses on this subject. However, all the countries studied have course material available that can be developed further in order to obtain more expertise in this field. One course of action to support the supply side would be to install a course on the specific topic of the project management of integrated renovations.

Quality-assurance actors (confirmation) – The limited knowledge of implementing actors and the issue of user trust led to some concerns about processes in

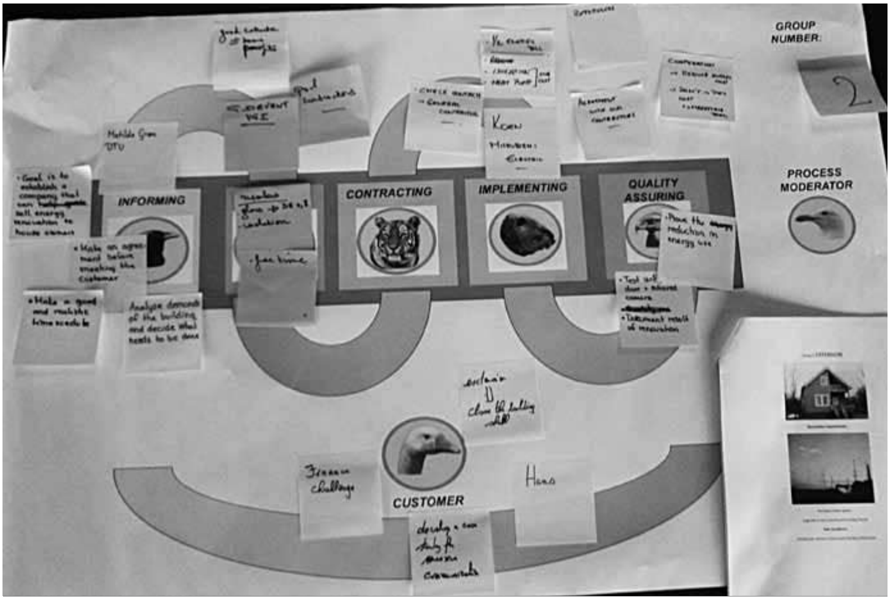

Figure 4.1 Impression from the Business Zoo workshop (animal gathering canvas development)

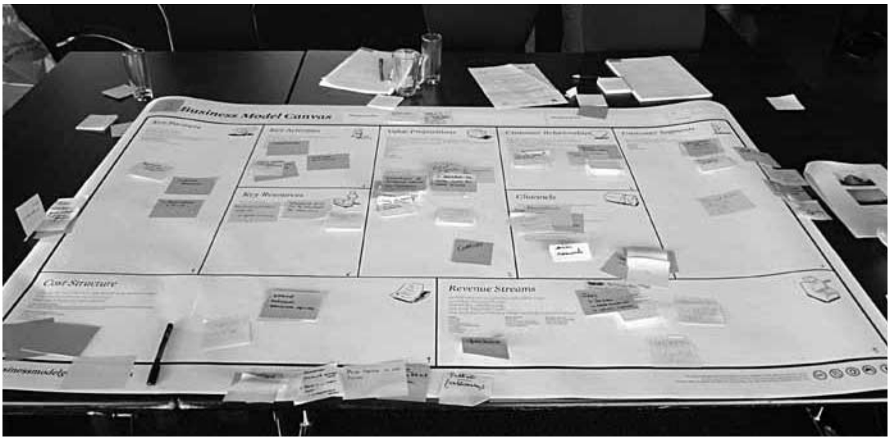

Figure 4.2 Impression from the Business Zoo workshop (business model canvas development)

which actors collaborate. Major renovations were perceived to need some form of quality assurance. Energy performance guarantees, avoiding thermal bridges and achieving high airtightness are particularly important. In the partner countries, there is currently no general use of a specific quality assurance mechanism for integrated energy renovations. All countries rely on the applicable legal warranty period. To some extent, different voluntary labels are available in different countries. For example, the Belgian Passive House Platform offers a passive house certificate for renovated housing.

Further research focused on exploring opportunities for collaboration between actors from different categories as explained above. As part of the One Stop Shop project, a specific networking methodology was developed which involved clustering innovative players to detect novel business models and reduce the fragmentation of the renovation process for single-family houses. A unique international business networking event was developed, entitled 'Business Zoo', and was first held in Antwerp, Belgium on 18 April 2012 (see Business Zoo website[3]). This event aimed to inspire actors regarding novel forms of collaboration in the renovation chain in order to realise integrated sustainable housing renovation, using elevator pitches and problem discussions in small groups.

In group discussions, the participants were grouped into the actor categories mentioned above using animal pictograms, and were asked to brainstorm on renovating a particular house. In this exercise, the homeowner was given a central role in enforcing strict and ambitious demands, so that the supply side actors were forced to think from the client's perspective. The groups used a predefined 'animal gathering' canvas (see Figure 4.1) to facilitate this process. At the end of the day, the participants were urged to take up the challenge of developing new business models, expanding the previous case development to the volume market. Different groups developed specific integrated business models for deep and sustainable renovation, using a business model generation canvas (see Figure 4.2).

The 'Business Zoo' methodology – a new method of networking – allowed different market players to identify collaboration opportunities with potential national and international partners. The questions addressed during the networking event included various important issues such as how to make the cost of renovation fully transparent, how to speed up the renovation of large stocks of post-war housing with faster construction methods, how to adapt energy performance certificates – and energy performance advisors – for integrated renovations, and so on. Furthermore, new business opportunities were explored resulting in the development of a fictitious business model for collaboration between different renovation market players, such as architects, contractors, project managers, suppliers, do-it-yourself stores, owners, financers, city councils and communities, and so on.

During the event, we detected that substantial innovation was still needed on the supply side, especially regarding collaboration between different craftsmen and experts. In the growing market for deep renovation, homeowners can no longer be expected to coordinate the whole renovation process, to find all the information concerning deep renovation solutions and examples, to contact, contract and coordinate a range of individual craftsmen, to ensure quality while keeping costs and energy performance under control, and all the while managing the administrative burden and the uncertainty over financing the whole project. In order to prepare for a growing market, companies must be aware that the homeowners expect one single point of contact to take responsibility, act as project manager, and ensure quality and efficient, rapid execution.

3 http://www.b2match.eu/businesszoo.

More detailed results from this research are described in a separate paper, available on the One Stop Shop website (One Stop Shop, 2012). The business development opportunities identified provide a valuable insight into how market player's responsibilities and tasks might change in the near future and under which conditions companies would like to collaborate in a business development.

4.6 Conclusion

The current fragmentation – separate SMEs each doing a fraction of a supposedly integrated renovation – cost escalation, lack of knowledge and lack of project management are very important barriers to the advanced energy renovation of single-family housing. However, many companies are willing to collaborate and expect their share of this market segment to grow. The research has found that renovation processes need to be reformulated and better collaboration structures need to be developed to unburden the client. In order to respond better to the supply-side concerns identified, both supply and demand side actors need to be informed in a more targeted way. A 'One Stop Shop' web portal could both inform actors, as well as reducing the burden on homeowners. To model such a web portal, Rogers' innovation diffusion theory provides inspiration. The five steps in innovation-decision processes (information, persuasion, decision, implementation, confirmation) provided an interesting basis for the further development of a communication model that integrates opportunities from both the perspective of both the supply and the demand sides.

The study also related different actor categories to the homeowners' innovation-decision phase in the partner countries (Belgium, Norway, Denmark, Finland) and identified a common need to develop a pool of experienced actors for implementation and quality-assurance, as well as a need for support schemes for integrated renovation. Collaboration by different actor categories would support the market development that is needed, as well as the development of a web platform. A particular challenge is to increase the flow of technical information on integrated renovation that is required, as well as project management knowledge, from the many informing actors to the many less experienced implementing actors, which are mostly SMEs.

The study also gained further insights when networking different actor categories. In the single-family housing renovation market, it appears that market-proof solutions are needed when it comes to alleviating financial burdens and project management. Ideally, innovators would jump into this gap in the market and set themselves up as project coordinators who can support the homeowner throughout the decision-making process.

Acknowledgements

Funding for this research was obtained within the ERANET Eracobuild project 'From demonstration projects towards volume market: innovations for one stop shop in sustainable renovation'. The Flemish partners were funded by IWT, the agency for innovation by science and technology of the Flemish Community. The Norwegian and Danish partners were funded by the Nordic Innovation Agency. The Finnish partner was funded by Tekes – the Finnish Funding Agency for Technology and Innovation, the Technical Research Centre of Finland (VTT), City of Porvoo, The Housing Finance and Development Centre of Finland (ARA).

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5 Development of the passive house market: challenges and opportunities in the transition from innovators to early adopters

*Previously published as: E. Mlecnik, Development of the passive house market: challenges and opportunities in the transition from innovators to early adopters, Chapter ID: 6364) in: Santos Cavalcanti E.F. & M. Ribeiro Barbosa (Eds.), **Energy Efficiency: Methods, Limitations and Challenges**, Hauppauge, N.Y. (Nova Science Publishers Inc.), pp. 135-152, ISBN: 978-1-62081-817-6.*
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Abstract
To diffuse highly energy-efficient housing, market development barriers and opportunities must be identified and understood, particularly regarding the adoption of relevant innovations by different companies in the housing sector. This research investigated some characteristics of enterprises in order to better understand how to facilitate the transition of the market for single-family passive housing from the innovation stage towards the stage of early adoption.

The research was approached from construction innovation theory and a case study. The literature study focused on characteristics of innovating enterprises, particularly regarding company size, the time of adoption of the innovation and collaboration with other enterprises. Case study data were collected from an enterprise network dedicated to passive house market development in Flanders.

The research results provide guidance on how enterprises and innovation policy can respond to market development challenges. While small enterprises are needed to kick-start regional radical innovation, large companies contribute in an early adoption phase through incremental innovation. To eliminate know-how barriers and provide networking opportunities, multi-player networks are important in both phases, and it is recommended that innovation policy should specifically support networking efforts. Collaboration is the key, particularly between innovators and foreign suppliers in the market introduction phase, and later between regional innovators and large companies in order to bridge the transition to the early adoption phase.

5.1 Introduction

The European Energy Performance of Buildings Directive (EPBD, 2010) requires all European member states to develop a framework for achieving high energy efficiency in new housing with the ultimate aim of 'nearly zero-energy buildings' by the end of 2020. The implementation of this Directive implies a considerable innovation challenge for the construction sector, particularly since the construction sector has a rather conservative image and is dominated by small and medium enterprises (SMEs). It is anticipated that research into the barriers to and drivers for innovation will speed up progress towards high energy efficiency (European Commission, 2010). When exploring these barriers and drivers, it is essential to investigate real innovation trajectories in the construction sector.

One persistent problem is that innovation in construction is not automatically diffused beyond a limited group of innovators or demonstration projects, and the potential of demonstration projects to become a strategy for systematic successive learning and development is known to be limited (Femenias, 2004). A perspective is needed that includes the active collaboration of actors in the construction sector (van Hal, 2000; 2009). Also, the players needed – and thus innovation policy strategies used – may differ when introducing innovations or targeting the early adoption market (Rødsjø *et al.*, 2010). In order to understand better how market development from innovation to early adoption can be facilitated, an empirical investigation of experiences regarding this transition would be useful. In particular, it is important to understand better the experiences of enterprises that have adopted innovations in highly energy-efficient construction, as well as the opportunities and barriers they encountered. It is also useful to examine which enterprises adopt innovations sooner than others.

Several studies have already confirmed the existence of demonstration projects and the development of business opportunities for so-called 'passive houses' (for example: IEA SHC Task 28, 2006). Developing a business opportunity for passive houses implies adopting multiple construction innovations in products, systems and services (Mlecnik, 2011), and thus enterprises involved in passive house business development provide an interesting pool for research. Enterprise networks geared towards passive house construction already exist in most European countries. Some of these networks have been highly successful in introducing passive house innovation and facilitating innovation transition towards early adoption, and their member enterprises therefore provide an interesting pool in which to research enterprise characteristics. Within this framework, then, researchers now have the opportunity to investigate the perceived barriers and opportunities for enterprises involved in such networks.

5.2 Research strategy

In anticipation of the rapid market development of highly energy-efficient homes that will be required, this study investigates some opportunities and challenges for the market development of highly energy-efficient housing, focusing on single-family passive houses. This will be done by analysing the characteristics and experiences of the commercial members of a passive house network. The study aims to contribute to a better understanding of how the transition from the introduction of innovations (passive house-related technologies, systems and services) to early adoption can be facilitated. The enterprises chosen for this research – both innovators and early adopters – are mainly active in the market for individual single-family (passive) housing projects. Compared to other European countries such as the Netherlands, Elswijk and Kaan (2008) noted that the development of the passive house in Belgium is now rapidly following that of pioneering countries such as Austria and Germany. In order to gain a better understanding of the experiences of commercial organisations, the commercial members of the Belgian Flemish passive house network 'Passiefhuis-Platform vzw' (or PHP) were chosen as the subject of this analysis. This particular enterprise network makes an interesting subject of study because it was set up in 2002 with the specific aim of stimulating enterprise innovation in passive housing (IWT, 2007; PHP, 2007).

The author followed the evolution of the enterprises in the network using participatory observation throughout the period 2002-2011. To collect additional empirical data, a questionnaire was designed, including both open and closed questions, and distributed to all PHP company members in 2008-2009. This focused on: the company's relationship with the passive house concept; the type of decision-making in the company (optional, collective, authority); the use of communication channels (e.g. mass media or interpersonal); the nature of the enterprise environment (e.g. its environmental behaviour, degree of network interconnectedness, and so on); and an evaluation of the appreciation of different network's promotion efforts. Using these data, the research examined the characteristics of, and the differences between, innovators and early adopters, focusing on the company's size, the time of adoption of innovations and collaboration with other enterprises. Participatory observation allowed permanent monitoring of the changing composition of the network and regular semi-structured company interviews to take place.[1] Furthermore, an analysis of the media coverage of passive houses (collected by PHP during 2002-2007) supported the research.

The research did not therefore attempt to identify what enterprises have to do to reach the early adoption phase, but to review and integrate experiences which may help to understand the importance of enterprise innovation

1 Participatory observation also allowed for regular interviews with lead companies, focusing on: What are the characteristics of the member? How is the collaboration with the network? How is information obtained during a building process? What kind of information and initiatives are still missing? What are the observed needs for the future?

behaviour and enterprise collaboration, and identify innovation policy opportunities in order to address challenges in the transition from innovation to early adoption.[2]

The following section (5.3) introduces the theoretical framework of this study. This section focuses on the available research into innovation phases, the characteristics of enterprises – particularly company size – involved in the adoption of innovations, and the importance of collaboration between enterprises.

Section 5.4 then describes the case study and a reflection on the literature introduced. This section first traces network observations in the transition from innovation to early adoption. Subsequently, the characteristics of innovators and early adopters are analysed. Then, the research looks at the influence of company size in the case study.

Finally, the opportunities for and barriers to collaboration on the road to early adoption are related to literature findings. Based on this research, the conclusion (Section 5.5) makes some recommendations based on the results of the research in order to ease some of the market development challenges and support some innovation opportunities in the transition to early adoption.

5.3 Enterprises involved in the adoption of innovation

When studying the experiences of enterprises involved in the adoption of innovation, empirical research can be found using a number of theoretical frameworks that usually covers various sectors other than the construction sector.

For example, relevant research can be found in literature on innovation diffusion (for example: Moore, 1999; Rogers, 2003), enterprise networks (for example: Brenner and Fornahl, 2003; DeBresson and Amesse, 1991), cluster formation (for example: Porter, 1998; Sölvell *et al*., 2003), strategic niche management (for example: Kemp, 1994; Kemp *et al*., 1998; Rotmans *et al*., 2000; Schot *et al*., 1994; Van den Belt and Rip, 1984) and marketing approaches (for example: Porter, 1980; Grove, 1996; Miller, 2009). Broadly speaking, the real

2 Activities and compositions of networks tend to have a very specific emergence history that is highly related to local context and side conditions in a social context, which can limit the way research findings can be transferred to another region or social context. Also, local success of a transfer process highly depends on motivation and competences of the lead actors, resources and social capital generation. When reading, one should be careful regarding time frame and contextual limits. The focus on a market directed to owner-occupancy probably plays a significant role. Results might not be representative for networks that use other focusses. In particular, the described network emerged with a focus on the construction of single-family owner-occupied houses.

innovation behaviour of firms seems to be influenced by a combination of cultural, institutional, macro-social/economic and technical factors, as well as organizational networks (Lutzenhiser, 1994).

It is not the purpose of this research to review all theoretical frameworks, but only to reflect on specific issues. This part introduces the literature findings used in this study. Some literature regarding the relevance of innovation stages is briefly described. Subsequently, the relevance of company size to innovation is discussed from available literature, as well as the need for enterprise collaboration.

5.3.1 Relevance of innovation phases

On the basis of Rogers' innovation diffusion theory (2003), one should be able to classify enterprises into 'adopter categories' (innovators, early adopters, early majority, late majority and laggards) on the basis of how early an enterprise is to adopt an innovation relative to other enterprises. Amongst others, Rogers (2003) showed that different adopter categories can show different socioeconomic characteristics, personality variables and communication behaviour. Due to these differences in characteristics, various categorization systems and titles for adopters have been used in past studies. In general, when it comes to adopter categories in function of innovation phase, important is the idea that innovators differ from early adopters and should not be regarded simply as adopters with similar characteristics. Authors such as Moore (1999) emphasise that dedicated marketing efforts are required to go from one innovation adopter category to the next.

Generally, only a limited amount of material has been published on the specific situation of the enterprises in the construction industry that are involved in the transition from introduction to the early adoption of innovation. For example, using innovation diffusion theory (Rogers, 2003) and marketing approaches (Miller, 2009), Rødsjø *et al.* (2010) looked at adopter categories for advanced housing renovation as different categories of stakeholders and they distinguished different players that are of specific importance in the various innovation diffusion phases (the 'innovation' phase, the 'growth market' phase and the 'volume' phase).

5.3.2 Relevance of size of enterprises

There is a specific body of literature concerning the innovation differences between large companies and SMEs, but the results of these studies are inconclusive and depend on how one measures and interprets the capacity for innovation (Tether, 1998). In general, when it comes to company size and innovation, some authors present small firms as having an innovation advantage, while others see large firms as having an innovation advantage. More important is the idea that SMEs innovate differently from large companies and should not be regarded simply as 'big business' in miniature (Bos-Brouwers, 2010). Sustainability entrepreneurship research and corporate sustainability literature have so far neglected the differential roles of large and small firms in transforming industries towards sustainable development (Hockerts and Wüstenhagen, 2010).

Despite the range of definitions, researchers understand that radical innovation within an organization is very different from incremental innovation, and that it is critical to the long-term success of firms (McDermott and O'Connor, 2002). Some authors argue that small firms are in a better position concerning radical innovation and product innovation, while large firms are better at producing materials-based (Rothwell and Dodgson, 1991), incremental (Sen and Egelhoff, 2000) and process innovations (Abernathy and Utterback, 1988). Research by several authors (e.g. Berry and Taggart, 1994; Acs and Audretsch, 1988; King *et al.*, 2003) suggests that small firms could be the source of innovation during the earliest stage of a technology's evolution, with the locus of innovation shifting to larger firms for the early adoption market. Verhees and Meulenberg (2004) proposed that innovations by SMEs are often based on off-the-shelf technologies, concepts and/or resources offered by supplying industries. Owner-managers in SMEs were shown to be essential for the generation and implementation of new ideas and their role is detected to be crucial to the innovation process (Docter *et al.*, 1989, Hartman *et al.*, 1994). Furthermore, organizational culture might be important for fostering motivation for innovative behaviour (Hartmann, 2006).

5.3.3 Collaboration between enterprises

Amorim *et al.* (2003) emphasised that firms of different sizes may find themselves working towards compatible interests when they target different, but related markets. For example, manufacturing competence is most common among large firms (Klepper, 1996). But on the other hand, collaboration need can also be related to innovation phase. Since characteristics of adopters are different in each innovation phase, enterprises are known to seek collaboration with players that are more experienced in reaching the next market segment. Particularly, in the transition to the early adoption phase, collaboration opportunities are often explored. For example, Tushman and Romanelli (1985) proposed that, as a product matures and competition shifts to cost and efficiency, it is important to have or attract critical manufacturing competence in order to achieve business success in the early adoption market. Furthermore, to develop new niche markets, different strategic niche management literature case studies showed that collaboration can also extend to setting up multi-player networks and the development of joint (sustainability) visions and learning processes in multiple dimensions in multi-player networks involving multiple stakeholders (Kemp *et al.*, 1998; Weber *et al.*, 1999; Elzen *et al.*, 2004; Hegger *et al.*, 2007; Caniëls and Romijn, 2008).

In brief, literature confirms that different enterprises can have different characteristics and different innovation behaviour. Clearly, innovators and early adopters are different 'adopter categories' and transferring innovations from innovators to early adopters brings a specific challenge. While company size is an important and thoroughly researched characteristic of innovating enterprises, this characteristic alone can not explain whether an early adoption of an innovation can be reached. On the other hand, literature suggest that collaboration between enterprises might be crucial to jump from the innovation phase to the early adoption phase.

Only a limited amount of material has been published on the specific context of enterprises in the construction industry involved with the early adoption of an innovation. In particular, it is important to understand better the characteristics and experiences of enterprises that have adopted innovations in highly energy-efficient construction. This was researched with a case study, presented in the next section.

5.4 Experiences from a passive house transition to early adoption

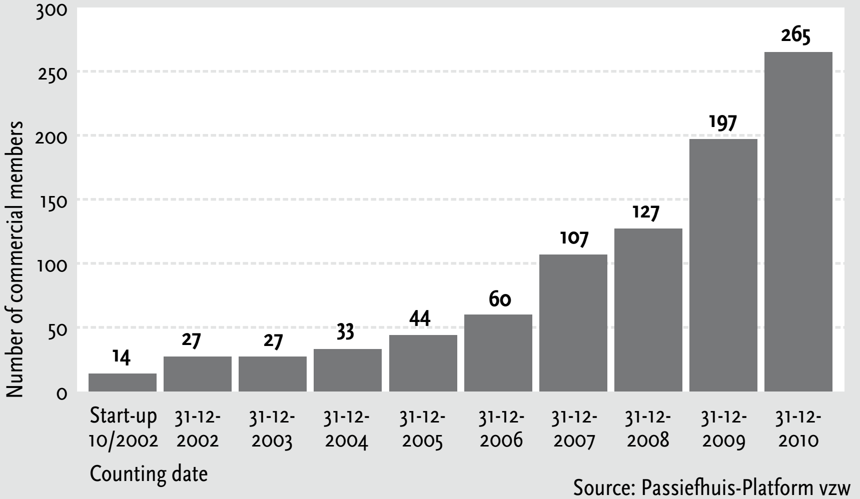
In this section, first general market changes from innovation to early adoption were traced within (commercial membership of) the Belgian Flemish passive house network (the PHP). Then the questionnaires were analysed to detect possible differences in characteristics between innovator and early adopter enterprises. Thereafter, the importance of company size is reflected on literature. Finally, the detected opportunities for and barriers to collaboration between enterprises are discussed.

5.4.1 Enterprise network data showing transition from innovation to early adoption

The PHP was formally established in October 2002 with 18 founding members. These included 14 enterprises, complemented with individuals and non-profit organizations. Enterprise members of the PHP were expected to contribute to the development of the supply and/or demand of passive houses by their own means. The PHP's enterprise members were drawn from different types of professions, including architects, engineers, distributors, materials producers, system providers, installers, contractors, and so on.

Figure 5.1 shows that the PHP enterprise network expanded considerably over the years and attracted dozens of new commercial members each year. This graph can also be interpreted as representing the increasing interest in

Figure 5.1 Number of commercial members of PHP per year (status 31 December 2010)



Source: Passiefhuis-Platform vzw

engaging in passive house development within the regional (Flemish) construction sector, especially over the last four years. At the end of 2010, 265 enterprises were member of the PHP, 92% of which were SMEs. While membership has expanded, the relative shares of small, medium and large enterprises have not changed significantly, as can be observed in Figure 5.2.

Although invited to join, traditional companies and even construction research institutes were reluctant to participate in the network at first. At the beginning, it was mainly micro and small enterprises which joined the network. Of the four large enterprises that joined from the beginning (2002-2003), one joined with a small business unit, and two discontinued their membership in the market introduction phase after a few years.[3] Figure 5.2 shows that the platform remains[4] dominated by micro-enterprises with an annual turnover of less than €500,000. This is in part because the majority of the construction sector consists of SMEs, and because the network emerged from a specific focus on single-family housing demonstration projects. The membership fee for each group was also set according to the category.[5]

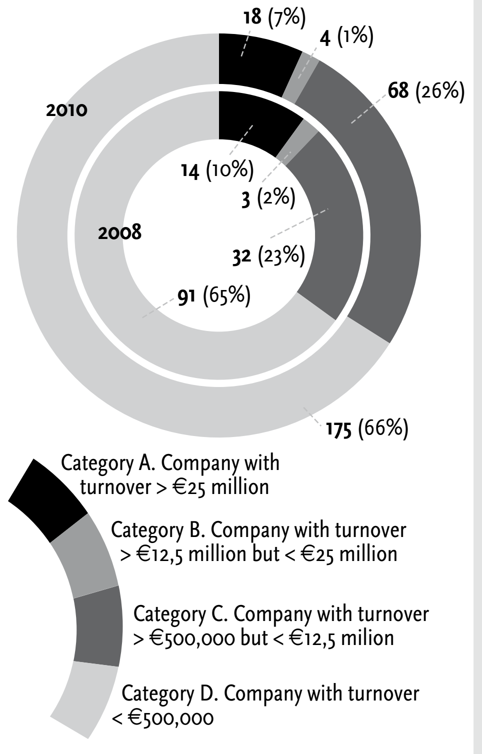
The increase from 2007 onwards shown in Figure 5.1 is also reflected in the

3 Special efforts were undertaken to include at least one large enterprise from the beginning, a contractor. Some larger enterprises specifically stated that the niche of highly energy-efficient single-family housing market was too limited in market volume for them. The experiences of the network enterprises showed that companies involved in single-family housing created direct spill-over in larger projects or different types of building.

4 In comparison, the membership structure of the network at its foundation also consisted of eleven small or micro-enterprises, compared to three medium or large enterprises.

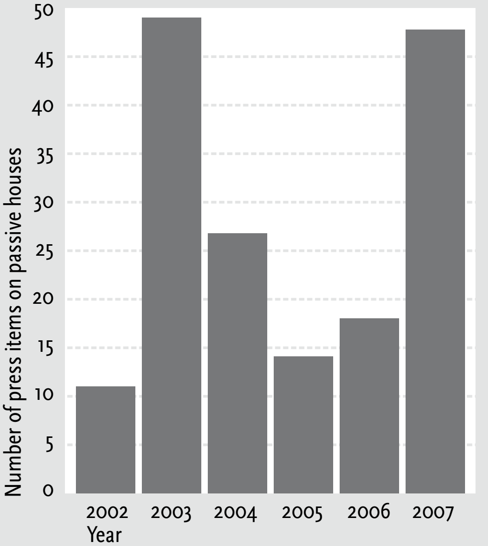
5 The membership fee system was proposed by the management board as an answer to the general assembly's request to take into account the limits of financial capacity and risk-taking behavior of each enterprise. Current annual membership fees for companies vary from €345 to €2,760 (excl. VAT). In the introduction phase the enterprise membership fees were limited between €600 and €2,400, making distinction only between small, medium and large enterprises. However, €600 was perceived as too high for micro-enterprises.

Figure 5.2 Distribution of number of PHP enterprise members according to company size (comparing status December 2008 with 2010)



Source: Passiefhuis-Platform vzw

Figure 5.3 Number of (inventoried Dutch) press items on passive houses per year in Belgium



Source: Passiefhuis-Platform vzw

analysis of Belgian press items covering the passive house concept, as shown in Figure 5.3. Figure 5.3 shows the first spike in media attention – mainly concerning regional 'houses without heating' – in 2003, which coincided with the realization of the first demonstration projects, followed by a back-drop in media attention. The passive house concept only became the focus of more media attention in 2007. This shows some evidence of the existence of a gap between innovation and early adoption, as suggested by Moore (1999).

From 2003 to 2008, the main activities of the PHP and the relative composition of the network did not change significantly. This means that the sharp increase from 2007 onwards cannot be explained by changes in the membership or the network's activities. Since 1 January 2006, as part of the process of demonstrating compliance with the energy performance requirements, the assessment of the energy performance of design of new dwellings has been mandatory in the region of Flanders.[6] Although this increased awareness of the energy performance of buildings, it cannot explain the increasing inter-

6 For most buildings requiring a building permit, requirements were set for the energy performance and indoor climate.

est in the concept of the passive house.[7] Several enterprises reported a perception that policy was influential from 2007 onwards, specifically since passive house grants were introduced by municipalities and energy distribution net managers, and income tax reduction initiatives were put in place for passive houses.

These initiatives apparently led to renewed interest in the passive house concept, and provided good marketing arguments for companies to broaden their market appeal. The policy development apparently attracted early adopter enterprises, as shown in the following section, which details the findings from the questionnaires.

5.4.2 Innovator versus early adopter enterprises

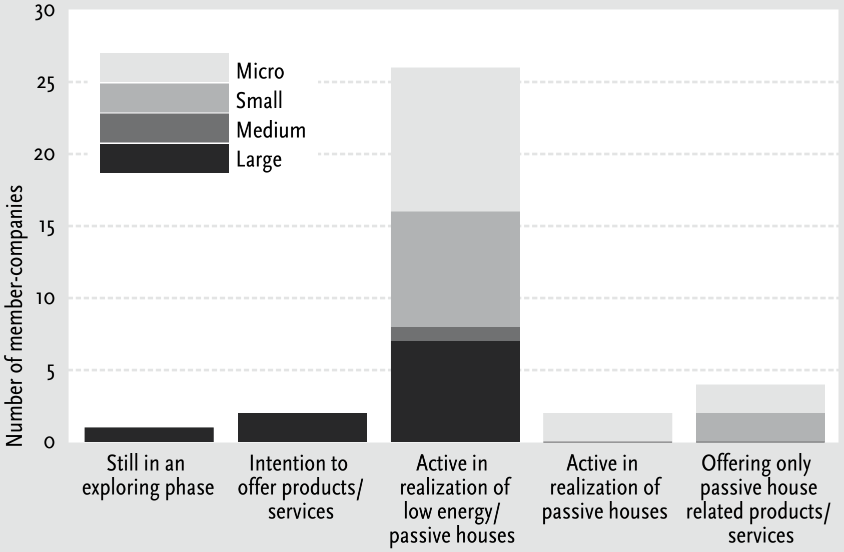
A total of 38 respondents from various companies completed the questionnaire sent to them in December 2008. The response rate was 29.9%, which is good for paper-based questionnaires. The respondents represented a cross-section of the companies, which were categorized into micro-enterprises, SMEs, large enterprises and others (knowledge institutes, non-profit organizations, and so on).

Figure 5.4 shows, using data from the member poll in December 2008, that most members considered passive house technologies as a stimulus for a more specific focus on the low-energy housing market as a whole, not necessarily only passive houses. However, some companies reoriented their range of products and services almost completely towards the passive house concept. This is in sharp contrast with the situation in 2002-2003, when all members were still exploring how passive house technologies, systems and services could be implemented.

One remarkable point is that in 2008, all the large enterprises that responded to the questionnaire were either still in the exploratory phase or just beginning to address low-energy solutions, while some micro-enterprises had already shifted their products and services completely to passive houses. This 'innovator' group of passive house market pioneers was found to consist mainly of micro or small enterprises, more specifically the passive house design and engineering offices, contractors, installers and suppliers that were also involved in the initial demonstration projects in 2003-2006. The interviews revealed that some of these innovators accepted a radical discontinuity

7 In contrast, the EPBD development was perceived as incompatible with the already developed passive house communication efforts. For example, the reporting of the energy requirements was to be undertaken by officially recognized EPB reporters using required EPB software and the EPB software would serve as a basis for the production of building energy certificates, while many enterprises were already trained in using passive house calculation software and convinced to aim for a passive house quality declaration.

Figure 5.4 How PHP member-companies assessed their own position in relation to the passive house concept, grouped according to company size (directed to all members December 2008, 38 respondents)



Source: Passiefhuis-Platform vzw

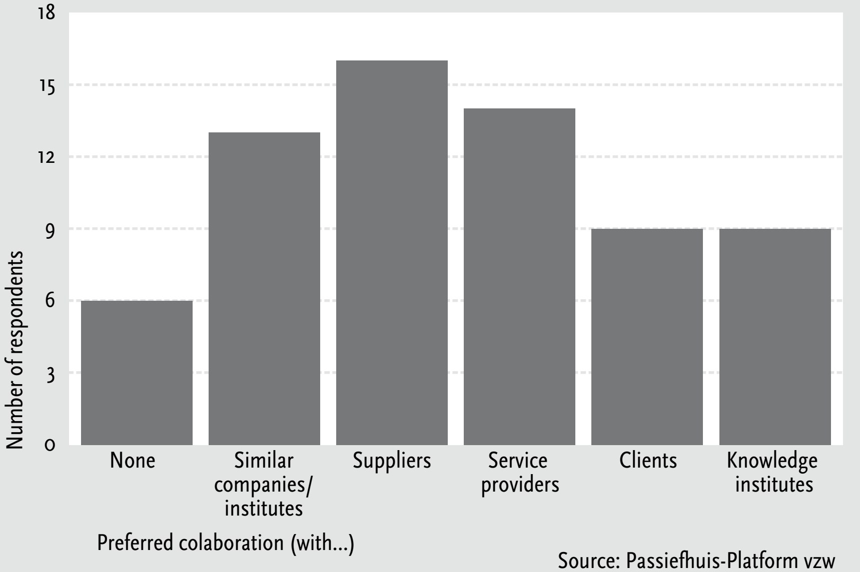
between old methods and new ones. For example, one of the founders businesses of the PHP had mainly been involved in selling air conditioning systems and transformed his business gradually into one selling ventilation and heat recovery systems (imported from Denmark); another heating installer transformed his business to selling passive house windows (imported from Austria).

For companies that joined the network from 2007 (referred to as 'early adopters'), the new European Energy Performance Directive (EPBD, 2010), grant initiatives and tax reduction for passive houses were reported as important drivers that convinced companies to move towards the passive house concept. Most large enterprises are in this group of early adopters (about 24% of the respondents), as well as small enterprises that tried to find a new niche market.

The detected barriers for early adopter enterprises were a lack of knowledge, a lack of funding and difficulties in attracting the interest of homeowners. For example, all enterprises that stated that they followed a PHP course on passive houses (16 of 38 respondents)[8], stated that they did so to increase general knowledge about passive houses. Understanding that the passive house network contains most passive house innovators in the Flemish Region, Figure 5.5 shows the results to the question "With what other parties of the passive house network did you collaborate on passive house projects?".

8 Seven of nine large enterprises responded that they did not follow such course yet, although some of them confirmed that they were still planning to do so.

Figure 5.5 Identification of preferred collaboration partners for Passive House projects (results for a total of 38 respondents; multiple options possible per respondent)



Source: Passiefhuis-Platform vzw

Figure 5.5 shows that most enterprises did collaborate with other enterprises. While suppliers and service providers (such as architects, engineering offices, and so on) are obvious parties for construction collaboration, it can be noticed that some enterprises also worked together with similar companies/ institutes or knowledge institutes. Some enterprises even identified their clients as important information source in building teams. To the question "How can this collaboration be characterized?" 20 respondents answered 'instructive' and 14 confirmed it as 'innovation stimulating'.

In follow-up interviews, some of the enterprises confirmed that they learned from or collaborated with the innovators to redefine their business opportunities using more incremental forms of innovation. For example, an architect involved in demonstrating a passive house project launched a spin-off company providing 'insulation and air tightness services'. A former employee of a carpentry business involved in a demonstration project developed his own company building passive houses using similar construction methods. A company providing I-shaped beams for floors examined the opportunity for using these beams in passive house walls.

Specific cooperation between members of the network was detected. For example, the architect of a demonstration project helped a large supplier company to design a building method using traditional building products. Another architect involved in a demonstration project helped a large project developer to redesign and standardize their system of construction for passive houses. In a later phase, some large companies joined forces with innovators and/or other large companies to present an integrated concept to the building market (for example the 'massive passive' concept, the 'healthy building' concept, the 'multi-comfort house', and so on). These findings show that large companies gained expertise from more developed SMEs.

Summarizing, a transition from innovation to early adoption is visible in the analysis of the number of commercial members of the PHP and the media coverage received. Figure 5.1 showed that in the start-up period of 2003-2006, the number of innovating enterprises that adopted the passive house concept did not increase rapidly, but began to increase rapidly later. The previous findings have made clear that the companies in the PHP can now mainly be classified as innovators and early adopters.

Innovators expected to benefit from a head start over future competitors by focusing on highly energy-efficient housing and this motivation did not change for early adopters.[9] The early adopters expect to learn from the innovators in the network. Mixing innovators and early adopters in a (formal) network – bringing together experienced and less experienced companies, as well as large and small companies – appears to be an important success factor for exploring collaboration opportunities and for the diffusion of innovation to early adopters.

Suppliers and service providers are important players for collaboration for the realization of passive houses, and thus for the diffusion of highly energy-efficient housing. But also the collaboration and knowledge exchange between similar businesses plays a role in innovation diffusion. Furthermore, the role of the client and of knowledge institutes can not be neglected. In the next sections the results are reflected on theory (focusing on the issue of company size), and some collaboration opportunities on the road to early adoption are discussed in more detail.

5.4.3 Reflection on theory regarding company size and innovation

According to Rogers, relatively earlier adopters are generally larger-sized units (Rogers 2003: 298), but this does not seem to be the case when it comes to the adoption of the passive house by innovators. Companies involved in the innovation and early adoption of passive house technologies and services have mainly been micro-enterprises or small enterprises. Their tendency is towards radical innovation. Larger companies have mainly been early adopters with a tendency towards incremental innovation. This can partly be explained by the fact that most companies in the building sector are SMEs, and large companies are slower to adopt because of their larger decision-making units. On the other hand, the observation that larger companies have been slower to adopt corresponds with Rogers' statement (2003) that the more

9 The results in Figure 5.4 show that a majority of interviewees (both innovators and early adopters), although they agreed to promote the passive house concept, still consider passive house technologies as a means by which to expand their activity in the low-energy housing market more generally, not necessarily only passive houses.

people are involved in making an innovation decision, the slower the rate of adoption.[10]

The observations in previous sections confirm the findings of Sen and Egelhoff (2000) that small firms are in a better position to implement radical innovation, while large firms are better at incremental innovation. It was noted in this research that (radical) innovation by SMEs was based on off-the-shelf technologies from the supply industry, which confirms the thinking of Verhees and Meulenberg (2004). In this case, innovation in SMEs was often kick-started by imports from foreign suppliers, which highlights the benefits of information and product transfer between different European countries in stimulating regional innovation.

That large firms are better at producing materials-based innovation (Rothwell and Dodgson, 1991) is confirmed by recent product-related passive house developments by large companies, such as the 'multi-comfort-house' (relates to thermal insulation) and the 'massive passive house' (relates to bricks). However, it is surprising how slowly large companies have reacted when it comes to materials-based innovation, especially since similar innovations were already available from these companies in some of their European markets. Apparently, they felt the need first to attract the necessary skills and expertise from regional innovators and use the ideas developed in regional demonstration projects, in order to provide solutions adapted to regional construction methods. One might thus speculate whether large companies were only motivated by the prospect of a large potential market (as a result of financial incentives).

Nevertheless, attracting large companies has proved essential since, unlike the innovators, large companies can provide considerable resources to channel into innovation using their own products and systems as a reference. In general, this resulted in the growth of the group of early adopters, and a considerable increase in market interest, including from new SMEs. Innovation research involving the passive house thus confirms general suggestions by authors (Berry and Taggart, 1994; Acs and Audretsch, 1988) that small firms tend to lead innovation during the earliest stage in the evolution of a technology, with the locus of innovation shifting to larger firms in the early adoption market.

10 One means of speeding the rate of adoption is to alter the unit of decision so that fewer individuals are involved. From interviews it was apparent that for large companies, often individual persons within these companies kick-started a process to convince their management to join the PHP network or a specific related passive house innovation development goal. So it was also noticed that passive house innovation started by business owners tended to be adopted faster than initiatives started by middle management or administration personnel. The fastest innovation response to passive house network effort appeared to occur when opinion leaders and micro-enterprises (often limited to one or two people) adopted. This somehow confirms author's suggestions (Docter *et al.*, 1989, Hartman *et al.*, 1994) that motivated owner-managers in SMEs are essential for innovation.

5.4.4 Opportunities for and barriers to collaboration on the road to early adoption

The reported needs of enterprises in the early adoption market focused mainly on attracting know-how from more experienced and/or complimentary players. This confirms suggestions by researchers (van Hal, 2000; Rødsjø *et al.*, 2010) that some of the most important challenges in the early adoption phase are how to stimulate cooperation and knowledge transfer (from innovators to early adopters). In general, a lack of knowledge is still perceived among early adopters, and passive house innovation learning is still valued in the early adoption phase.

The construction of single-family passive houses is still dominated by SMEs, which is an inherent characteristic of this segment of the construction sector. This poses challenges in terms of learning, since SMEs have limited time, research and development resources and skills. While their commitment to radical innovation appears crucial in the market introduction phase, the transition towards the early adoption phase requires collaboration with larger regional enterprises, as was illustrated by several examples in the previous section and confirmed by literature (Tushman and Romanelli, 1985; Klepper, 1996; Amorim *et al.*, 2003).

The research confirms that firms of different sizes may find themselves with compatible goals (Amorim *et al.*, 2003). While larger companies take longer to engage in innovation development and seem less flexible, their development of innovation can speed up when they attract expertise from innovator SMEs. A success factor in the early adoption phase appears to be the active presence of an enterprise network that links both experienced and less experienced enterprises (and both large and small) in the construction sector. The PHP, as a multi-player network, facilitated interaction between large and small companies, and between innovators and early adopters.

This confirms that a multi-player network is in itself a crucial element in developing a niche market (Hegger *et al.*, 2007; Elzen *et al.*, 2004; Kemp *et al.*, 1998; Caniëls and Romijn, 2008; Raven, 2005; Weber *et al.*, 1999) as well as a sheltered space for learning and the incubation of ideas (Kemp *et al.*, 1998), in this case formalized as an enterprise network (the PHP). Regarding network composition, different authors (Kemp *et al.*, 2001; Elzen *et al.*, 2004; Schot and Geels, 2008) have suggested that one success factor is bringing together a broad range of representative actors or potential adopters. This was achieved by the PHP which involved different types of actors in the construction chain. While market players such as contractors, architects, suppliers, consultants, and engineers are important contributors for collaboration and know-how transfer, the collaboration with knowledge institutes or (sometimes well-informed) clients can not be neglected in building teams. Within such network the incentive of sharing innovation risk (particularly for demonstration projects) and attracting clients and projects in collaboration with other companies, can be an important motivator for collaboration.

During the early adoption phase, larger companies play an important role, providing the necessary momentum by means of their own broader network. It was observed that larger companies tend to watch the experience of small companies – and that large companies preferably engage in larger projects than individual housing. Therefore strategic decisions in general policy development play an important role in the transition to early adoption. The introduction of policy incentives aimed at stimulating the early adoption market, such as introducing grants or tax relief for passive houses, was a driver for the greater involvement of large companies, it was noticed. The results suggest that regional initiatives such as grants or tax relief for passive houses can contribute significantly to bridging the gap in this market towards more rapid early adoption. Summarizing, it can be stated that the differences between the various phases of innovation diffusion have seldom been examined in literature, although the importance of these different phases is often acknowledged (Moore, 1999; Rogers, 2003; Rødsjø *et al.*, 2010).

This case study suggested that, in order to bridge the gap between the different phases, it is important to define consistent network management solutions and innovation policy actions according to the innovation phase. In a market introduction phase, radical innovation among SMEs should be encouraged, whereas in an early adoption phase, the transfer of know-how to and from large companies is needed. In both phases, collaboration between different types and sizes of companies should be the focus. According to Moore (1999), a more important gap – between the early adopters and the late adopters – is yet to come and will provide perspectives for future research. Further research into the differences between the market introduction of innovation, the early adoption market and the late adoption market is needed. Specifically, the role of networks in order to support communication, collaboration and transitions between phases could be investigated in more detail.

5.5 Conclusion

This study has investigated the opportunities and challenges for the development of the market for highly energy-efficient housing, focusing on single-family passive houses, by analysing the characteristics, opinions and experiences of commercial members of a passive house network in a region that has moved successfully from market introduction to the early adoption of passive houses.

The study showed that a market in highly energy-efficient homes needs to be developed relatively rapidly, but that in reality the volume market cannot be targeted directly. The study showed the need to develop, characterize and nurture the various subsequent innovation phases and transitions between phases. Notably, the transition from the introduction of an innovation (passive house-related technologies and systems, demonstration projects) to early adoption, poses a considerable challenge, which implies gradually involving and motivating a range of enterprises.

The research focused particularly on the characteristics of the enterprises involved in passive house development, specifically the company size, the time at which an innovation was adopted and collaboration with other enterprises. The results showed that – in the case of the development of the Flemish single-family passive housing market – it was mainly small enterprises that kick-started regional innovation, while large companies contributed in the early adoption phase through incremental innovation. The research provides an example of a situation in which larger companies can be slower to adopt innovation, particularly when no (financial) incentives are in place which target a large market.

An important challenge for enterprises in both the market introduction phase and the early adoption phase is attracting skills and expertise in innovation. The market introduction of innovation can be facilitated by formal collaboration between (regional) innovators and foreign suppliers. In a later phase, collaboration between innovators and large companies was detected, and this type of collaboration proved essential in order to bridge the transition to the early adoption phase. Thus business-to-business collaboration was found to be key to the development of innovation in both the market introduction phase and the early adoption phase.

Multi-player networks – in which different types of actors (in the case of the passive house network, architects, installers, contractors, consultants, and so on) can collaborate – were important for eliminating know-how barriers and providing networking opportunities, in both the market introduction phase and the early adoption phase. The results thus suggest that collaboration between specific types of enterprises can be facilitated by regional (passive house) enterprise networks. The involvement of clients and knowledge institutes in such networks should not be neglected, since these players also collaborate with enterprises in passive house development.

Regarding the development of innovation policy, further research is still needed to understand key elements in the transition from early adoption to late adoption. However, the research results suggest that in order to stimulate enterprise innovation to realize highly energy-efficient single-family housing, regional micro-enterprises and their partnerships with advanced foreign suppliers first need to be targeted. In a later phase, collaboration between these innovators and larger regional companies can be encouraged. Since multi-player networks are key in facilitating such collaboration, it is recommended that innovation policy should specifically support their networking efforts.

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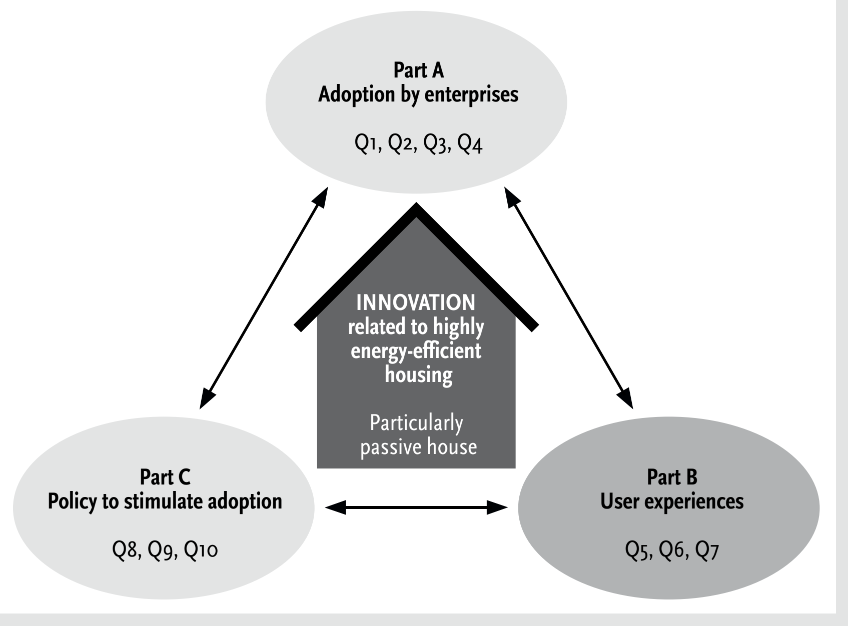
Introduction to Part B: User experiences

Figure B.1 The research defined the 'innovation' and studied its adoption by end-users in Part B, studying research questions Q5, Q6 and Q7



Part B investigates the adoption of the innovation from the demand-side perspective. The research discussed in this part addresses end-user appreciation of nearly zero-energy houses and certified passive houses, in order to determine critical issues in the adoption of innovations related to highly energy-efficient housing concepts. Specific attention is devoted to the situation in countries with emerging market development, although the results have broader implications for the development of recommendations regarding innovation adoption in newly built homes and major renovations.

Chapter 6 examines end-user experiences in the Netherlands
To examine critical issues in the adoption of nearly zero-energy houses by end-users, it is important to understand end-user experiences with low-energy houses, passive houses and zero-energy houses. The outcomes of research exploring barriers to and drivers of non-technical aspects (e.g. behaviour) could be expected to accelerate the transformation of the market. This study deliberately focuses on the Netherlands, as this country has apparently had more difficulty than several other countries (e.g. Austria, Germany, Switzerland and Belgium) have experienced in introducing passive houses to the

market. For this reason, Chapter 6 focuses on end-user appreciation of innovations related to highly energy-efficient housing concepts in the Netherlands, according to the following research question:

Q5. *What are the experiences of Dutch occupants with nearly zero-energy houses (e.g. passive houses)?*

Previous researchers at TU Delft have analysed user experiences from projects for various research purposes, including the explanation of the relationship between housing-occupant behaviour and health indicators (Hasselaar, 2006), the effects of user behaviour on actual energy use (Guerra Santín, 2010) and the satisfaction levels of inhabitants regarding various comfort criteria (Schütze, de Vries and Jansen, 2011). The study addressed in this section examines user experiences with highly energy-efficient housing concepts (e.g. passive houses) from the viewpoint of innovation adoption. The availability of research data collected by Schütze, de Vries and Jansen (2011) offered the opportunity to study the experiences of end-users, which could have either positive or negative effects on their perceptions, and thus their likelihood to adopt innovations (e.g. passive houses). The study contributes to the development of construction-innovation diffusion theory, by enhancing understanding regarding how specific characteristics of concept innovations (e.g. passive houses) can be studied using specific research methods. In this study, post-occupancy evaluation research on existing nearly zero-energy houses is used in order to formulate general recommendations for the large volume market of nearly-zero energy houses that could be expected in the future.

Chapter 7 examines end-user experiences in certified passive houses
Chapter 6 uses post-occupancy evaluation research to identify critical issues that are largely related to comfort concerns in passive houses. According to these results, various parameters (particularly thermal comfort and indoor air quality) can be related to either positive or negative end-user appraisals. For this reason, a study was performed in order to identify opportunities for improving the acceptance of passive houses in relation to the comfort expectations of end-users. Passive house certification has previously been proposed as a possible tool for convincing customers of the quality of realised passive houses (Beedel, Phillips and Hodgson, 2007). The following research question addresses the possibility of improving this tool:

Q6. *What are recommendations for the improvement of passive house certification, based on end-user experiences?*

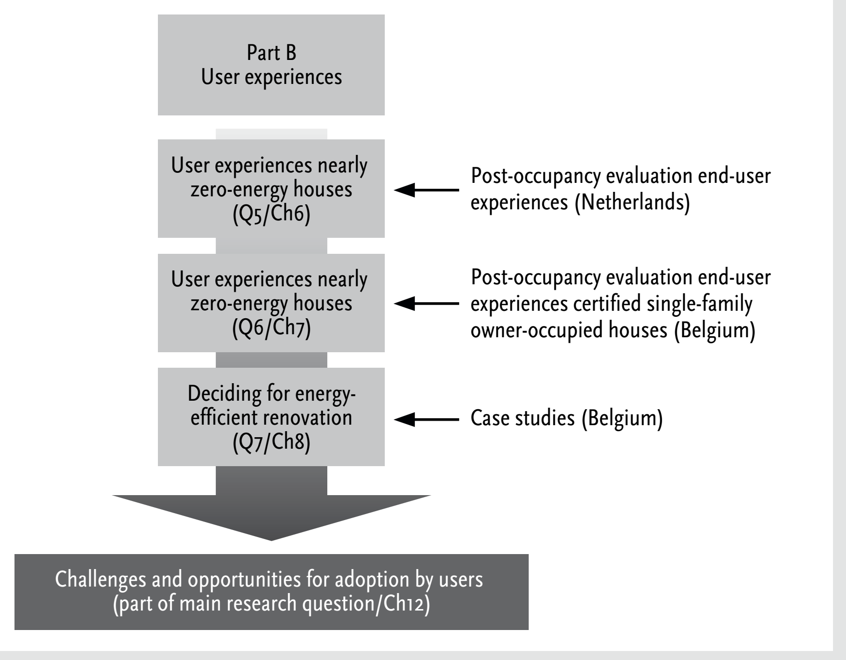
A comprehensive review of the comfort concerns of passive house end-users was conducted, in order to identify ways of improving the uptake of innovation by end-users. A literature study identified examples of the particularities of passive house certification. In addition, an original research project focused on identifying the comfort concerns of end-users in certified passive houses. This study was conducted with specific attention to the perspective of single-family owner-occupied passive houses in Flanders, northern Belgium, although its results have broader implications for the development of recommendations regarding building services in newly built homes. This study contributes to the development of construction-innovation diffusion theory by enhancing understanding with regard to the ways in which perceived characteristics of building services can relate to the acceptance or rejection of concept innovations. Findings from this original post-occupancy evaluation research on existing single-family owner-occupied certified passive houses are used to formulate general recommendations for improving the acceptance of passive houses by end-users.

Chapter 8 studies the adoption of renovation by end-users
In most cases, innovations are not included in buildings unless they are specifically requested by the commissioner or client (Buijs and Silvester, 1996). Compared to the adoption of single renovation measures, owner-occupiers appear to be less likely to opt for highly energy-efficient renovations. For this reason, a subsequent study was designed with a focus on the adoption of high energy efficiency in major renovation by owner-occupiers (single families). The focus on owner-occupiers was also influenced by the Dutch policy programme Meer met Minder [More with Less] (Boerbooms, Diepenmaat and van Hal, 2010). Moreover, the focus on owner-occupiers is justified from the perspective of innovation diffusion, as the decision-making unit regarding the adoption of highly-energy efficient housing is relatively small, thus increasing the expected rate of adoption (Rogers, 2003). Based on these arguments, the following research question was formulated:

Q7. *How were owner-occupants persuaded to apply highly energy-efficient renovation concepts in renovations of single-family houses?*

Because the construction of single-family owner-occupied passive house renovations is more advanced in Belgium than it is in the Netherlands, experiences from Belgian projects were studied in detail. This research focuses on decision processes related to the adoption of highly energy-efficient housing concepts, with the goal of enhancing understanding regarding factors that motivate owner-occupiers to opt for such concepts. This study contributes to the development of innovation diffusion theory by providing examples of the utility of Rogers' theory and by identifying drivers and barriers related to innovation-decision processes regarding highly energy-efficient

Figure B.2 The main topics covered in Part B, the research input used in each chapter of Part B to explore a specific research question and the research output expected from this part



renovations. This chapter provides a detailed description of the experiences of existing single-family owner-occupiers with highly energy-efficient home renovations, in order to illustrate how perceived innovation characteristics could increase the rate of innovation adoption. The study also identifies opportunities for and barriers to the stimulation of the adoption of highly energy-efficient housing concepts in major renovations.

General overview of Part B (see Figure B.2)
As illustrated in Figure B.2, the research reported in this part thus analyses the experiences of end-users with innovation adoption (Q5, Q6), as well as decision processes related to the adoption of innovation (Q7). Chapters 6 and 7 draw upon the findings of post-occupancy evaluation research in order to analyse the experiences of end-users with newly built homes. Chapter 8 examines decision processes related to innovation adoption in the more slowly developing market for housing renovations.

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6 End-user experiences in nearly zero-energy houses

Previously published as: Mlecnik, E., T. Schütze, S.J.T. Jansen, G. de Vries, H.J. Visscher & A. van Hal, 2012, End-user experiences in nearly zero-energy houses, ***Energy and Buildings 49****, pp. 471-478.*
doi:10.1016/j.enbuild.2012.02.045; www.elsevier.com/locate/enbuild

Abstract
High end-user satisfaction levels are key for the acceptance of nearly zero-energy housing. Post-occupancy evaluation research on highly energy-efficient dwellings can lead to recommendations which will influence their performance in the expected future large volume market of such houses. This study analysed mainly German, Austrian and Swiss post-occupancy evaluation research results on nearly zero-energy dwellings and undertook a survey of occupants of nearly zero-energy houses in the Netherlands. The study determined how various comfort parameters (such as winter thermal comfort, summer thermal comfort, indoor air quality and acoustics), information provision and control parameters are related to positive or negative end-user appraisal, finding that summer comfort design and the quality of – and information about – heating and ventilation systems are critical factors which must be addressed to improve user satisfaction in nearly zero-energy dwellings.

6.1 Introduction

From the end of 2020 all new buildings in the EU will have to be highly energy efficient and will be expected to use 'nearly zero energy' (EPBD, 2010). The remaining energy demand will have to be covered 'to a very large extent' by renewable energy which is produced in and/or on the building or in the neighbourhood (EPBD, 2010). Today, most EU countries have already built some nearly zero-energy houses, at least as demonstration projects. It is expected that future supply and demand will be stimulated by promises of lower CO_2 emissions, lower energy bills and also comfort benefits. In the marketing framework of several European countries, different definitions and terminology for such housing have already been introduced (Mlecnik, 2011). Popular marketing terms include 'low-energy houses' (LEHs), 'passive houses' (PHs) or 'zero-energy houses' (ZEHs). 'Low energy' usually refers to buildings with the explicit intent of using less energy than standard buildings. However, often no specific requirements are stipulated. With respect to 'passive' houses, specified requirements usually have to be fulfilled, such as a maximum end-energy use for space heating and a limited primary energy demand for all end-uses. 'Zero energy' usually refers to net zero energy. This means a building where the net energy used over one year is matched by an equal amount of energy produced on site. In the Netherlands, for example, the national policy programme

'Clean and Efficient' ('Schoon en Zuinig'), as well as foundations such as the 'Stichting Experimenten Volkshuisvesting' (Platform31), 'Stichting Passiefbouwen.nl' and 'Stichting Passiefhuis Holland', aim to spread information about newly built LEHs, PHs and ZEHs in order to increase the market uptake of such buildings.

However, demonstration projects are often insufficiently or inadequately monitored, analysed and evaluated, meaning that the learning effect for future projects is generally poor and insufficient (Femenias, 2004). Amongst other suggestions, Preiser and Vischer (2005) highlight the need for post-occupancy evaluation (POE) research. Poor demonstration projects risk leading to low credibility and investment for future projects should they not fulfil the expectations of and/or not be appreciated by the inhabitants (Treberspurg *et al.*, 2009). End users are particularly important as multipliers and often act as peer-to-peer 'experience' experts for the acceptance or disapproval of advanced energy concepts (Danner, 2003). In the Netherlands, for example, end users were found to be sceptical about mechanical ventilation systems (Jongeneel *et al.*, 2011); however, it appears that mechanical ventilation in housing may have been negatively perceived due to problems related to poor installation (Van Ginkel, 2007).[1]

A key issue for the successful implementation of increased energy efficiency in the housing sector will be the user demand for nearly zero-energy building concepts – such as LEHs, PHs and ZEHs – which directly relates to the perceptions of users, their acceptance and satisfaction. On digging deeper, users can have different concerns, reflecting differences in the quality of different buildings (Hauge *et al.*, 2011). Living conditions in the houses realised (particularly comfort and health criteria such as indoor temperature, humidity and noise level) and their operability (for example of mechanical ventilation systems) are important factors influencing occupants' perceptions of energy-efficient houses, and thus their further adoption. Therefore, this study investigates end-user satisfaction in nearly zero-energy dwellings and aims to provide recommendations for the improvement of quality and comfort.

6.2 Research strategy

The goal of the study is to detect barriers to and opportunities for the promotion of nearly zero-energy dwellings based on end-user experiences, by study-

1 Dutch scandals concerning the improper functioning of ventilation systems created quite a stir, leading to the recommendation to ensure better installation quality through effective commissioning and to better inform home buyers. The controversy was mainly focused on one specific LEH estate (see also Duijm *et al.* (2007) and Kuindersma & Ruiter (2007)).

ing end-user satisfaction in current LEHs, PHs and ZEHs. The central research question is: What are the experiences of end users with nearly zero-energy houses? Based on the analysis and evaluation of end-user satisfaction with LEHs, PHs and ZEHs, suggestions for improvement can be made in order to establish the basic conditions for the widespread adoption of nearly zero-energy dwellings.

The first part of this paper introduces the theoretical framework (Section 6.3). It addresses the experiences in central European countries, particularly Germany and Austria where the development and market implementation of highly energy-efficient building concepts (such as the PH) is more advanced (Elswijk, 2008). Many researchers in these countries have already contributed to our understanding, relating end-user satisfaction to parameters of highly energy-efficient building concepts. However, most of these studies have only been published in German. To obtain a better understanding of experiences in these countries, German, Austrian and Swiss literature on this subject is reviewed and discussed here. The findings drawn from the literature will be analysed in terms of key subjects addressed in end-user evaluation research.

The second part of this study (Section 6.4), presents the results of a first end-user evaluation study of highly energy-efficient houses in the Netherlands. Issues such as the reasons for choosing such a house, general satisfaction and satisfaction with indoor climate and ventilation systems were addressed in this survey. These results are compared with the findings from the literature discussed in the first part of the study.

The recommendations at the end (Section 6.5) will discuss the opportunities for and barriers to the improvement of end-user satisfaction and reflect on the framework for the improvement of nearly zero-energy houses.

6.3 End-user experience research in Germany, Austria and Switzerland

6.3.1 The literature on nearly zero-energy housing

The post-occupancy evaluation (POE) of buildings is an established research approach in the social sciences (Preiser and Vischer, 2005; Marans and Spreckelmayer, 1981; Preiser *et al.*, 1988; Meir *et al.*, 2009). POE methods are used for the systematic study of buildings once occupied, so that an assessment can be made, for example, through feedback from inhabitants and/or physical measurements made during the operation of buildings (Hauge *et al.*, 2011). POE research has gained particular importance for nearly zero-energy housing, especially where the demand for PHs has increased, for example in Austria (Keul, 2010). Regarding nearly zero-energy housing, various studies have also focused on onsite investigations and measurements evaluating indoor climate, energy and comfort, thereby assessing various aspects of the operation and performance of the occupied building (for example Pfluger and Feist, 2001; Ebel *et al*., 2003; Schnieders, 2003; Schnieders and Hermelink, 2006; Berndgen-Kaiser *et al*., 2007; Wagner and Mauthner, 2008a; Wagner and Mauthner, 2008b; Mahdavi and Doppelbauer, 2010).

Rohrmann (1994) pioneered end-user satisfaction research into PHs by investigating experiences with the first PHs in Darmstadt. Subsequently, POE research focused on the characteristics of PH inhabitants as a special segment of the population with a specific lifestyle, appreciation patterns or user behaviour, possibly also related to environmental awareness (Flade and Härtel, 1991; Ebel and Feist, 1997; Feist, 1997; Flade, 1997; Loga and Knissel, 1997; Schmitz and Hübner, 1997; Ebel *et al*., 2003; Flade *et al*., 2003; Flade and Lohmann, 2004; Hallman and Mack, 2004).

POE analyses followed on larger, more or less identical, housing samples – such as the PH housing estate Hanover-Kronsberg in Germany (Danner and Vittar, 2001; Von Oesen, 2001). In 2001 Keul (2001) compared PHs with other types of houses – analysing 614 living units of which 15 were PHs, in the Salzburg region of Austria – while Stieldorf *et al*. (2001) investigated 12 Austrian demonstration projects in the Austrian Vorarlberg Region, including one with 13 PH living units. In Germany, Hallmann (2003) investigated end-user experiences in 22 PHs and 24 LEHs in the Lummerlund area in Wiesbaden and compared these experiences to those of a control group of users living in 11 conventional houses. A first Swiss study appeared when Gräppi *et al*. (2003) surveyed and analysed 73 inhabitants of certified PHs in Germany, Austria and Switzerland. The largest study to date was undertaken by Treberspurg *et al*. (2009), who monitored 1367 living units, of which 492 were PHs, in the Vienna area. This study compared the user appreciation of 225 PH households with 156 conventional ones. POE research has also been executed in the framework of social rental housing (Hübner and Hermelink, 2001, 2002, 2003), student housing (Treberspurg and Smutny, 2007; Treberspurg *et al*., 2007; Engelmann *et al*., 2008), renovation designed to achieve LEHs and PHs (Hacke and Lohmann, 2006; Hermelink, 2006) and the evaluation of regional grant policy (Berndgen-Kaiser *et al*., 2007).

All of these studies identified innovation opportunities as well as problems and the reasons for unsatisfactory building performance. The following sub sections will analyse the literature above, in order to obtain a better understanding of which factors are appreciated by end-users and which can lower user satisfaction. This study thematically investigates the conceptual terminology itself (for example ‘passive house’), general satisfaction with the house (particularly thermal comfort), satisfaction with the indoor climate systems, the importance of user-friendliness and controllability issues, the relevance of information provision, and possible time-related changes in opinions and behaviour.

6.3.2 The concept of nearly zero energy as a reason for choosing a house

The literature revealed that for PH inhabitants, energy saving[2] was not a very important criterion when choosing a house (Treberspurg *et al.*, 2009; Danner, 2003; Keul, 2001). It also showed that PH inhabitants are not politically 'greener' than mainstream customers (Treberspurg *et al.*, 2009). While Treberspurg *et al.* (2009) attributed a high marketing branding value to the PH concept, Keul (2009) noted that the PH concept played a role in users' decision-making processes in only one out of six residential multifamily buildings. Schnieders and Hermelink (2006) reported PH branding as least important from the viewpoint of marketing, whereas the presence of a balcony, for example, was a very important reason to move in. One study (Hallmann, 2003) showed that end users of conventional houses, LEHs and PHs, respectively, cited the importance of the neighbourhood in which the house is located (a control group of 11 inhabitants), the economic benefits (a group of 24 LEH users) and the importance of having their own property (a group of 22 PH users) most frequently.

6.3.3 General satisfaction according to end users

In general, nearly zero-energy houses are appreciated by the inhabitants (Treberspurg *et al.*, 2009; Danner, 2003; Schnieders, 2003; Schnieders and Hermelink, 2006; Berndgen-Kaiser *et al.*, 2007; Danner and Vittar, 2001; Hallmann, 2003; Gräppi *et al.*, 2003; Hübner and Hermelink, 2003; Keul, 2009; Hermelink, 2003). Various studies have noted that inhabitants of PHs would generally recommend a PH to other clients (Danner, 2003; Schnieders, 2003; Berndgen-Kaiser *et al.*, 2007). Keul (2009) noted that satisfaction levels related to new PH dwellings were higher than those related to average Viennese housing. Although the average sample showed some distortion towards single-family housing, the study found that there was no correlation between the satisfaction of inhabitants and parameters such as age, gender, household size or number of children in the household.

Comfort was revealed to be an important parameter with regard to positive appreciation. A number of studies have found that occupants perceive their living conditions to improve after moving into PHs (Schnieders and Hermelink, 2006; Hübner and Hermelink, 2003), particularly with regard to winter thermal comfort and indoor air quality. In some studies, not one occupant gave a negative rating on the perceived indoor climate during winter (Schnieders, 2003; Schnieders and Hermelink, 2006). One of the important

2 Keul (2001) noted that 'conventional' residents generally have no interest in energy-saving lifestyles and are overconfident regarding their knowledge about energy saving.

beneficial parameters experienced by the inhabitants was, for example, fresh air in bedrooms in the morning (Hübner, 2001). Different research reports based on indoor air quality measurements confirmed that the air quality in PHs was indeed better than that of conventional buildings (for example Wagner and Mauthner, 2008a and 2008b; Wagner, 2006).

Users of PHs often feel more comfortable during the winter than during the summer (Berndgen-Kaiser, 2007; Wagner and Mauthner, 2008a and 2008b). Thus, summer thermal comfort requires specific attention. For example, in the Hanover-Kronsberg estate, 40% of end users invested in additional solar shading (Danner and Vittar, 2001). Additionally, Ebel and Feist (1997) stressed the importance of reducing internal heat gains – heat coming from, for example, household equipment and lighting – in order to avoid overheating in summer. In contrast to these findings, some studies (Schnieders, 2003; Schnieders and Hermelink, 2006; Hübner, 2001) reported high levels of summer comfort satisfaction.

6.3.4 Satisfaction with indoor climate systems

Perceived comfort levels can also be influenced by the level of satisfaction with indoor climate systems, such as those associated with heating and ventilation. A correct dimensioning of the heating system is needed to facilitate sufficient heating during the winter, especially in houses which are only equipped with air-heating (Ebel and Feist, 1997). Technical deficiencies in the heating system were discovered in the first demonstration buildings investigated by Danner (2003), Ebel *et al.* (2003) and Flade *et al.* (2003). Hübner (2001) argued that in the first largescale PH dwellings the quality of components such as ventilators, heat exchangers and control elements did not meet the expected standards, with the breakdown of ventilators or control elements and air leakage in exchangers possibly resulting in low user satisfaction. In addition to the general quality of design and execution, specific attention to air humidity, noise and odour is also needed, as is apparent below.

Different studies (Danner, 2003; Gräppi *et al.*, 2003; Hübner, 2001) reported cases in which the air quality during winter was perceived to be too low. The dimensioning of air exchange rates is usually the key to solving this problem (Hübner and Hermelink, 2003; Pfluger and Feist, 2010). End users of PHs mentioned problems with insufficient noise control related to either the ventilation system or noise originating inside the building, for example, from neighbours or other floors (see, for example, Wagner, 2010). Noise caused by ventilation equipment functioning during the night is less tolerated than during the day (Gräppi *et al.*, 2003). Amongst other reasons, noise problems can be caused by insufficient noise reduction measures, such as inadequate sound absorbers in the ventilation ducts. Schnieders and Hermelink (2006) reported that a problem with noise pollution could be solved by small technical enhancements and providing better information to tenants – for example, explaining that ventilators become noisier when filters are not cleaned or changed.

Furthermore, some studies identified odour as a potential nuisance that was possibly related to the performance of the ventilation system (Hallmann, 2003). Some possible causes were found to be exhaust air mixing with fresh air when there is insufficient distance between the air inlet and exhaust, and a lack of sufficient ventilation in some spaces, such as common stairwells (Schnieders and Hermelink, 2006; Hübner and Hermelink, 2003). There may also be a relationship between odour complaints and exposure to volatile organic compounds from materials, especially formaldehydes (Rothweiler *et al.*, 1992), but this has not yet been thoroughly investigated.

6.3.5 The influence of control parameters on satisfaction levels

Users might be dissatisfied with building services such as heating and ventilation systems when they cannot control them sufficiently. In general, end users wish to control temperatures in different rooms (see, for example Danner & Vittar, 2001; Hermelink, 2003). Ebel and Feist (1997) recommended the simplification of control devices for heating and ventilation in order to avoid confusion as well as incorrect use and poor performance. For example, Hübner (Hübner, 2001) noted complaints about unreadable control devices and a lack of information regarding the status of operation. A study (Schnieders & Hermelink, 2006) noted possible conditions other than the set temperature due the slow change in room temperature inherent to PHs. In later PH projects, the initial correct setting of the heating and ventilation system was discovered to be a crucial parameter related to positive user satisfaction (Treberspurg *et al.*, 2009).

Studies (Schnieders & Hermelink, 2006; Hübner & Hermelink, 2003) have reported a relationship between an increased level of user-driven free ventilation (opening windows) and a negative perception of controlled ventilation systems. Ventilation systems need to be correctly dimensioned in order to avoid the opening of windows by residents in winter (Loga & Knissel, 1997), as this contributes to heat and energy losses. However, various studies (for example Feist, 1997; Richter *et al.*, 2003; Schnieders, 2003; Feist *et al.*, 2005; Schnieders & Hermelink, 2006; Wagner & Mauthner, 2008a; Wagner & Mauthner, 2008b; Mahdavi & Doppelbauer, 2010) have acknowledged that the influence of end users on the absolute values of energy use in nearly zero-energy houses is rather limited. Using energy measurements and comparing PHs and LEHs, Feist (1997) showed that careless end users in PHs still use less energy than careful end users in LEHs.

6.3.6 The influence of information and communication on satisfaction levels

Various studies stress the need for specific user instructions regarding building services such as heating and ventilation systems in PHs, including information about their properties, operation and maintenance (Ebel & Feist, 1997; Loga & Knissel, 1997; Danner, 2003; Gräppi *et al.*, 2003; Hübner & Hermelink, 2003; Hacke & Lohmann, 2006; Keul, 2009; Treberspurg *et al.*, 2009). For example, Treberspurg *et al.* (2009) found that inhabitants had uninformed opinions about PHs which resulted in less positive appreciation. According to various studies (Hübner, 2001; Hübner & Hermelink, 2003; Schnieders & Hermelink, 2006; Treberspurg *et al.*, 2009; Wagner *et al.*, 2010), the perceived barrier of 'poor controllability of indoor climate' can be partially removed by providing specific information to the end users. Some of these studies (Hübner, 2001; Wagner *et al.*, 2010) have also proposed using more effective communication methods to increase satisfaction, for example, during meetings of owners and/or tenants. Moreover, the early communication of technical problems by end users can be very useful, since solving such problems can lead to increased satisfaction (Treberspurg *et al.*, 2009).

Wagner *et al.* (2010) confirmed the need for specific information regarding the ventilation system. In particular, establishing the correct settings for the heating and ventilation systems on first use requires the provision of specific information, beyond the usual oral communication of instructions and the availability of a manual (Treberspurg *et al.*, 2009). Moreover, the importance of explaining specifics such as reducing the air-exchange rate of ventilation systems during the winter in order to avoid dry air (by switching the control to a low position) was highlighted (Schnieders & Hermelink, 2006). Furthermore, it was found that some user groups, for example those in social housing, might not be aware of whether a ventilation system is functioning or not, or whether a filter needs to be replaced. To enhance awareness regarding these issues Hübner and Hermelink (2003) recommended clear instructions be given on components and control panels. Additional assistance, for example by the landlord or building manager, as well as guidance and proper introduction to the systems were also suggested. In addition, system control and maintenance issues, for example demonstrating how to change the filters, should be addressed. One factor in a tenant's appreciation of extremely low heating costs might also be an easily understandable energy bill (Schnieders & Hermelink, 2006).

6.3.7 Influence of the time factor on satisfaction levels

Various studies have argued that the period of investigation plays an important role in POE research (Treberspurg *et al.*, 2009; Schnieders and Hermelink, 2006; Flade *et al.*, 2003; Hallmann, 2003; Hübner, 2001). For example, Hübner (2001) showed that residents tend to forget information provided when they moved into their new dwellings, which can lead to less satisfaction over time. However, the trend is also often positive. For example, Treberspurg *et al.* (2009) showed that the number of PH residents with high levels of appreciation for the dwelling increased from 84% to 94% in 1 year. It has been suggested that this might be related to the fact that it takes some time before inhabitants gain an overview of their energy costs and become aware of lower energy prices in PHs compared with their previous home (Schnieders and Hermelink, 2006). Some studies showed that originally sceptical users later related ventilation systems to comfort improvement (Schnieders and Hermelink, 2006). Various studies (Hallmann, 2003; Hübner, 2001) have shown that the time factor plays an important role with respect to the positive appreciation of aspects such as not having to open windows in winter in LEHs and PHs.

6.3.8 Conclusion

The studies generally confirm that the decision to choose a nearly zero-energy house is usually based on a combination of different criteria, such as reflection on architectural layout, economic costs or benefits, various environmental arguments, interest in PH technology, the site of the house and the influence of consultants (see also Danner, 2003). Energy efficiency and the branding of the dwellings as nearly zero energy – currently often regarded as essential to their promotion – are in themselves not enough to convince customers to choose this type of house.

General user satisfaction and comfort satisfaction is very much dependent on the properties of specific projects and positive or negative appreciation cannot be generalised. End users appreciate comfort in PHs mainly because of better winter thermal comfort and better indoor air quality. However, indoor climate systems need to be carefully planned and checked regarding heating provision, ventilation capacity, indoor air humidity control, noise protection and odour removal. Satisfaction is found to be lowered by deficiencies in heating and ventilation technologies, caused either by insufficient product quality, or poor design and/or poor construction of the climate system.

The controllability of the indoor climate is a relevant evaluation parameter in satisfaction research on nearly zero-energy houses. While the energy efficiency of PHs appears to be robust with regard to the influence of occupant behaviour, the design and provision of user-friendly heating and ventilation controls require specific attention. Especially for end users not involved in the design or building process, specific information provision, particularly regarding heating and ventilation, is considered crucial to facilitate the proper operation of systems and thereby achieve higher levels of user satisfaction and better energy performance. Furthermore, it is important to be aware that time changes experiences and influences satisfaction levels. The satisfaction of inhabitants can increase over time as end users become aware of the energy savings and grow familiar with the indoor climate systems. These results confirm the importance of information provision regarding building related energy savings and indoor climate systems in order to satisfy end users.

6.4 End-user experience research in the Netherlands

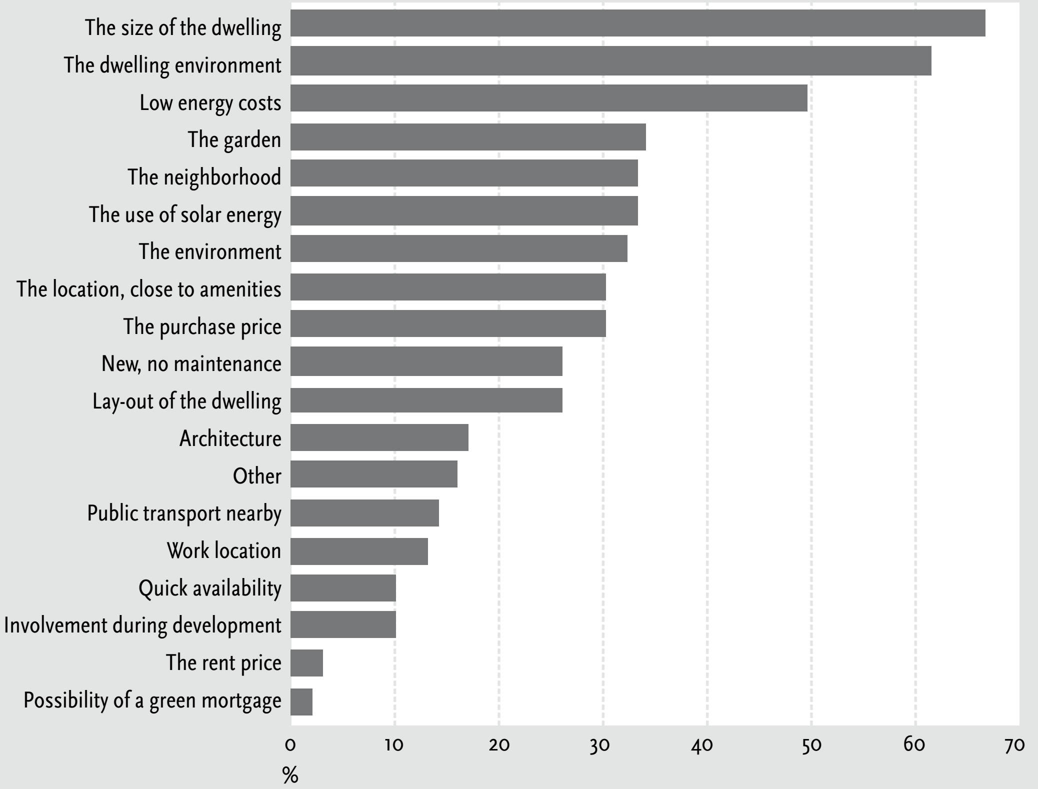
6.4.1 Advancing end-user experience research

The findings described above are generally based on satisfaction research on LEHs and PHs in Germany and Austria, and reveal the importance of design, execution, information and time as research parameters when investigating satisfaction with nearly zero-energy houses. A focus on evaluating experiences with indoor climate systems, particularly satisfaction with winter and summer thermal comfort, air quality, noise, controllability and information issues is required. To address these issues, a Dutch questionnaire was developed to undertake POE research on frontrunner projects in the Netherlands.

In June 2010, the questionnaire was sent to 441 known LEH, PH and ZEH households. The dwellings chosen had to have been occupied before June 2009 to guarantee that the users had experience living in their dwellings for at least one year. The questionnaire contained open-ended as well as multiple-choice questions addressing the following topics: sociodemographic characteristics, satisfaction with the house (13 questions); awareness and experiences regarding energy saving installations (6 questions); building services and energy (12 questions), indoor climate (58 questions), design issues (14 questions) and information issues (5 questions). Out of 441 questionnaires, 90 were completed and returned (a response rate of 21%), a good result for

3 See also Schütze *et al.* (2011) for an analysis of energy end-use data and more detailed information. A comparison with conventional houses was not included. It should be noted that the energy data were submitted by the end-user and were not affirmed by onsite inspections or energy measurements and that the projects chosen were initially provided with a marketing name by regional players. In this research the choice of the term PH was not directly related to the German definition or to the availability of a PH certificate. The categorisation of the buildings as LEH, PH and ZEH was based on the occupants' reported average end-user energy use: 10,050, 7,233 and 5,119 kWh/a, respectively. The non-parametric Kruskal-Wallis test showed that the end-user energy use differed between the three groups ($p < 0.01$). There were also differences between the groups with respect to average primary energy use, but this could not be tested statistically due to the small sample size. Note that in the ZEH category the primary energy balance of most households indicates that they use more energy than they produce, and are therefore in reality not 'zero energy' buildings.

Figure 6.1 Percentage of respondents who indicated that a particular aspect was an important factor in choosing their LEH, PH or ZEH (multiple answers possible)



paper-based questionnaires. The results concern 63 LEHs, 7 PHs and 20 ZEHs.[3] These projects were newly built single-family dwellings and varied in typology from single detached houses to terrace and town houses and apartment buildings.

6.4.2 Motives for choosing a house

Figure 6.1 shows the percentage of respondents who indicated that a particular aspect was an important factor in choosing their particular dwelling (multiple answers possible).

Figure 6.1 shows that the dwelling size and direct dwelling environment were the most important reasons for choosing the house. However, Figure 6.1 also shows low energy costs was the third most important reason. For about one-third of the respondents, the environment, the neighbourhood, a location close to amenities, the garden, the use of solar energy and/or the purchase price were important. When asked specifically, about half of the respondents stated that architectural design was important to them, but for most this was not one of the most important reasons for choosing the house.

6.4.3 General satisfaction according to end users

Almost all residents (87 of 90 responses, 97%) indicated that they were satisfied with their house (yes/no). Only one respondent was dissatisfied with the indoor temperature during winter and complained that the heating system was not able to provide sufficient heating for a comfortable indoor temperature on the upper floor of their building during winter. The respondents were also asked to provide an indication of the level of satisfaction with their dwelling on a scale of 1–10, where 1 was the lowest satisfaction level and 10 the highest. The overall satisfaction rate was 8.0 (std = 0.9, n = 90), which can be considered 'good'. In the Netherlands a rating of 6 is often perceived as 'sufficient'. Only two residents provided a score lower than 6, both giving a 4.

The study then examined whether the mean satisfaction score differed between energy types (PH, LEH and ZEH) using non-parametric tests (Siegel and Castellan Jr., 1988). The results revealed that the mean satisfaction level did vary between the three categories (nonparametric Kruskal-Wallis test; $p < 0.01$).[4] Further analyses using the non-parametric Mann-Whitney U-test showed that the mean satisfaction score of residents living in PHs (mean = 8.93, n = 7) was statistically significantly higher than the mean satisfaction score for LEHs (mean = 7.93, n = 63) and for ZEHs (mean = 7.80, n = 20). It should be noted, however, that despite the non-parametric tests, the number of respondents for the PH and ZEH groups was too low to provide reliable results.

6.4.4 Satisfaction with indoor climate

The results with regard to satisfaction with the indoor climate are summarised in Table 6.1. An analysis of additional results showed that the specific systems for ventilation, heating and hot water as well as the presence of PV generators did not statistically significantly influence the general satisfaction levels of the inhabitants.

Four respondents (4% of 89) were not satisfied with the indoor climate in the living room during winter. Eight respondents (9% of 88) were not satisfied with the indoor climate in the bedrooms during winter. For both findings there was no statistically significant difference between the three different types of dwellings ($p = 0.72$ and $p = 0.09$, respectively, Fisher's exact test [FET]).

Six respondents (7%) indicated that they were not satisfied with the climate in the living room during summer and 14 respondents (16%) were not satisfied with the climate in the bedroom during summer. Twenty-nine respond-

4 $p < 0.01$ means that the chance (p = probability) that the zero hypothesis of 'no difference' is unjustifiably rejected, is less than 1%.

Table 6.1 Frequencies of responses with regard to satisfaction with the indoor climate

Indoor climate	Very dissatisfied		Dissatisfied		Neutral		Satisfied		Very satisfied		Total	
Living room in winter	1	(1%)	3	(3%)	11	(12%)	48	(54%)	26	(29%)	89	(100%)
Living room in summer	-		6	(7%)	12	(13%)	47	(53%)	24	(27%)	89	(100%)
Bedrooms in winter	1	(1%)	7	(8%)	12	(13%)	51	(58%)	17	(19%)	89	(100%)
Bedrooms in summer	1	(1%)	13	(15%)	17	(19%)	47	(53%)	11	(12%)	89	(100%)

ents (34% of 86) experienced the summer indoor temperature in the living room as too hot (at least sometimes) and 49% (of 88 respondents) found the bedroom too hot in summer. There were no statistically significant differences between the three energy categories with regard to satisfaction with indoor climate in the living room ($p = 0.47$, FET) or bedrooms ($p = 0.22$, FET).

In this study the reason for the relatively high proportion of dissatisfied respondents with regard to the indoor climate in the bedrooms in summer can probably be attributed to architectural design aspects such as south orientation of the bedrooms and a lack of shading systems.[5] Also, in some cases it can be assumed that problems with ventilation systems, such as an improperly functioning bypass, led to high indoor temperatures.

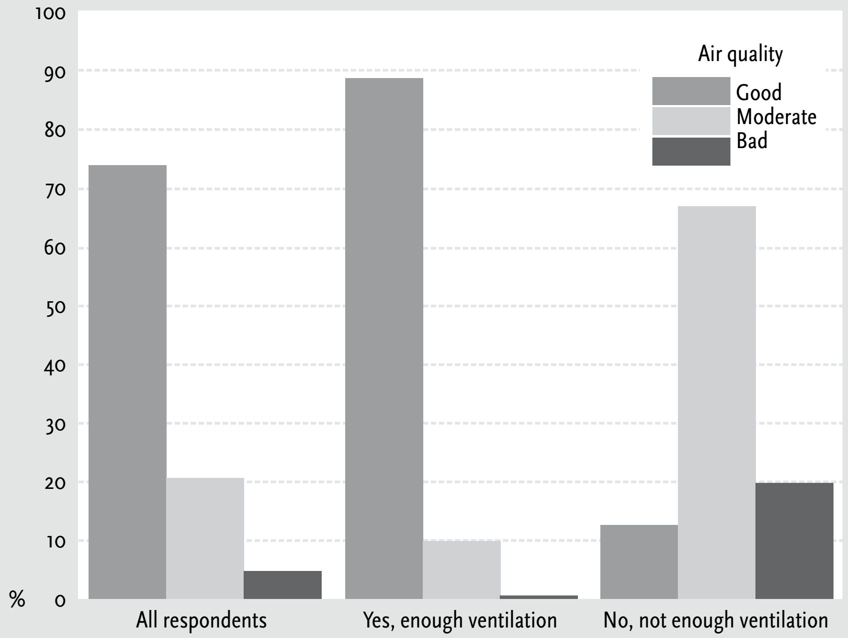
Of 88 respondents, 12 (14%) were not satisfied with their level of control of their heating system. There was no statistically significant difference between the three types of dwellings ($p = 0.18$, FET). Many respondents who were less satisfied with the temperature control in their dwelling were also less satisfied with the indoor climate during winter. This relationship was statistically significant, for both the living room and bedrooms ($p < 0.01$, FET). In addition, many respondents who were less satisfied with the temperature control in their dwelling were also less satisfied with the indoor climate during summer. This relationship was statistically significant for the living room ($p = 0.05$, FET) but not for the bedroom ($p = 0.08$, FET).

6.4.5 Satisfaction with ventilation systems

The results with regard to satisfaction with air quality and amount of ventilation are summarised in Figure 6.2. Of 86 respondents, 74% experienced the indoor air quality as good, 21% as average and 4% as bad. Of 88 residents, 81% regarded their dwelling as sufficiently ventilated and 17 (19%) reported that their dwelling was not ventilated well enough. These residents were also more frequently dissatisfied with the air quality in their dwelling ($p < 0.01$, FET). Most of the 71 residents who reported that their dwelling was ven-

5 The availability of external shading systems was investigated using various questions. 71% of 88 households had an external shading system, 14% had a structural horizontal shading element and 16% had no external shading system at all for the windows in their living rooms. 55% of 85 households had an external shading system, 9% had a structural horizontal shading element and 35% had no external shading system at all for their bedroom windows. Regarding the availability and the use of internal shading systems, 40% of 86 households had such a system in their living rooms and it was used in 83% of these cases. 48% of 85 households had an internal shading system in their bedrooms and used it in 90% of the case.

Figure 6.2 Frequencies of responses with regard to the evaluation of air quality and amount of ventilation



tilated well enough indicated that it had good air quality (89%). In contrast, of the seventeen respondents who reported that their ventilation was not good enough, only two (13%) reported good air quality.

The levels of smoking were not statistically significantly different between those who reported that their dwelling was well ventilated and those who did not ($p = 0.65$, FET; $n = 88$). Moreover, there was no statistically significant difference between LEHs, PHs and ZEHs regarding the perceived air quality ($p = 0.26$, FET) and the perceived amount of ventilation in the dwelling ($p = 0.21$, FET).

The vast majority of the respondents were satisfied with the levels of humidity in the living room (83% of 82 respondents) and in the bedroom (83% of 87 respondents) during winter, as shown in Table 6.2. A small percentage, 16% and 14% (for living room and bedrooms, respectively) experienced the air as too dry, and 1% and 2% (living room and bedrooms, respectively) as too humid. There were no statistically significant differences regarding the perception of the levels of humidity in the living room ($p = 1.00$, FET) or the bedroom ($p = 0.53$, FET) during winter between the three different types of dwellings.

The results for humidity levels during summer are quite similar. Only a small percentage (9% of 87) of respondents experienced the air as too dry in the living room, and only 6% of 87 respondents reported that the air was too dry in the bedroom, while 3% experienced the living room as too humid, and 6% found this to be the case in the bedroom. There were no statistically significant differences between the three categories regarding the perception of humidity in the living room ($p = 0.13$, FET) or the bedroom in summer ($p = 0.41$, FET).

Fifty-seven respondents (63%) indicated that they used a mechanical ventilation system with heat recovery for the ventilation of their living room and

Table 6.2 Frequencies of responses with regard to the evaluation of air humidity

Humidity	Too dry		Good		Too high		Invalid		Total	
Living room in winter	13	(16%)	68	(83%)	1	(1%)	-		82	(100%)
Living room in summer	8	(9%)	74	(85%)	3	(3%)	2	(2%)	87	(100%)
Bedrooms in winter	12	(14%)	72	(83%)	2	(2%)	1	(1%)	87	(100%)
Bedrooms in summer	5	(6%)	76	(87%)	5	(6%)	1	(1%)	87	(100%)

62% for the ventilation of the bedrooms. The presence of a mechanical ventilation system with heat recovery in the living room could not be related to satisfaction with the indoor climate in the living room in winter/summer, or air quality and humidity in the living room in summer. However, it could be related to perceived humidity in the living room in winter. Residents with a mechanical ventilation system with heat recovery in the living room indicated more often that it was too dry in the living room (too dry: n = 12 of 51, 23%) than residents without this type of ventilation (too dry: n = 1 of 31, 3%). The presence of a mechanical ventilation system with heat recovery in the bedrooms could not be related to satisfaction with indoor climate in the bedrooms – neither in winter nor in summer – or air quality and humidity in the living room in summer or winter.

6.4.6 Conclusion

The literature study showed that a promotion strategy emphasising concept branding or energy efficiency might not be very useful (see also Treberspurg *et al.*, 2009; Danner, 2003; Schnieders and Hermelink, 2006; Keul, 2011; Hallmann, 2003). The Dutch study shows that, if people are to choose to live in a nearly zero-energy house, the size and the environment of the dwelling are obviously important, but an emphasis on the energy costs of the dwelling can also attract interest. This study confirms that, like in other countries, the perceived comfort levels of residents of nearly zero-energy housing in the Netherlands are generally high, and an awareness of this might be an additional attraction for potential customers. However, perceived comfort levels are generally independent of energy category and further research is needed in order to confirm whether the level of appreciation of PHs is different, because the sample here was very small.

Like in other countries, this study shows that, while end users show high levels of acceptance and satisfaction with nearly zero-energy houses, the technical equipment (ventilation/heating) is sometimes criticised on the basis of perceived comfort deficiencies. The results highlight that more attention to the problems of overheating in summer and the provision of good air quality (particularly air humidity) and temperature control in winter is required. The high satisfaction levels of occupants could not be correlated with the presence of certain equipment and/or building services installations (ventilation, PV, heating, etc.). Apart from possible dry air in living rooms, the presence of a mechanical ventilation system with heat recovery could not be related to indoor climate satisfaction parameters. A limitation of the present study was that no control group of Dutch houses was available.

6.5 Discussion and recommendations

The goal of this study was to detect barriers to and opportunities for promoting nearly zero-energy dwellings on the basis of end-user experiences, by studying end-user satisfaction with nearly zero-energy houses. Developments in Germany and Austria (mainly the building of passive houses) are related to the European requirement for the market development of nearly zero-energy houses. POE research from these countries already provides lessons from the projects realised and the Dutch study contributes to this.

The study indicates that energy costs associated with a dwelling might be an important aspect, alongside other factors (for example, size, location, neighbourhood and purchase price), which encourage potential residents to choose a nearly zero-energy dwelling. However, the relevance of emphasising energy efficiency or concept branding is limited. End users living in highly energy-efficient houses are quite satisfied with their dwellings and indicate a high comfort level, findings which could be used as additional arguments in the promotion of such dwellings.

A barrier to the adoption of nearly zero-energy houses might be a perception of insufficient summer comfort and/or air quality, independent of energy category. Some respondents were less satisfied with comfort levels related to the indoor temperature during summer, particularly in the bedrooms, as well as the indoor air quality. Sometimes a less comfortable indoor climate can be directly linked to design deficiency (for example, lack of shading or ventilation bypass) or technical deficiencies in the heating and ventilation systems. This illustrates the importance of quality assurance regarding design and execution, alongside requiring the high energy performance of nearly zero-energy houses.

End users relate perceived comfort levels directly to heating and ventilation systems. Careful design and execution, including noise protection, sufficient air humidity control and odour removal strategies, are critical points for attention in relation to possible improvements in all housing categories. In addition, simplicity and the user-friendliness of control systems are of utmost importance. Detailed information provision – including, but not limited to, initial oral instructions and providing written manuals – is of critical importance and should not be neglected. For example, the perception of poor levels of control, dry air in winter, as well as noise or odour problems, can sometimes be eliminated by providing specialised information. In particular, in relation to first-time occupancy, the importance of the start-up phase for the operation of heating, ventilation and control systems can be critical for optimising performance, with feedback from occupants' effectively contributing to detecting and eliminating deficiencies. It is recommended that inhabitants be given additional information to that provided in the standard short introduction to the house, including, at the very least, operation manuals, but preferably also detailed instructions concerning the specific advanced housing concepts they will encounter in the dwelling.

POE research itself has the potential to become a valuable instrument for eliminating adoption and communication barriers. Questionnaires can detect the apparently small percentage of unsatisfied end users, who can then be assisted by eliminating deficiencies in quality and providing the necessary information. Particularly for end users who are not involved in the building process, for example in rental housing, it is recommended that user-oriented technical information and/or training by qualified persons be provided.

In conclusion, it is apparent that there is a specific need to provide quality assurance and improve information transfer to the end users of nearly zero-energy houses. Quality assurance should include the evaluation of comfort in relation to aspects such as indoor climate and thermal comfort during winter and summer, air quality and noise protection, as well as social parameters such as information transfer to and communication with end users. To maintain high levels of comfort and user satisfaction in future projects, the further development of quality assurance schemes for nearly zero-energy houses using POE research methods to detect deficiencies is recommended.

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7 Improving passive house certification: recommendations based on end-user experiences

In press as: Mlecnik, E., Improving passive house certification: recommendations based on end-user experiences, ***Architectural Engineering and Design Management****, 2012, doi:10.1080/17452007.2012.738044*
http://dx.doi.org/10.1080/17452007.2012.738044

Abstract
The house construction sector in Europe is facing the need to meet stricter energy requirements. For example, some customers are demanding passive houses with almost no demand for space heating. Passive house quality assurance systems have been introduced to certify the energy performance of such houses. The aim of this study was to identify opportunities for improving passive house certification in line with customer's comfort expectations.

Questionnaires, site visits and interviews were carried out to identify and assess the comfort concerns of owner-occupiers in certified single-family passive houses in Flanders, northern Belgium. The results show that certified passive houses in Flanders are well rated and perceived as very comfortable. However, there were some cases where comfort concerns were expressed related to perceived flaws in the design or construction of the building services. In particular, the study recommends incorporating criteria for the planning and installation of user-friendly ventilation systems into passive house certification and providing end-users with better information.

7.1 Introduction

The recast of the European Energy Performance of Buildings Directive (EPBD, 2010) demands that Europe's member states achieve nearly zero-energy housing by 2020. The European construction sector faces extensive challenges in fulfilling such stricter regulations regarding the energy performance of houses. One way to achieve the nearly zero-energy target is to build very energy-efficient houses, such as those meeting 'passive house' (PH) – alternatively also referred to as 'Passivhaus' – energy requirements. According to a popular European definition (Feist, 1992; PEP, 2008), PHs have to reach a target energy demand for heating of equal to or less than 15 kWh/m^{2}a. Typically, this includes excellent insulation and airtightness with thermal-bridge-free design, while indoor air quality is to be guaranteed by a mechanical ventilation system with heat recovery (PEP, 2008)[1]. Previous research illustrated some concerns of occupants in terms of noise from equipment, maintenance problems, summer comfort, air quality and lack of climate control (Hasselaar, 2006; Van Ginkel, 2007).

The term PH is often perceived as a house without traditional heating systems and without active cooling (PEP, 2008). Customer scepticism about the construction sector's ability to build houses 'without heating' has led to the emergence of different labels and certificates that aim to guarantee energy performance and building airtightness for customers (Mlecnik, Visscher and van Hal, 2010; PEP, 2008). Meanwhile, comfortable conditions during both winter and summer are expected from the definition (PEP, 2008), but these requirements are not always expressed in PH certification procedures (Mlecnik *et al.*, 2010).

PH certification relies mainly on the attainment of pre-determined energy performance in housing. Energy users tend to value these energy benefits, but they appreciate the non-energy benefits even more (Skumatz *et al.*, 2000; Skumatz and Stocklein, 2004). For example, in addition to energy savings, it is claimed that PHs (IEA SHC Task 28, 2006) provide better air quality, reduce the risk of asthma, lead to higher comfort levels and have a higher market value. Comfort and air quality in particular are aspects that could be better reflected in PH certification.

Firstly, customers might be more concerned about the thermal comfort of 'houses without heating' than about their energy performance (Mlecnik *et al.*, 2012). Secondly, customers might be unaccustomed to using mechanical ventilation systems and may be reluctant to live in an 'airtight' building because of concerns about the indoor air quality. It is thought that PH certification could be improved if it took thermal comfort and indoor air quality requirements on board (see for example Hasselaar, 2009; Mlecnik, 2009; Mlecnik, Van Loon, and Hasselaar, 2008; Mlecnik and Van Loon, 2010; Pfluger and Feist, 2010), since – like energy performance – guarantees of better comfort can be perceived as customer value. It therefore makes sense to examine how PH certification could include such comfort concerns, in order to improve its market potential as a service.

The construction of certified PHs has already begun across Europe, but for PH certification to fully capture user needs, it is necessary to create a more complete and holistic customer value system that relates directly to end-user's thermal comfort and indoor air quality concerns. Instead of just meeting energy goals, a guarantee of higher comfort can be an important customer value for PH certification services. In many cases, particularly in Belgium, the end-users in PHs are also the individual commissioners of single-family PHs and those who will pay for the PH certification (Mlecnik and Marrecau, 2008; Mlecnik and Van Loon, 2010). PH certification would therefore be better if it related more to the comfort concerns of the end-user.

1 The space heating can for example be achieved by using mechanical ventilation systems that heat the inlet fresh air to maximum 52°C without recirculation or ventilation volumes that exceed hygienic ventilation requirements. In theory, the installed heating power is therefore often less than approximately 10 W/m².

7.2 Research framework

7.2.1 Goal of the research

The aim of the study was to find out how PH certification for single-family owner-occupied PHs could be improved by learning from end-user experiences in certified PHs in Flanders, northern Belgium. Recommendations were sought for the improvement of future PH certification by determining end-user comfort concerns in existing PHs – particularly in relation to thermal comfort and indoor air quality. The research results can complement European research on the improvement of requirements for PHs (Passivhus.dk, 2010) and the development of guidelines for a new generation of PHs (AEE Intec, 2012). The research can also give input to the development of needed action plans for achieving high quality of building services in housing (Kroese *et al.*, 2009; Aedes *et al.*, 2012). Previous research in the neighbouring Netherlands (Kroese *et al.*, 2009) showed that an increasing number of problems occur regarding a low quality of ventilation and heating services in newly built housing, and that it is very desirable to introduce specific commissioning procedures for building services. Therefore, close attention was paid to the perception of the indoor climate systems of PHs and to the PH certification procedures as a testing ground for improved commissioning.

7.2.2 Structure of the research

To identify ways of improving PH certification, a comprehensive review of the end-user's comfort concerns of PHs was carried out. First, a literature study was set up to investigate the particularities of PH certification, specifically in Flanders (literature study). The subsequent study identified the critical issues that relate to comfort concerns in PHs from the post-occupancy research literature. Furthermore, an original research determined the end-user comfort concerns in Flemish-certified PHs. This research was conducted with specific attention to the perspective of single-family owner-occupied PHs in Flanders, but has wider implications for the development of recommendations regarding building services in newly built homes.

7.3 Passive house certification in Flanders

The Flemish PH certification procedure has been refined on several occasions on the basis of hands-on experience. The voluntary PH label (originally known as a 'passive house statement of quality') has been used in Belgium[2] since 2005 (Cobbaert, 2005). The label was introduced nationally by the Passiefhuis-Platform vzw (PHP). Consequently, grants were made available in Flanders in accordance with PH criteria that were introduced locally by grid managers and municipalities. The first PHs were 'certified' in 2005 by the PHP on the sole basis of a check on the calculations from a specific Passive House Planning Package (PHPP 2003 Benelux edition) and a verification of the airtightness values for the building (Cobbaert, 2005). Since 2008, further requirements, such as window thermal efficiency, space cooling demand requirements and the format in which the plans, reports and energy efficiency values have to be delivered, have been formalized more comprehensively in a specific compendium that uses a revised software (PHP, 2009).

A definition of PHs was also recognized in legislation on income tax relief at a national level in Belgium (BS, 2009)[3], while the application of this definition in legal documents led to its being used more consistently when issuing PH certificates. According to the Belgian definition (BS, 2009), PHs must lead to a total energy demand for space heating and cooling of equal to or less than 15 kWh/m^{2}a (per m^2 of conditioned floor surface). Secondly, during a pressurization test (according to the NBN EN 13829 norm) at a pressure difference of 50 Pascal between inside and outside, the air loss should not exceed 60% of the volume of the house per hour ($n_{50} \leq 0{,}6/h$). The limits on the energy demand value for space heating and cooling are based on the idea that it should be possible to avoid active cooling and meet the demand for heating by heating the inlet fresh air while tailoring air flows for ventilation only.

However, the income tax relief system for PHs was abandoned in 2012 due to the regionalization of policy responsibilities. For the moment, one can only speculate how changing cost-benefit aspects interfere with the market development of PH certification. It is expected that large developers and companies will still offer the PH certificate to their clients to confirm PH 'branding', and that less experienced architects and designers will still ask for an independent confirmation statement of the 'quality' of their first-time demonstration project and/or services.

The most important comfort-related PH certification requirements are listed in Table 7.1 (based on the compendium). PHP carried out research into the effects of climate conditions and the typical characteristics of buildings in Belgium and Germany in the Passive House Planning Package in 2003, and it was decided to use the same heating demand and airtightness requirements

2 When comparing the evolution of PHs in different countries, it is important to note that there are numerous differences in the interpretation of, for example, outdoor climate conditions, the building dimensions, building use, criteria for heat losses and the included (sources in the) total or primary-energy demand (Passivhus.dk, 2010).

3 The income tax relief over 10 years for a PH was €600 per year and the zero-energy house had to comply with the PH conditions. To obtain income tax relief, compliance with the PH definition had to be proven with a certificate issued by PHP or by Plate-forme Maison Passive asbl (PMP). More recently, the Flemish energy agencies has also issued certificates.

Table 7.1 PH certification requirements that can influence comfort set by PHP for new houses from 1 July 2009 (PHP, 2009)

Heating demand	The annual total net energy demand for space heating should be limited to 15 kWh/m² of conditioned floor surface
Airtightness	According to the NBN EN 13829 norm (under pressure and over pressure): $n_{50} \leq 0.6$/h
Cooling demand	Frequency of temperature above 25°C ≤ 5% (no active cooling required)
Energy demand	Calculated with Passive House Planning Package 2007 Benelux and its default parameters for certification, e.g. occupancy and regional climate

as used in Germany (Feist, 1992; PEP, 2008). Owing to criticism of occasional summer overheating in PHs, the cooling demand requirement has been strengthened: the allowed frequency of room temperatures above 25°C was reduced from 10% to 5% as of 1 July 2009.

This cooling demand requirement is specific to the PHP certification and is not included in the Belgian tax relief definition (BS, 2009), nor in the European PH definition (PEP, 2008). There are no certification requirements for the design and execution of technical installations in single-family houses in Flemish regulations. However, the passive house certification compendium (PHP, 2009) does 'strongly recommend' a ventilation distribution report and certain energy performance levels for ventilators and ventilation heat exchangers. This implies that it is very important to look at ventilation systems in passive house certification, but that it is not (yet) a regular practice to verify the quality of the planning and installation of such systems.

7.4 Post-occupancy evaluation research on passive houses

7.4.1 Detected critical issues related to comfort concerns

Post-occupancy evaluation (POE) (Preiser, Rabinowitz and White, 1988; Preiser and Vischer, 2005) attracted strong interest as a potential assessment tool for building performance, particularly in relation to the investigation of PHs (Biermayr *et al.*, 2002; Keul, 2010). Various POE researchers have addressed the issue of end-user appreciation/experiences of PHs, approaching it from a social, innovation or environmental psychology perspective.

A comprehensive literature study was provided in a previous study by Mlecnik *et al.* (2012).[4] It is not the intention of this article to repeat all the results of these references but it can be noted that POE researchers generally report a high positive appreciation of (the indoor comfort of) PHs. In some cases,

4 Most of these investigations focused on multi-family dwellings or larger developments in social housing, for example. In only a few studies were owner-occupied single-family houses evaluated besides individual cases, and usually the results were mixed with the results from multi-family dwellings. For example, ILS NRW (Berndgen-Kaiser, 2007; Berndgen-Kaiser *et al.*, 2007) did a POE of 176 PH projects in North-Rhine Westphalia to follow up PHs that had received a regional grant during the previous 5 years.

end-users expressed concerns about summer comfort (Berndgen-Kaiser, Fox-Kämper and Holtmann, 2007; Hallmann, 2003; Wagner and Mauthner, 2008a, 2008b). Some researchers related (possible) deficiencies in heating and ventilation to perceived poor quality or installation (Berndgen-Kaiser *et al.*, 2007; Danner, 2003; Hermelink, 2003; Keul, 2010).

Ventilation and heating systems were identified as critical points of attention, for example, because of the limited user friendliness or because of perceived comfort problems such as the air being too dry in winter and/or the system generating too much noise. End-user concerns like user-friendly control elements (Hermelink, 2003; Treberspurg *et al.*, 2009) and the need for better user information (Gräppi, Künzli and Meyer, 2003; Hübner and Hermelink, 2003; Keul, 2010; Schnieders and Hermelink, 2006; Treberspurg *et al.*, 2009; Wagner *et al.*, 2010) occur time and again. Additionally, first-time occupants do not always express the need for more detailed information on PHs, although researchers noted that dedicated information on PHs – the concept, the heat recovery and how to behave in normal and exceptional circumstances would be helpful.

POEs of specific comfort issues in some individual houses were performed in Flanders (see for example de Bruyn, 2008; Eykens, 2007; Hens, 2004; Mlecnik, 2008; Mlecnik *et al.*, 2008; Taelman, 2007; Willems, 2004), but no integrated effort has yet been undertaken to evaluate end-users' experiences of certified PHs. The next section contributes to this research body through POE research (results from questionnaires and walkthroughs) for Flemish certified single-family PHs, in order to understand the potential for improvements in Flemish PH certification.

7.4.2 Research approach in Flanders

On the basis of the findings of previous researchers and the requirements for PH certification, a questionnaire-based study was carried out among owner-occupiers of PHs in Flanders. The questionnaire was sent to all known listed owner-occupiers of certified PHs in Flanders (2010). This list was received from PHP. It was sent out in 2009 and again in 2010. The responses were only taken into account if the PHs had been inhabited for at least one season (winter/summer). The questionnaire was designed in such a way that it was possible to detect end-user comfort concerns, particularly by looking at end-user indications for improving the quality, comfort and health-related aspects. The questionnaire contained both open and closed questions and addressed different issues so that data could be compiled about the perceived comfort, which included the general appreciation and perceived performance of the heating, ventilation and passive cooling systems. Different groups of questions referred specifically to the perceived quality of the construction (11 items), building services (10 items), indoor temperature (35 items), air humidity (18 items) and ventilation and air quality (71 items). Additionally, the respondents were asked to compare the health-related conditions with their previous dwelling (11 items). Since it might be useful for future researchers, designers and architects, a selected number of key questions for detecting end-user comfort and quality concerns are described in the Addendum of this chapter.

The questionnaire was sent to the owner-occupiers of 51 different single-family houses in Belgium, built between 2002 and 2010. The research sample therefore included PHs that fulfilled the new cooling demand requirements (see Table 7.1) as well as PHs that showed only basic compliance (space heating demand and building airtightness). Fully completed questionnaires were received from 24 respondents, 16 of whom were from owner-occupied, certified, single-family Flemish PHs. This represented a response rate of 47% and 33%, respectively, which was good for printed questionnaires. It can be remarked that the total number of respondents is too low to draw general conclusions. However, the aim of the questionnaire was not to gather statistics on the relationships between PHs and certain socio-demographic or energy use characteristics, nor to conduct a cross-analysis or correlate results with certain aspects of occupant behaviour that influenced energy use, cost-efficiency or general quality issues. It focused solely on how owner-occupiers perceived comfort in their passive houses in order to assess concerns expressed in the literature and to identify those cases with possible comfort problems. To gain a clearer understanding of possible deficiencies, detailed on-site interviews and walk-throughs were performed in those cases that expressed lower appreciation for certain comfort aspects. Visiting these cases allowed the author to gain insight into factors that could improve PH certification in the Flemish housing market.

7.5 Research results

7.5.1 Results of the questionnaire: detecting important end-user concerns

Of the 16 owner-occupier survey respondents, all PHs were occupied by at least two adults, with the number of children or extra adults ranging from zero to three. The respondents reported a medium (10 of 16) to medium-high income (6 of 16). All 16 projects with a PH certificate (built between 2002 and 2010) met the requirements that are obligatory for PH certification. The ventilation systems were similar in most projects (see Table 7.2)[5], but the respondents reported different heating strategies, and not necessarily only air heating. Central post-heating of the ventilation air appeared to be a popular option (eight respondents), although some also reported (extra) room-based

Table 7.2 Presence of building services in Flemish certified PHs according to questionnaire results

Installed building services	Number of affirmations/ total number of respondents/ number of respondents with no answer	Percentage of respondents affirming presence (excluding respondents providing no answer)
Ventilation system with heat recovery	6/16/0	100%
Dust filter in the central ventilation system	16/16/0	100%
Course filter outdoor before the ventilation system	15/16/0	94%
Earth-air heat exchanger before the mechanical ventilation	14/15/1	93%
Solar shading	14/15/1	93%
Ventilation air heating (centralized or room-based)	12/13/3	92%
Solar panels (thermal)	8/15/1	53%
Photovoltaic panels (electrical)	7/14/2	43%
Control system/domotics	5/14/2	36%
Pellet oven	3/14/2	21%
Centralized air cooling (active)	1/16/0	6%

post-heating. Three respondents reported the room-based post-heating of ventilation air, two noted in open remarks the presence of extra heating in the living room and two noted extra heating in the bathroom. Some owner-occupiers preferred pellet ovens in the living room (three respondents). It emerged later from interviews that a preference for a central 'fireplace' and for renewable energy systems[6] sometimes influenced the end-user's choice of space heating systems. The results of the questionnaire also revealed different user behaviour among the respondents regarding space heating in winter. Out of all the 16 respondents, 54% stated that they heated the living space during the whole winter period, 21% heated it for a maximum of three months, 11% heated it according to the outdoor temperature and 14% heated it only on cold days.

Out of all the 16 respondents, 5 indicated that they were 'pleased' (P), and 11 stated they were 'very pleased' (VP) with 'living in their house'. These results are similar to other research findings on end-user appreciation of PHs (see for example Berndgen-Kaiser *et al.*, 2007; Keul, 2010; Treberspurg *et al.*, 2009). All the respondents were pleased or very pleased with the cost of heating and hot water (VP: 9/16; P: 7/16). The majority were pleased or very pleased with the electricity costs (VP: 8/16; P: 6/16; not so P: 2/16) and with

5 The entrance of fresh air usually occurred in the living room (13 of 13 respondents), bedroom (12 of 12), hobby room/playroom (8 of 9 cases), workroom (7 of 7) and hall (2 of 2), while extraction was usually noted in the kitchen (11 of 13), bathroom (12 of 12), washroom (7 of 7) and toilet (11 of 11). According to the interviewees' comments, the earth–air exchanger was perceived as useful for avoiding electric frost protection of the air-to-air heat exchanger and/or for providing passive cooling in summer.

6 Furthermore, 8 of 15 respondents had installed thermal solar panels and 7 of 14 reported the presence of photovoltaic collectors (see Table 7.2). During PH visits, some interviewees presented integrated units that combined ventilation, heat recovery from ventilation air, hot water production and solar thermal collectors in compact (heat pump) units.

energy use (VP: 8/16; P: 6/16; not so P: 1/16; no answer: 1/16). Most of the occupants were also pleased or very pleased with the quality of the building envelope[7] and the building services[8].

Most respondents experienced the mean room temperature as 'pleasant' for different types of rooms during the heating period. Whereas the winter indoor temperature was generally considered 'pleasant', the summer indoor temperature had a tendency to be regarded as 'warm', particularly in living rooms and kitchens. When presented with the statement 'I find the temperature in summer too high', half of the respondents ticked 'usually not', while the other half ticked 'usually yes' or 'sometimes' (2 and 6 respondents of 16, respectively). The mean indoor temperature in winter indicated by respondents from 15 PHs – one respondent provided no data – was 20.0°C. User-recorded maximum temperatures in winter ranged from 20°C to 23.9°C; minimum temperatures ranged from 17°C to 20.3°C. Set points for the space heating system reported by the respondents in predefined ranges varied from '18.4ºC or lower' to '22.5°C or higher'. The mean indoor temperature in summer indicated by 14 respondents was 23.1°C. Recorded maximum temperatures in summer varied from 25°C to 30°C; recorded minimum temperatures from 18°C to 24°C.

The end-users were generally pleased with the air humidity in their PH although there were some cases in which the air was perceived as 'dry' or, in one case, as 'too dry'. According to the respondents – a total of 10, 8 of whom indicated 'measured' and 2 'estimated' – the mean air humidity in winter was between 37.5% and 75%. In comparison, in summer the mean air humidity levels were between 45% and 70%.

Such results are similar and comparable to results from previous POE research on PHs (Mlecnik *et al.*, 2012). However, some end-users were 'not very pleased' or 'not pleased' with the space heating (4 and 1 out of 15 respondents, respectively) and some were 'not very pleased' or 'not pleased' with the

7 When asked 'How satisfied are you with the quality of the building envelope?' most respondents said they were (very) pleased with the quality of the roof, walls, floors, finishing materials, thermal insulation, airtightness, windows, doors, gates, grids and special details. The highest ratings were for thermal insulation and airtightness: 75% of 16 respondents were 'very pleased' with this specific aspect. All 16 respondents were particularly (very) pleased with airtightness and finishing materials. In some cases, owner-occupiers said they were 'not very pleased' with certain aspects: in two cases with the roof, in one case with the walls, in one case with the floors, in one case with the thermal insulation, in one case with the windows, and in two cases with the doors. One respondent was not satisfied with the room acoustics.

8 Responding to the question 'How satisfied are you with the quality of the installations?' all respondents said they were particularly (very) pleased with the hot water systems (VP: 6/16; P: 10/16), the solar shading (VP: 9/14; P: 5/14), the occasional renewable energy systems (solar panels thermal: VP: 4/8; P: 4/8; solar panels electric: VP: 4/7; P: 3/7) and the occasional pellet oven (VP: 2/3; P: 1/3).

indoor comfort conditions[9]. Also remarkable was that only 4 of 14 respondents had received a report stating that the air flows had been adjusted (others: nine 'no', one 'don't know'). Three out of 16 respondents stated that the craftsmen did not adjust the ventilation hoods in each room. Only six said that they had a maintenance manual for the ventilation system (others: eight 'no', one 'don't know'). On the other hand, all the respondents were aware of the need to change or clean ventilation filters regularly. Out of 16 respondents, several expressed concerns about air quality: three respondents were 'less satisfied' with the heat from the ventilation air, four respondents had concerns about the humidity of the ventilation air (two 'less satisfied' and two 'not satisfied'), five respondents were 'less satisfied' with the coolness of the ventilation air in summer.

Related to these results, some individual cases with comfort concerns were selected for more detailed study based on the following specific questionnaire results:

- In response to the statement 'I have the feeling that some rooms do not get enough fresh air', one respondent noted 'sometimes' while the others (14) noted 'usually not'.
- In one PH the living room and the kitchen were appreciated as 'too cold'. In another the living room temperature in summer was 'too warm'.
- All respondents except one said that they did not use additional appliances to cool the indoor air. The respondent who had installed air-conditioning also filled in 'too warm' for the summer indoor temperature in the living room.
- Noise was perceived as disturbing, particularly in bedrooms (two respondents 'less pleased' and one 'not pleased'), from the central ventilation unit (two respondents 'not pleased') and from the fan extractor in the kitchen (four respondents 'less pleased).
- Two respondents found the 'ventilation system still not performing well'.
- In answer to 'I often shut down the ventilation system', two respondents confirmed for winter conditions.

The open remarks from the questionnaire provided some further guidance since end-users attributed the perceived shortcomings to design or installation issues. For example, one respondent reported excessive energy use and noise and heat from a converter. One respondent remarked that the ventilation was badly designed with insufficient tubes in the living space and diameters that were too small.

9 Most respondents were (very) pleased with the temperature in winter (VP: 7/16; P: 6/16) and in summer (VP: 5/15; P: 9/15), and with the air quality in winter (VP: 9/16; P: 6/16) and in summer (VP: 9/15; P: 6/15). Three respondents ticked 'not so pleased' for temperature in winter, one ticked 'not so pleased' for temperature in summer, and one ticked 'not pleased' for air quality in winter.

7.5.2 Results from the site visits in two cases (interviews and measurements)

In addition to the questionnaires, walkthroughs and interviews, several Flemish single-family owner-occupied passive houses were examined in detail, using POE methods, including measuring indoor temperature in winter and summer, measuring air humidity, controlling air flow rates, checking for the presence of volatile organic compounds in bedrooms, measuring tap water flow and verifying installations for heating, ventilation and hot water in detail. This article only presents summarized results for two cases to illustrate shortcomings to design or installation.

Case 1

Complaints were noted in the questionnaire about poor heating, noise and dry air. The occupants also indicated that they were unaware of how to control the central system and how to use the set points. Measurements were taken in all rooms during two weeks in June 2010. Temperature and humidity measurements did not show very significant deviations from usual mean values for PHs. However, CO_2 levels in the children's bedroom were relatively high. During occupancy intervals, the measured CO_2 concentration systematically tended to be above 1,200 ppm indoors, with a recorded maximum of 2,218 ppm during the whole measurement period. For avoiding (the perception of) poor indoor air quality and health complaints one would have to limit the CO_2 concentration indoors to maximum 800-1,200 ppm (Dusseldorp *et al.*, 2004).

The interview confirmed that the occupants regularly shut down the whole ventilation system. This was due to the fact that the owners had difficulty sleeping because of the noise, according to the occupiers, produced by the heat pump. A temperature decrease was then experienced in bedrooms due to the fact that the owners thought that if they shut down the system, they should open the window in their bedroom. Unfortunately, their child was afraid of keeping the window open at night. The design of the air system appeared to be a crucial aspect of noise production. The noise was mainly generated by a current converter that was needed to make the heat pump work. In this case, the noise could have been avoided by choosing another heat pump that would not need a converter. Not only did the unit produce more noise than usual, the heat exchanger and fan unit were also positioned in the dwelling in such a way that they transferred noise. The master bedroom was located next to an upper storage room, and there was no acoustical insulation or airtight finishing between the upper storage room and the lower technical room.

Case 2

In the questionnaire, the occupant reported less satisfaction with energy saving and electricity costs and no satisfaction with heating and ventilation, despite the windows and doors never being opened unnecessarily in winter. During the interview the occupant complained that in the beginning the sleeping rooms on the first floor were too warm, while the living space on the ground floor was too cold. Another complaint was that the air was too dry in the living space in the winter and there was too much noise (from the heat pump) in the master bedroom. Measurements did not provide a significant correlation since the owner had already changed the system and solved this problem.

Originally the owner of the building had selected a compact unit with an integrated heat pump and central air heating. Owing to the ventilation requirements in the official energy performance regulation, the first floor needed higher supply air flow rates than the ground floor, as it included three bedrooms and an office (the ground floor was one large living space). This meant that most of the heat was originally distributed to the first floor. The result was a warmer first floor. The temperature difference was amplified by a large (mainly north-facing) window surface at ground level, with a smaller window surface area on the first floor.

The interviewee mentioned that the house was originally provided by the installer with a compact heating unit for heating and hot water production (air/air heat pump). According to the interviewee, the heating system was under-sized to 1,700W instead of the required 3,000W, and no integrated extra air heating was provided. The noise from the compact system was originally too high according to the inhabitant, especially in the master bedroom. Furthermore, the air ducts were too small in some cases due to flaws in the design. Insufficient heating resulted in extra heating elements being placed in the living room.

To resolve these problems the owner decided to use his own technical expertise to install two additional valves actuated by an automatically controlled servo-motor which allowed heat and air flow to be distributed in different proportions. The interviewee also chose to disable the heat pump during the night to stop the noise in the master bedroom. This new strategy resolved some of the problems, but could not address the inadequate heating capacity. An extra electrical heating element is now used as a back-up in cold periods. As a result, the mean temperature is now 20°C on the ground floor and 18°C in the bedrooms and this feels 'perfectly comfortable' according to the interviewee.

7.6 Opportunities for improving end-user satisfaction via passive house certification

7.6.1 Using POE questionnaires to detect and address low appreciation

According to the literature, end-users often detect potential deficiencies in heating and ventilation technologies arising from perceived poor planning or execution (Berndgen-Kaiser *et al.*, 2007; Keul, 2009). This was confirmed by the research findings for the owner-occupied single-family passive houses in Flanders. The answers of respondents who had reported perceived flaws in design or installation could be linked with specific statements regarding comfort concerns. It was possible to detect the origins of some of the problems by conducting some additional interviews. For example, in one case low satisfaction levels turned out to be related to excessive energy use, and noise and heat production, which appeared to be due to a technical component (converter). In another case, low ratings for indoor air quality and noise were related to the regular disabling of the (poorly selected) integrated heat pump/ ventilation unit to avoid noise in the master bedroom.

Treberspurg *et al.* (2009) show that when problems are detected early by end-users, potential technical deficiencies can be addressed more easily. In the present research, the end-user ratings helped to pinpoint some of the causes of deficiencies. Furthermore, it emerged in at least one case that certain technical deficiencies were indeed corrected when the relevant parties were confronted with the deficiency reports of the end-users. This result suggests that questionnaires and interviews about end-user appreciation could play an important role in enhancing quality through the detection and correction of technical deficiencies.

7.6.2 Integrate additional passive house certification requirements

This study confirmed that end-users generally appreciate the winter and summer indoor comfort and air quality in PHs – and this could be integrated more effectively in PH certification (in direct relation to comfort). However, important user concerns were detected that could improve PH certification. The following additional requirements were identified that could possibly improve PH certification and lead to greater end-user appreciation.

Limit the total energy demand for space heating to ≤ 15 kWh/m^{2}a (per m^2 of conditioned floor surface), avoid active space cooling (for housing in moderate and cold climates) and limit the frequency of temperature above 25°C to ≤ 5% – Since the summer indoor temperature tended to be regarded as 'warm', summer comfort conditions emerged as a possible area for improvement in some PHs.

These findings confirm the results of earlier research (Berndgen-Kaiser *et al.*, 2007; Hallmann, 2003; Wagner and Mauthner, 2008a, 2008b). Comparing findings with PH certification files showed that the cases with low ratings for summer indoor temperatures did not comply with the new, revised cooling demand requirements, while cases with positive ratings for indoor temperatures in summer did. Also, in one case air-conditioning was installed. This project did not comply with the new summer cooling demand requirement. These findings confirm the need for strict requirements on space cooling demand.

Limiting noise from building services – The noise from ventilation systems is a recurring issue that affects user appreciation (see Case 1 and Mlecnik *et al.*, 2012). Gräppi *et al.* (2003) found that tolerance of the noise from ventilation systems is lower during the night than during the day. This can influence the perception of noise particularly in the bedrooms. For example, Passivhaus Institut Darmstadt recommends that the sound pressure level L_p for building service units should be equal to or below 35 dB(A) based on a 4 m^2 equivalent absorption area or that the units are placed in a separate sound-insulated room for building services. Particularly, this research identified two cases of a poor design choice for integrated heat pump units. In these cases, the owner-occupiers shut down the ventilation system to stop the noise in the bedrooms. This confirms the need for a noise limit in order to ensure good indoor air quality in PHs.

Requirements for ventilation systems – The fact that some respondents mentioned ‘dry air’ confirms the scope for improvement in the ventilation system in this regard. It should be noted that the problem of relatively low humidity – as detected in some questionnaire results – can sometimes be addressed by reducing relatively high ventilation rates (Hübner and Hermelink, 2003; Schnieders and Hermelink, 2006). The need for a low-ventilation setting in order to avoid dry air could be explained better. This study found that users who commented that the air was dry had also installed (or intended to install) mobile humidifiers, particularly in the bedrooms. Again, this impacts on energy performance.

The study generally confirmed the findings of other studies that PH occupants should be provided with better and more specific information (Hübner, 2001; Hübner and Hermelink, 2003; Schnieders and Hermelink, 2006; Treberspurg *et al.*, 2009; Wagner *et al.*, 2010). It also showed that the information supplied to owner-occupiers of Flemish PHs is rather poor, particularly on the presence of an operation manual of the mechanical ventilation system. Previous research (Wagner *et al.*, 2010) has already highlighted the need for specific expert information for occupants in addition to manuals about the ventilation system. The study confirms that several owner-occupiers appeared to be unaware of the required air flow rates per room. The results of the questionnaire showed that not adjusting the ventilation flow rate is an important point of concern. Indoor air humidity can also be influenced by the size of the air exchange rate and the ventilation system design (Pfluger and Feist, 2010). Case 2 confirmed that relevant contractor experience regarding ventilation sizing cannot always be expected. It can be noted that the detected shortcomings of ventilation installations are not only specific to the single-family PH typology surveyed but can also be found in other housing typologies as well. See for example Kroese *et al*. (2009) for a report on experiences with mechanical ventilation in various types of existing housing, or Keul (2009) for experiences with the multi-family passive house typology. For example, requiring a frequency of indoor CO_2 concentrations above 1,200 ppm ≤ 5% could be a way forward to avoid complaints in certified PHs.

7.7 Conclusion and recommendations

The aim of this study was to find out how PH certification for single-family, owner-occupied PHs can be improved by learning from end-user experiences in certified PHs in Flanders. In keeping with findings by other authors, high levels of satisfaction were found for the energy performance and indoor comfort in Flemish PHs. However, the current obligatory requirements for PH certification did not always lead to end-user appreciation of indoor comfort. Particularly, some households were less satisfied with indoor temperatures, indoor air humidity levels and/or noise levels. The results showed that end-user appreciation of summer comfort could indeed be improved by a cooling demand requirement. In some cases, there is also scope for improving the design and installation of indoor climate systems. Another very important course of action is improving user-friendliness and information on building services, particularly mechanical ventilation systems.

The following recommendations for the further development of PH certification could improve end-user satisfaction:

- maintain an obligatory 'passive' cooling demand requirement for PH certification;
- integrate quality control in the planning and installation of heating and ventilation systems;
- introduce additional requirements for indoor air quality: obligatory airflow rate reports (now only 'strongly recommended') and regular inspection of mechanical ventilation services while checking indoor CO_2 concentration;
- require limitations on noise levels from building services;
- provide dedicated end-user information – more than just user manuals, also demonstrations by PH professionals – about the operation and maintenance of ventilation systems;
- make end-user satisfaction research a part of the quality assurance scheme

since it enables the detection and correction of deficiencies, thus creating a loop of confidence;
- use comfort appreciation more effectively as a marketing opportunity.

These recommendations should be considered for implementation by PH certifying institutes all over Europe. Furthermore, the recommendations should be discussed in the development of widely supported plans that aim to improve the general quality of building services in housing, preferably by involving multiple stakeholders. For example, a Dutch initiative (Aedes *et al*., 2012) shows a pathway how multiple stakeholders can be engaged in the development of an action plan for general quality improvement of ventilation services in housing. Such plan should indicate on which pieces of regulations recommendations can be introduced and what building codes require updating.

In various countries, PH is still an emerging concept and there is still much to be learnt – particularly with regard to summertime overheating, perceived level of control and occupant apprehensions towards living in an 'air-tight' mechanically ventilated dwelling. On the other hand, also factual data about the quality of building services in recently built dwellings are limited (Kroese *et al*., 2009). Although previous European studies (see Mlecnik *et al*., 2012) have investigated end-user experiences in PH demonstration projects using questionnaire-based surveys, more attention is needed for the evaluation of the quality and user-friendliness of building services, and the follow-up of requirements, particularly for space heating, cooling and ventilation. Particularly in countries with an emerging PH market, end-user experience surveys on demonstration projects can detect ways of improving future projects and requirements. Since the PH market is rapidly developing now, future research can now extend the number of sampled PHs surveyed and compare results when integrating results from PHs from other regions in Belgium and Europe. The Addendum attached shows key issues that should be studied in such surveys.

Acknowledgements

The author thanks the survey respondents for their support and time, as well as colleagues involved in setting up the questionnaire. The author also thanks the two anonymous reviewers for their various detailed remarks and suggestions for improvement.

Addendum: Key questions for detecting building service related comfort/quality concerns in passive houses

How pleased are you about the following aspects of your house?					
	very pleased	**pleased**	**less pleased**	**not pleased**	**not applicable**
cost for heating and hot water					
your energy use					
temperature in winter					
temperature in summer					
air quality in winter					
air quality in summer					
room acoustics					

How pleased are you about the quality of the building services?					
	very pleased	**pleased**	**less pleased**	**not pleased**	**not applicable**
ventilation					
space heating					
space cooling					
hot water production					
solar panels (thermal)					
photovoltaic panels (electrical)					
solar shading					
ground-air heat exchanger					
pellet oven					
control systems					

How do you experience the average room temperature?					
	too warm	**warm**	**pleasant**	**a bit cold**	**too cold**
during the heating period					
during the summer period					
in the living room					
in the sleeping room					
in the bathroom					
in the kitchen					
in hobby or play rooms					

How do you experience the air humidity during the heating period?					
	too dry	**dry**	**pleasant**	**a bit moist**	**moist**
in the living room					
in the sleeping room					
in the bathroom					
in the kitchen					
in hobby or play rooms					

Do you use additional mobile devices to adjust the room temperature (post-heating)/to control the room humidity?			
	yes	**no**	**I don't know**
in the living room			
in the sleeping room			
in the bathroom			
in the kitchen			
in hobby or play rooms			

Did you install additional building services after first-time occupancy?			
	air conditioning	**space heating**	**mechanical ventilation**
in the living room	Yes/no/I don't know	Yes/no/I don't know	Yes/no/I don't know
in the sleeping room	Yes/no/I don't know	Yes/no/I don't know	Yes/no/I don't know
in the bathroom	Yes/no/I don't know	Yes/no/I don't know	Yes/no/I don't know
in the kitchen	Yes/no/I don't know	Yes/no/I don't know	Yes/no/I don't know
in hobby or play rooms	Yes/no/I don't know	Yes/no/I don't know	Yes/no/I don't know

How do you experience the operation of the ventilation system?			
	yes	**no**	**I don't know**
no problems since operation			
operating well after adjustment			
OK after habituation			
not performing well			

Did the installer adjust the air volumes per room?	
Yes	
No	
I don't know	

Do you have the following documents?			
	yes	**no**	**I don't know**
manual ventilation devices			
plan ventilation system			
maintenance guide ventilation			
room air flow report			

How pleased are you about the ventilation/ sound of ventilation?					
	very pleased	**pleased**	**less pleased**	**not pleased**	**not applicable**
in the living room					
in the bathroom					
In the sleeping room					
in the kitchen					
in hobby or play rooms					

How pleased are you about...?					
	very pleased	**pleased**	**less pleased**	**not pleased**	**not applicable**
odours in living spaces					
the sound of the mechanical ventilation unit					
the heat of the indoor air in winter					
the heat of the indoor air in summer					
the humidity of the indoor air in winter					
the humidity of the indoor air in summer					
the control of the ventilation system					
the maintenance of the ventilation system					

Do you often shut down the mechanical ventilation unit?			
	yes	**no**	**I don't know**
In summer			
In winter			

Do you often open windows in the bedroom during sleeping?			
	yes	**no**	**I don't know**
In summer			
In winter			

Do you have other remarks about the heating/cooling/ventilation in your house?

How often did you experience in your previous home...					
	always	**very often**	**often**	**sometimes**	**never**
colds					
airborne infections					
allergies					
headaches					

How often do you experience in your new home...					
	always	**very often**	**often**	**sometimes**	**never**
colds					
airborne infections					
allergies					
headaches					

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8 Adoption of highly energy-efficient renovation concepts[1]

Previously published as: Mlecnik, E., 2010, Adoption of highly energy-efficient renovation concepts, ***Open house international 35*** *(2), pp. 39-48.*
http://www.openhouse-int.com/abdisplay.php?xvolno=35_2_5

Abstract
More significant reductions in residential primary energy use and in space heating in particular, can contribute to achieving climate change and energy efficiency objectives. Project information from demonstration projects is now becoming available for highly energy-efficient renovation concepts. The goal of this research is to understand how owner-occupants can be persuaded to apply far-reaching energy-efficient renovations of single-family houses. To this end, the research examines drivers and barriers of owners to adopt highly energy-efficient renovation concepts. Theory on decision processes in innovation diffusion is used, in order to examine the adoption of integrated concepts to achieve high energy performance. Belgian case studies (different building typologies) were examined. Adoption drivers and barriers perceived by owner-occupants are analysed. This leads to improved understanding of characteristics that can persuade future adopters. Possible measures are discussed to overcome barriers in the introduction phase of innovation diffusion, and are illustrated more in detail with a case study. The research shows that especially expectations of improved comfort provide an opportunity for the market entry of integrated concepts. Owners, architects and contractors could benefit from increased attractiveness, competitiveness, affordability and availability of highly energy-efficient renovations. Holistic approaches (stronger coordination and clustered renovation concepts), higher skill competence (education) and improved communication (actor networks, significant economic incentives) are recommended.

8.1 Introduction

8.1.1 Highly energy-efficient renovation

Promoting energy efficiency in the existing building stock is essential to

1 This chapter does not provide a full review of all the relevant studies related to highly energy-efficient housing renovation that were coordinated and conducted by the author. For more information about challenges and opportunities related to low energy housing renovation – full research reports, scientific papers, illustrated project files including design details, movies about user motivations, and so on – the reader is kindly referred to the web site of the project 'Low Energy Housing Retrofit – LEHR', http://www.lehr.be. This research project was coordinated by the author. This specific paper was chosen for inclusion in the present study to illustrate how user motivation can be studied in the framework of innovation theory.

achieve the goals of the United Nations Framework Convention on Climate Change and its Protocols, for example Kyoto. Reducing energy use in buildings is considered to be one of the most important and affordable means to mitigate climate change (IPCC, 2007). Buildings represent the largest end-energy use, since they account for approximately 40% of the world's total energy use (Laustsen, 2008). Despite signs of improvement, Europe's buildings are still a large energy user comprising 40% of final energy use and 36% of EU CO_2 emissions (ACE *et al.*, 2009; Itard *et al.*, 2008). There are considerable differences between different European countries, but on average the residential stock, consisting of households, is responsible for 30% of the total final energy use, where use is proportional to the useful floor area. On average, domestic hot water and space heating are responsible for over 60% of the final energy use in both residential and non-residential stocks (Itard and Meijer, 2008). Given the considerations mentioned above, it is obvious that significantly reducing residential primary energy use and space heating in particular, can contribute towards mitigating climate change and to energy efficiency objectives.

European practice shows that it is technically feasible to renovate houses to a limited energy demand for heating of less than 15 to 30 kWh/m^2 net floor area and per year (kWh/m^2a), and a total primary energy demand of less than 120 kWh/m^2a (E-retrofit-kit, 2008; IEA SHC Task 37, 2010). These projects make use of integrated renovation concepts, such as the passive house concept, and use innovative technologies, such as triple glazing, thermally insulated window frames and doors, thermal bridges and air tightness solutions, and mechanical ventilation with heat recovery (see for example: Guschlbauer-Hronek and Grabler-Bauer, 2004). Measurements confirm that these technologies, particularly when clustered together in an integrated concept (IEA SHC Task 37, 2010; Mlecnik *et al.*, 2010), can lead to a significant reduction in energy demand for existing buildings after renovation.

If a reduction of energy use in the building stock is to be achieved, owner-occupants need to consider the adoption of energy-efficient renovation concepts. One can try to influence decision making processes of housing owners in such a way that an energy efficient renovation concept presents an attractive solution. Since highly energy-efficient renovations are still in a demonstration phase in many countries, there is a lack of empirical data derived from decision processes in demonstration projects.

8.1.2 Innovation adoption

Already in the sixties, Rogers (1962) defined leading research about innovation diffusion. Rogers (2003) defined 'innovation' as an idea, practice, or object that is perceived as new by an individual or other unit of adoption. For renovation of houses, Buijs and Silvester (1996) also interpreted innovation in this broader sense that includes not only products, but also techniques, methods, services and abstract ideas or notions in parallel and closely related to product development. Rogers' diffusion of innovations theory (Rogers, 1962; 2003) has been applied to the diffusion of demonstration projects (Silvester, 1996; van Hal, 2000), and the diffusion of some energy saving or environmental technologies has been explored (amongst other: Dieperink *et al.*, 2004; Egmond *et al.*, 2006; Alkemade and Hekkert, 2009).

The innovation-decision process was defined by Rogers (2003) as the process through which an individual (or other decision making unit) passes from first knowledge of an innovation, to forming an attitude towards the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision. According to Rogers' model, communication channels, and prior knowledge and conditions, can influence adoption. In the persuasion phase, the decision making unit can be influenced by the perceived characteristics of the innovation. From the communication perspective, Rogers (2003) defines five perceived attributes of an innovation, which can help explain the better adoption of an innovation. Different studies have shown each of these attributes to be relevant for residential energy use (Wilson, 2008).

Decision making in renovation has scarcely received scientific attention, although similar decisions as in new built constructions might play a role (Thissen, 2008). With environmental innovations in mind, Alkemade and Hekkert (2009) defined, amongst other, the creation of legitimacy as one of the basic functions of innovation systems development. Thissen (2008) has formulated some decision selection criteria with a relative importance suggested by industrial participants. Wilson (2008) investigated why and how homeowners decide to renovate their home, using different research models.

8.2 Research definition

The goal of this research is to understand how owner-occupants can be persuaded to apply highly energy-efficient renovation concepts in renovations of single-family houses. Therefore the paper detects drivers and barriers in innovation-decision processes.

The research focuses on owner-occupant residential buildings. Belgian demonstration projects were selected for the study: In Belgium the majority of the housing stock is in private ownership. In Belgium, in rural areas, 81,8% of dwellings are owned by the inhabitants; in city agglomerations, this percentage drops to 66,7% (Hilderson *et al.*, 2010). In order to obtain representative results for Belgium, reference buildings were chosen according to building typologies, which were defined on the basis of a statistical analysis of the Belgian residential sector (Mlecnik *et al.*, 2010). The Belgian building stock is relatively old compared to other European countries: 15% of the housing stock dates from before 1919 and 17% from between 1919 and 1945, compared

to European average values of 11% and 12% respectively (de Meester, 2010).
The main research question is:
How were owner-occupants persuaded to apply highly energy-efficient renovation concepts in renovations of single-family houses?
Three sub questions are derived from the main question:

1. *How does a motivated owner-occupant adopt a highly energy-efficient renovation concept (case study)?*
2. *What were detected owners' drivers and barriers from all Belgian Low Energy Housing Retrofit projects?*
3. *What can we learn from the adoption process in order to eliminate critical barriers for further diffusion?*

The case studies werse selected from the samples investigated during the research project 'Low Energy Housing Retrofit - LEHR' (LEHR, 2010).

The research presented is restricted to an analysis of the owner-occupants' adoption in the Belgian demonstration projects studied within the framework of the Belgian Federal Science Policy Project: 'Low Energy Housing Retrofit' (LEHR). Realised demonstration projects were chosen according to the relevance of certain building typologies for the Belgian building stock. In these examples owner-occupants have chosen for integrated concepts, and not for single measures like roof insulation, window replacement, and so on. In many cases the decision to apply an integrated concept led to the involvement of an architect; we remark that this is not usually the case when individual measures are applied. Core information about the design, construction and performance of these renovations was systematically collected. The empirical data were gathered by means of interviews with owners, occupants and architects, both during renovation and after renovation, using a questionnaire focussing on perceived attributes of innovations, with both open and closed questions. In some cases, hard data were also gathered from measurements (see Table 8.1 for further details). The questionnaire addressed amongst other:

- Characteristics of the decision-maker: social and economical background variables of the interviewees (4 items).
- Felt needs and problems: general satisfaction (12 items), quality of housing (12 items), construction (11 items), installations (10 items).
- Possible barriers to adoption of innovation: Perception of heating/temperature (35 items), air humidity (18 items), ventilation/air quality (71 items), health issues (11 items).

One can define many other factors influencing social and individual attitudes and behaviour related to the decision process, but this was not the focus of the study.

To answer the first question, a case study in an urban setting is discussed in detail. This illustrates how all projects were analysed. To answer the sec-

Table 8.1 Examined Belgian projects in the LEHR project according to Belgian building typology

Building typology	Project number and heating demand after renovation
Vernacular house: often rural detached house from the 18th to early 20th century, patrimonial value; various forms, large habitable volume, traditional construction methods (local resources), usually no gas provision	1: SHD_PHPP: 32 kWh/m²* 2: HD_EPB: 32 kWh/m²**
Average urban house from the beginning of the 20th century: row house/semi-detached, single-family dwelling, 5-6 m façade, average-large living area (min. 3 storeys + annexes), high ceilings, vaulted cellars, ornamented details (balconies, stonework, plaster), traditional and industrial materials, often lacking natural daylight, gas generally available	3: HD_m: 110 kWh/m²**** 4: SHD_m: 65 kWh/m²*** 5. SHD_PHPP: 32 kWh/m²
Interbellum village house: medium to large house (min 3 storeys), partially caved, simple elongated volumes sometimes with new annexes on the side, simple one-layered walls with industrial materials (concrete, brick), steel or wood, few ornaments, gas partially available	6: SHD_PHPP: 34 kWh/m²
'Modest' workman's house: row house dating before 1945, small volumes, relatively low ceilings, entrance hall often missing, 2 floors, small cave, simple construction often in bad state, frequently coal heating	7: SHD_PHPP: 23 kWh/m² 8: SHD_PHPP: 10 kWh/m²
'Villa' first urban extensions: medium/large houses from the 30s and 50-60s, detached/twin, 'first generation' cavity walls (frequent thermal bridges), various volumes, play with materials, often fuel-based central heating	9: SHD_PHPP: 15 kWh/m² 10: SHD_PHPP: 43 kWh/m²
Apartment building type 'Etrimmo': multi-storey building with balconies and elevator, dating from the 60s or 70s, often mixed ownership, roof often flat, concrete and/or steel skeleton, single glazing, often important thermal bridges, frequent electrical heating	11: HD_EPB: 75 kWh/m²
Detached house in new neighbourhood: single-family house with 4 façades, dating from the 70s to early 90s, first in suburban areas, later diffusion to rural areas, often 2 storeys (one partially under the roof), with or without caves, conventional construction materials (brick, concrete, cavity walls), gas sometimes missing	12: HD_EPB: 86 kWh/m² HD_m: 57 kWh/m²
Apartment in a building divided in several living units: different configurations and ages, often rented from private ownership	13: HD_EPB: 41 kWh/m² 14: SHD_m: 40-60 kWh/m²
Converted industrial or service building: different configurations and ages, often renovated to single-family houses, lofts or residential living units	15: SHD_PHPP: 14,7 kWh/m²

* SHD_PHPP: Space heating demand, value calculated with specialized Passive House Planning Package.
** HD_EPB: Heating demand, including hot water, value calculated with Belgian energy performance regulation software.
*** HD_m: Heating demand, including hot water, measured value.
**** SHD_m: Space heating demand, measured value.

ond question, the results from all projects were assembled, as well as the empirical data from interviews. Where applicable, the interviewees were contacted to provide additional details about persuading factors, the use of communication channels (e.g. mass media or interpersonal), the position of the innovator in the social system (e.g. norms, degree of network interconnectedness, etc.) and the extent of innovation efforts. To answer the third question, the paper discusses the detected drivers and barriers in order to facilitate innovation diffusion.

8.3 Detailed case study

This case study (number 8 in Table 8.1) is an example of an integrated highly energy-efficient renovation concept with a specified energy savings target. This section illustrates how projects, in this case a renovation of a 150 year old terraced house in the village of Eupen, were studied in detail in line with Rogers' perceived innovation characteristics (Rogers, 2003).

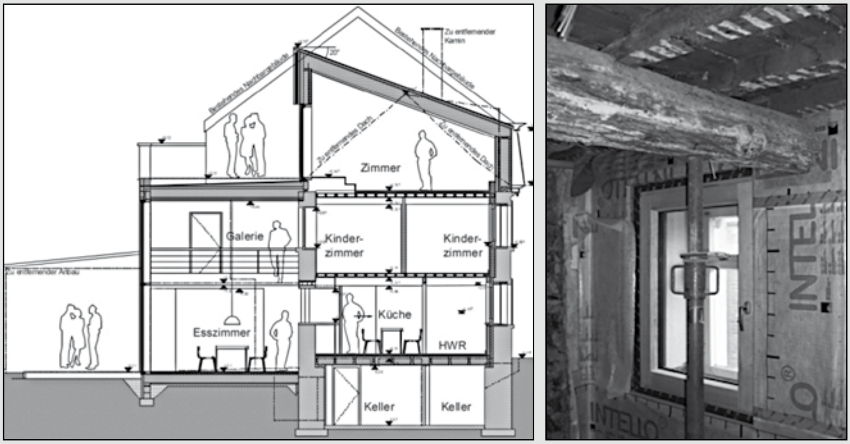
Initially, the owner wanted to reduce energy use by a factor of 10, since he had seen what was possible from these kinds of renovations in other countries. During the process, the owner specified a goal to reduce heating demand below 15 kWh/m^2.a. We remark that during the course of this project, grants and fiscal incentives for low energy housing retrofit were gradually introduced, particularly to support the passive house concept. However, these incentives were not available at the start of this project. Finally, a measured heating demand of 12 kWh/m^2.a was achieved in the first year, and the annual cost of energy use was reduced from €2,149/year before renovation, to €150/year after renovation. It can be remarked that the owner also behaved very consciously regarding energy use.

The renovation comprised a modified arrangement of spaces and the demolition of existing annexes, while a new annex and roof structure with a wooden frame construction were installed. Innovative solutions were provided for thermal insulation of the building shell (continuous inside insulation of the façade), building air tightness, elimination of thermal bridges, outer joinery with triple glazing, mechanical ventilation with air-air heat recovery including a ground-air heat exchanger, and the use of a pellet heater and external sun protection using solar collectors.

The innovator's desire to build a demonstration renovation project was inspired by the relative advantage of this kind of project. Instead of only replacing the worn-out roof and glazing, the owner was driven by the desire to increase the habitable area and to add an up-to-date extension. Another major factor that played a role was an asthmatic child. He reasoned that the old convectors and damp walls would certainly give rise to dust, moisture and lead to health problems. Therefore, the owner decided in an early stage of the design process to have mechanical ventilation with filtering and heat recovery. Renovation was preferred to a new built construction because of substantially lower value added tax.

The observability of the project further played an important role. The owner, an architect involved in the promotion of passive houses, was aware of the opportunity to increase social prestige by opting for a passive house standard, since extension, roof and glazing had to be replaced to obtain the transformation goal anyway, and the orientation of the building was suitable. In conclusion, the owner was driven by relative advantage, i.e. financial advantage, comfort improvement, and social prestige factors, and achieving the passive

Figure 8.1 Case study: integrated approach towards passive house standard resulted in 90% energy reduction for heating. Section of the row house in Eupen (before and after renovation, left) and detail of interior insulation, air tightness and cutting through carrier beam (right)



Source: IEA SHC Task 37, arch.: O. Henz, FHW architectes
Full project brochure: see http://www.lehr.be

house standard only required a few additional minor measures, as the next logical step for the owner. The economic and environmental impact was studied on completion of the project, and the intuitive decision of the architect could be confirmed by a scientific study on the economic and environmental impact (Vrijders and Delem, 2010).

The project proved to be complex and not particularly compatible with the contractors' prior experience, but it did present the owner-architect and the contractors with an opportunity to learn by doing. Being the first demonstration project of a renovation towards the passive house standard in Belgium, the owner had to find all the technological solutions at regional level. In the design stage, extra care had to be taken with the evaluation and solution of thermal bridges. The city did not grant a permit to insulate the façade on the street side, so a solution for interior insulation on the front façade needed careful study and development. The architect had to find this know-how from demonstration projects abroad. Making the building airtight was a technological challenge (see Figure 8.1), as was careful dimensioning and control of the ventilation system. An additional ground-air heat exchanger was installed for summer comfort.

8.4 Analysis

8.4.1 Detected drivers

Similar drivers and barriers were detected in many projects. Table 8.2 provides an overview of the most important detected drivers derived from the questionnaires. Clustering innovative technologies was observed as some-

Table 8.2 Detected drivers in Belgian projects in the LEHR project

Important detected drivers	Project number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Extension of living area	o	+	-	-	o	+	+	++	++	+	++	-	++	+	o
Rearrangement of spaces	++	o	-	-	+	o	o	++	++	o	++	-	++	+	++
Structural improvement	+	++	+	+	++	+	++	++	++	+	++	o	++	++	++
Improvement of thermal comfort	+	+	++	+	+	+	+	+	+	++	+	+	+	+	+
Improvement of air quality	+	-	o	+	o	o	+	++	o	+	+	-	o	+	+
Improvement of daylight/views	+	+	o	+	-	++	++	+	+	+	+	-	o	o	+
Elimination of air leakages	+	o	+	+	+	+	+	+	+	+	+	+	o	+	+
Elimination of outdoor noise	o	-	-	+	o	o	o	+	o	o	+	o	o	o	o
Wish to save energy	+	+	+	+	+	+	+	+	+	+	++	+	+	+	+
General environmental concern	+	+	+	+	+	++	+	+	+	+	++	o	+	+	+
Health/ecological concern	++	o	o	+	+	++	+	+	o	++	o	o	+	+	o
Wish to apply best technologies	o	++	-	+	o	+	o	+	-	+	+	+	o	+	+
Wish to learn	+	+	-	++	o	+	o	+	o	+	++	o	o	++	+
Aesthetical reasons	+	o	+	o	o	+	+	o	+	o	+	-	o	+	o
Eliminate old heating systems	o	+	-	o	o	o	++	+	+	+	+	-	+	o	o
Grants for low energy measures	o	-	+	o	++	-	o	-	o	++	+	o	o	o	o

Legend:

++	very important
+	important
o	not mentioned
-	not important
1, 2	vernacular house
3, 4, 5	average urban house, beginning of the 20th century
6	interbellum village house
7, 8	modest workman's house
9, 10	villa in first urban extensions
11	apartment building type 'Etrimmo'
12	detached house in new neighbourhood
13, 14	apartment in building divided in several living units
15	converted industrial building

thing obvious by owner-occupants in the demonstration projects. In several cases interviewees were thinking in integrated approaches. For example, one interviewee mentioned that the look of the building, air quality, and noise levels can be changed through renovation, for example by dealing with façades, ventilation systems and taking acoustic measures. For physical reasons, thermal insulation solutions were often combined with air tightness, thermal bridge solutions and the provision of adequate ventilation (except one case). Façade insulation was combined with window replacement (expect one case). Connecting insulation components led to innovative solutions (several cases). In most cases ventilation systems with heat recovery were chosen to provide for air quality. If we take a closer look at Table 8.2, we observe a number of important adoption parameters.

Increase of living area – A prominent adoption parameter is to extend the living area or to rearrange spaces and functions. Transition to owner-occupancy usually involves extension. In many cases, an integrated concept was considered because of a wish to extend a small house or a wish to relocate the domestic functions of the property. For more recent houses and for houses that had urban restrictions this criterion was less important.

Structural improvement – A second important adoption parameter is the wish to improve the structure of the residence and the basic amenities. The projects with the lowest perceived basic 'quality' had higher ambitions for energy saving and upgrading. Those owner-occupants were easier convinced to apply an integrated renovation concept. There was still room-based coal, fuel or electrical heating in some buildings before renovation. In most projects, interviewees did not wish to reuse these systems.

Comfort improvement – A third important parameter was the wish to improve the comfort of the residence. Important comfort parameters include thermal comfort (winter and summer), air quality, elimination of draught because of air leakages, visual quality, and, in some cases, elimination of outdoor noise. Interviewees also relate the comfort of residences to satisfaction with the living environment. The cases show that a lack of comfort prior to renovation can be related to the pre-World War heritage of old industrial and rural areas. On average, houses built more recently tend to have slightly higher comfort levels before renovation.

Energy saving – During the decision process, the implementation of energy saving technologies is usually only considered after the previous considerations. Most interviewees linked comfort improvement directly with energy saving by mentioning specific innovative technological solutions. Very motivated owner-occupants often link energy saving with increased personal status or an increase in future property value. The choice for renewable energy systems was also popular, although not considered essential to achieve highly energy-efficient buildings. The sheer will of the actors involved to save energy appears to be an important driver to reach overall good energy performance. In contrast, the existence of grants for energy saving measures did not appear to be a very important driver for the owner-occupants, except in the Brussels Capital Region, where the grants are substantially higher than in other regions.

Environmental concern – Some owners were driven by general environmental concern and especially the will to provide or demonstrate sustainable solutions for their children, or for clients (in cases where the owners were also architects). Some interviewees linked environmental concern directly with the use of ecological and healthy materials, and accepted energy saving merely as a partial solution in a more general future-oriented framework. Many interviewees were concerned about health issues of concepts and materials. The lower focus on energy saving sometimes resulted in lower final energy performance, since owner-occupants preferred to primarily invest in ecological or healthy materials.

8.4.2 Detected barriers

In all cases technological problems had to be solved, but the owner or the architect usually found a suitable technology available on the (international) market. The cost barrier proved to be less significant for the innovators, although significant grants were a driver in the Brussels region. Most owners thought they were not well informed at the outset, and almost all of them engaged in some form of self-education. In most cases, the integrated concept approaches required consulting an architect since the renovation activity had to be declared to the local community. In a few cases, existing urban policy led to more complex solutions. For example when local policy did not allow outside façade thermal insulation, owners had to choose for inside thermal insulation.

The difficult adoption by architects and contractors was detected as a very important barrier. In three cases architects were not involved or trusted and the owner did the whole coordination of the renovation. The owners of one other project had difficulties finding an architect willing to think in an integrated approach. In one case, the owner preferred to commission a specialized consulting agent to determine the best available technologies instead of an architect. Many owner-occupants stated that they had to check that the contractors were doing their job properly. Most interviewees had to look for suitable contractors themselves. Some interviewees suggested compiling a list of contractors specialized in highly energy-efficient renovations. Adoption problems by contractors occurred in very ambitious passive house renovations, but also 'more easy' low energy renovation concepts were sometimes experienced as cumbersome by contractors. For example, one roof contractor was not familiar with the carpentry for extending a roof border, and had to learn by trial and error. Some interviewees complained about diminished comfort for a long time, because many rooms in the house could not be used for months.

In one case the interviewees mentioned that this was due to contractors not sticking to the agreed time schedule. The resulting project was consistent with the required comfort and financial needs of the adopters, but the interviewees would not easily recommend others the same experience.

In general, a high ambition level of the owners, architects and contractors involved resulted in better performance achieved. Project with no specific energy savings target defined in advance, also reached less energy saving. The owners who wanted to spread their financing and who opted for phased retrofit, achieved lowest energy saving.

8.5 Discussion

The previous adoption research is discussed in the process of innovation diffusion. Innovation diffusion can be defined as the processes by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). In these terms, diffusion is mainly explained in terms of communication (attractiveness). Obviously, adoption is also constrained by situational factors such as lack of resources (project number 3: this lead to partial retrofit and only limited energy saving), or access to technologies (e.g. project number 2: passive house technologies were wished for, but not yet available on the Belgian market). A general overview is given of what all cases teach us about the perceived attributes that can lead to persuasion to implement highly energy-efficient renovations.

Relative advantage – We can expect that the greater the perceived advantage of the renovation idea, the more rapid its rate of adoption will be. What matters is not so much energy saving advantage, but whether an individual (owner-occupant, architect etc.) considers a highly energy-efficient renovation to be better than other traditional options. Increased space, structural improvement and improved comfort are important drivers next to energy saving. Also, provision of better health and environmental conditions can be considered as an advantage. Mainly non-energy and non-financial factors can drive the renovation: social prestige satisfaction (see detailed case study), convenience and comfort expectations. An important barrier is that many architects prefer to focus on new built construction, which is perceived as easier.

Compatibility – Energy benefits can be compatible with other main adoption criteria, such as structural and comfort improvements, general environmental concern, and even investment cost. The more energy motivated owner-occupants opted for high energy standards, leading to high involvement and finally also to better energy quality. People who had already renovated in the past could be convinced to take additional building-related measures to improve comfort (e.g. project number 3). In theory, this provides an opportunity for the market increase of innovative technologies for highly energy-efficient renovations, and for addressing new target groups. However, there is a risk that only partial renovations are performed, leading to lower energy saving.

Complexity – We can expect that when more convenient innovations are on offer e.g. with less intervention in the interior space, they will be adopted more rapidly. In most cases, the interviewees perceived renovation projects as difficult to understand and implement, requiring personal education. Internal thermal insulation in particular proved to be complex to implement. But also for low energy renovation, the architect and contractor sometimes do not have standard solutions for common problems. Continuous educational effort appears to be necessary to overcome this barrier, particularly for architects and contractors, and even for owner-occupants to self-educate. Also, standard solutions for renovation can be provided through public information sources (e.g. Zelger and Waltjen, 2009). Currently, the architects involved generally tried to make the best choices from a budget imposed by the client, while their know-how needed to be upgraded. The contractor often remained the executor of a task that the design team had specified in plans and often during informal discussions.

Trialability – The actors involved in all the demonstration projects had to learn by doing. When traditional actors were involved, this sometimes happened by trial and error. Almost all interviewees stated clustered approaches as a trial. Peer experience or social feedback for integrated concepts was often found in new built constructions, for example passive houses, or from architects' recommendations. The implementation of thermal insulation or mechanical ventilation with heat recovery in highly ornamented façades or interiors proved to be a challenge, but not unachievable.
Observability – interviewees reported that the proposed ease for individuals to see the demonstration project (in the LEHR project files) facilitated the process to obtain motivated architects and contractors. Indeed, market actors perceiving good relative advantage from their involvement in demonstration projects, documented as high quality projects, can be expected to be proud of their project and be willing to demonstrate it to other actors. In some cases, the actors involved increased visibility by referring to project leaflets, and easily accessible internet information. Therefore, a way forward for diffusion might be media campaigns, the recognition of demonstration buildings, and the explicit mentioning of the associated actors and change agents in listings and documentation.

8.6 Conclusion

In pursuit of the stated goal, characteristics of a decision model based on Rogers' innovation diffusion theory have been applied on a limited number of single-family owner-occupant case studies.

Demonstration projects in Belgium show that owner-occupants and architects alike can take a leading role in realising demonstration projects and achieving highly energy-efficient renovation. For all kinds of building typologies high energy-efficiency was achieved through clustering of energy-efficient solutions in integrated concepts. Renovation projects using clustered innovative passive house technologies led to the highest energy saving. In Belgium, the passive house concept in particular provides an opportunity for owner-occupants to negotiate a well-defined target with executing parties. The LEHR project now provides structured information according to building typology, so that potential adopters can try out similar concepts and learn from these demonstration projects.

The demonstration projects indicate that owner-occupants are motivated to adopt highly energy-efficient renovation concepts by the promise of structural improvement, increased surface area, and improved comfort next to lower energy use. Especially a concern for comfort improvement can lead to energy-saving solutions that cluster comfort oriented technologies in innovative concepts, like the passive house renovation concept. But also, owner-occupants can be driven by a more general concern for the environment and for improved health conditions. These issues should also be addressed in the further development of concept innovations, since for some owner-occupants non-energy benefits are more important than energy efficiency.

To date, only a few planners, consultants, building companies and suppliers of building materials, have adopted highly energy-efficient renovation concepts. In theory, the adoption problems by, amongst others, architects and contractors can be overcome by increasing the attractiveness, competitiveness, affordability and availability of highly energy-efficient renovation concepts for these target groups. Since eliminating barriers requires considerable effort both for low energy renovation concepts and more advanced concepts like passive house renovation, it is recommended to focus on providing competences and resources for the realisation of highest energy saving targets for existing building typologies.

It is not expected that demonstration projects alone will guarantee the associated market development required. Holistic approaches, higher skill competence and tighter coordination in the planning and construction phases are particularly important for highly energy-efficient renovation concepts. When it comes to the lack of knowledge among the actors involved in demonstration projects, social strategies can be recommended, for example setting up peer-to-peer knowledge exchange networks for owner-occupants, architects and contractors. To go beyond the demonstration project, dissemination and education are necessary to improve skills and competences. Consequently, communication plans, and possibly also quality assurance systems, have to be put in place to maximize the impact of the knowledge gained. The attractiveness of highly energy-efficient renovations could also be increased by providing reference networks, suitable tools and significant economic incentives for both customers and executing parties, in order to improve the relative advantage and visibility of the actors involved.

Acknowledgements

This paper uses material from two research projects. The ‘Low Energy Housing Retrofit (LEHR)’ project was supported by the Belgian Federal Science Policy and the research was conducted by collaboration between Passiefhuis-Platform, the Belgian Building Research Institute and UCL – Architecture & Climate. The author also used experience gained from participation in the IEA SHC Task 37 ‘Advanced Housing Retrofit with Solar and Conservation’ task A. Marketing strategies, and task C. Demonstration projects.

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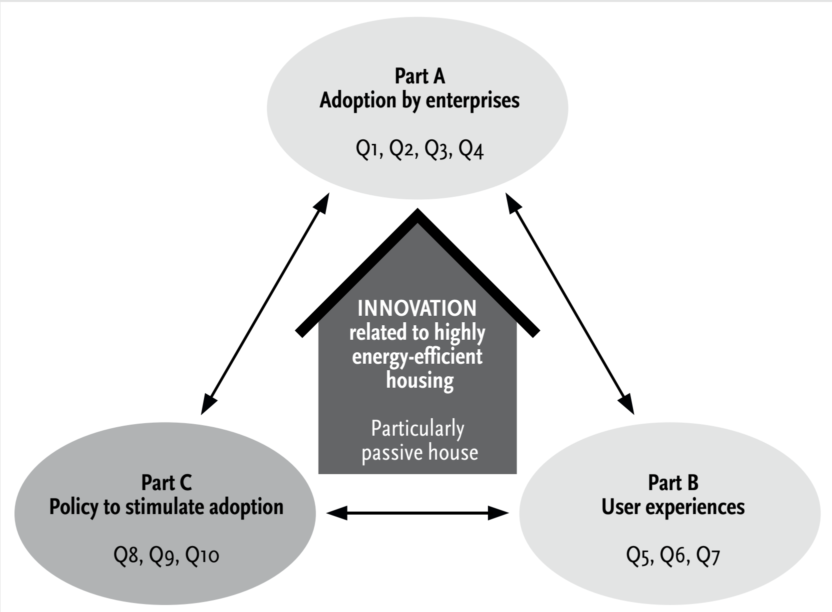
Introduction to Part C: Policy to stimulate adoption

Figure C.1 The research defined the 'innovation' and studied its adoption by government policy in Part C, studying research questions Q8, Q9 and Q10



Part C investigates the adoption of highly energy-efficient housing concepts from the policy perspective, focussing on energy policy and innovation policy. The research discussed in this part examines current discussion items in the policies of European member states, related to the required European policy implementation of nearly zero-energy houses by 2020 (EPBD, 2010). The goal is to derive lessons from these policies that could stimulate the adoption of highly energy-efficient housing concepts. The European Commission indeed expects the housing sector to evolve towards nearly zero-energy dwellings, and national policy actors should now be adopting systems to facilitate this transition (EPBD, 2010). One of the mandatory actions for buildings in the EU Action Plan on Energy Efficiency [COM(2006)545] prompted the Commission to devise a strategy for the adoption of a definition of nearly zero energy buildings, with a view towards a more widespread deployment of such buildings by 2020.

With regard to the improvement and development of energy policy for housing, previous researchers at TU Delft have enhanced understanding with regard to the importance of implementing the European Energy Performance of Buildings Directive (EPBD). For example, Sunikka (2006) examined various policies for improving energy efficiency in the European building stock and Beerepoot (2007) examined the effect of the EPBD on technology innovation. Considering the nature of the inertia affecting the improvement of energy efficiency in housing, national and local governments have been advised to take an active role in promoting energy efficiency through regulations, fiscal incentives and organisational measures (Sunikka, 2006; Beerepoot, 2007). Moreover, Visscher (2008) emphasises the importance of providing more effective quality control within the framework of EPBD implementation, and Van der Heijden (2009) recommends a public/private hybrid form of governance in enforcement regimes for building regulations.

As observed by some researchers (e.g. Lomas, 2010: 9), regulation may not be the most appropriate mechanism for controlling energy use within the complex socio-technical system of occupied dwellings. Experience has shown that classical instruments (e.g. legislation) may fall short with regard to achieving sustainable development (Boerbooms, Diepenmaat and van Hal, 2010). This has led to the use of new steering instruments – also known as 'second-generation steering instruments' (Bruijn and Heuvelhof, 1991) – including covenants, communication and network management (Buijs and Silvester, 1996), which are widely used in the Netherlands (see Chapter 1).

As illustrated by these considerations, the adoption of concepts by policymakers is a relatively complex topic to study. This complexity is underscored by the insights presented in Chapters 2-5, which demonstrate that innovators in the market apparently act in advance of policymakers to promote solutions, terms and even steering instruments and quality assurance tools. Researchers, companies and networks have already proposed best practices and definitions for significantly reducing the energy used by housing. Some communities, regions and energy-network providers have already created incentives for nearly zero-energy homes, highly energy-efficient renovations and passive houses. National policymakers are currently faced with this situation, and the necessity of implementing and recasting the EPBD is challenging them to re-address a general policy framework.

Chapter 9 studies policy definitions for nearly zero-energy housing
The previous parts of the research identify the passive house concept as a possible systemic innovation opportunity for businesses (Part A), in addition to identifying key concerns of end-users regarding the adoption of passive houses (Part B). Although conceptual approaches (e.g. passive houses) could arguably offer a direct response to the policy request for nearly zero-energy dwellings, this is not reflected in the available literature regarding energy policy. Given the needs of Belgium, the Netherlands and other countries to implement the recast EPBD, the following question was formulated:

Q8. Which definitions of nearly zero-energy housing are likely to be adopted in Belgian and Dutch policy?

To clarify various policy-related factors, an original research project began by clarifying the language used by policy and market actors and examining the evolution of general terms and research, marketing and legal definitions related to nearly zero-energy dwellings, with a particular focus on comparing situations in the Netherlands and in Belgium with those of other European countries. This study contributes to theory development by highlighting the utility of Rogers' innovation diffusion theory for developing an interview method and tracing the regional adoption trajectories of various terms and definitions. The findings are used to identify opportunities and barriers related to the inclusion of existing definitions in energy policy.

Chapter 10 studies the possible use of labels for highly energy-efficient housing

With regard to the topic of instruments related to passive houses, various initiatives involving energy labelling for highly energy-efficient residential buildings have emerged throughout Europe. These labelling schemes are considered an essential method for stimulating market demand, controlling grants and ensuring the quality and energy performance of demonstration projects (PEP, 2008). Based on international reflection, researchers (e.g. Elswijk and Kaan, 2008) have suggested incorporating existing passive house certification systems into further policy development. The following research question was formulated in this regard:

Q9. Which barriers and opportunities exist with regard to the further diffusion of labels for highly energy-efficient houses?

An original research project investigated experiences regarding such labelling schemes in various European countries, in order to provide input for investigating the adoption of such labels by the makers of energy policy. This study contributes to theory development by developing a systemic approach based on the theory of innovation diffusion, in order to analyse the perceived attributes of existing European labels. The study illustrates the utility of Rogers' theory for exploring the adoption of quality-assurance services, in addition to investigating the innovation characteristics of existing labels in Europe, focusing specifically on advanced countries. The issue of compatibility with the development of the EPBD is also examined in detail.

Chapter 11 studies opportunities for communication channels

Another major second-generation steering instrument addressed in this study involves the use of communication channels, given its close relation to Rogers' innovation theory. The realisation of innovation in the project-based building industry beyond adoption by single innovators poses a special challenge, and various researchers (e.g. Boerbooms, Diepenmaat and van Hal, 2010; Rødsjø *et al*., 2010) have agreed that facilitating a transition towards the volume market will require creating momentum. The experiences that communication channels (e.g. enterprise networks) have in the field of developing activities for influencing innovation-decision processes could provide interesting lessons regarding communication and the merger of interests, particularly for the makers of innovation policy. The following research question was formulated with regard to success factors regarding communication tactics in such networks, in order to derive lessons for policy:

Q10. *What are possible tactics and success factors in the stimulation of the adoption of project-based innovation (e.g. as determined from the activities of an innovation-oriented passive house network)?*

A study was conducted in order to determine success factors related to the promotion of the passive house concept as an innovation. The study draws upon examples of successful innovation-promotion activities carried out by the passive house network described in Chapter 5 and Appendix B, with the goal of framing these success factors as recommendations for the development of coherent communication policies that could stimulate both supply and demand. This chapter contributes to theory development by critically reviewing Rogers' concept of innovation-decision processes and developing a model of innovation diffusion theory with regard to addressing learning cycles and reaching various customer segments. This final study thus concludes the series of studies by highlighting important success factors in the promotion of passive houses.

General overview of Part C (see Figure C.2)
Part C thus focuses particularly on deriving lessons from European policies and initiatives that could stimulate the adoption of highly energy-efficient housing concepts. It does this by examining the definitions of nearly zero-energy houses, as included in the policies of European member states (Chapter 9), as well as their policies regarding the adoption of labels (Chapter 10). It also examines opportunities for increasing innovation adoption through communication policies that could stimulate both the supply of and demand for innovation (Chapter 11).

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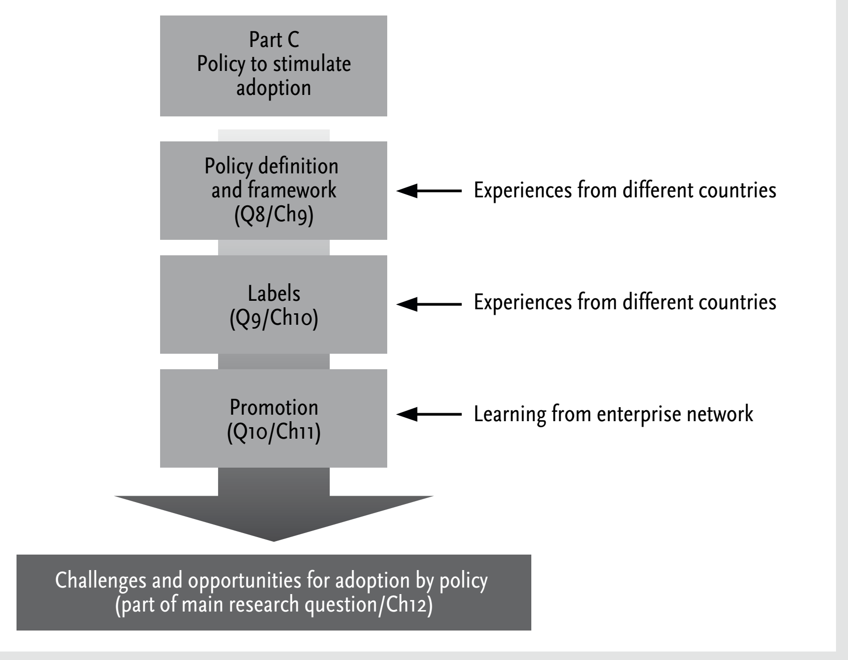
Figure C.2 The main topics covered in three studies addressed in Part C, the research input used in each chapter and the research output expected for the conclusions



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9 Policy definition of nearly zero-energy housing in Belgium and the Netherlands

Published as: Mlecnik, E., 2012, Defining nearly zero-energy housing in Belgium and the Netherlands, ***Energy Efficiency*** **5** *(3), pp. 411-431.*
doi: 10.1007/s12053-011-9138-2

Abstract
Europe expects the housing sector to evolve towards nearly zero-energy dwellings. Meanwhile, general terms and research, marketing and legal definitions considering such dwellings have already been introduced. Appraisal of existing definitions is now needed for further policy development. This paper examines what nearly zero-energy terms can be expected to be adopted in Belgium and the Netherlands. The research method uses an interview method based on innovation diffusion theory. The analysis traces the regional adoption trajectory of relevant definitions and examines the opportunities and barriers for the inclusion of existing definitions in regional energy policy. The analysis shows that – whilst international prominence of the terms 'net zero energy' and 'net zero carbon', in addition to 'low energy' and 'passive house', is observed – in Belgium and the Netherlands 'passive house' and 'energy neutral' are preferred. The research findings indicate that the adoption of already existing definitions for nearly zero-energy houses will depend on the region and can prove a very complex process with several conflicting issues. Terms should be clearly defined and used at all political and marketing levels. It is recommended to enhance the relative advantage, demonstrability, visibility and compatibility of favoured definitions by policy initiatives.

9.1 Introduction

In the European Union, the overall building stock is responsible for about 40% of the total use of primary energy. Housing, in turn, accounts for the bulk of the energy use in this domain (Itard *et al.*, 2008). Though there is significant potential for realising cost-effective energy savings and reductions in CO_2 emissions in both new and existing buildings (McKinsey and Company, 2009; Ürge-Vorsatz *et al.*, 2007) – which would benefit society at large – certain market, technological and end-user characteristics are inhibiting rational, energy-saving choices in purchase and use (Koeppel and Ürge-Vorsatz, 2007). This implies that marketing strategies and policies aimed at overcoming the barriers that are inhibiting the application of energy-efficient technologies and concepts[1] are crucially important in the efforts to lower greenhouse gas emissions from buildings.

More governments and companies are realising the energy-saving potential of dwellings and are pursuing the required strategies and policies. Researchers and networks have proposed different building codes and definitions to significantly reduce the energy used by housing. The first energy efficiency codes for dwellings were set in the 1970s in response to the oil crisis (Deringer *et al*., 2004). Since then, the range has expanded considerably, from regulatory and voluntary instruments in the initial phase to financial incentives and economic instruments (IEA, 2005). These instruments regularly introduce definitions for highly energy-efficient housing concepts. 'Passive house'[2], for example, has recently been successfully defined and introduced in different countries and policies (Elswijk and Kaan, 2008; Mlecnik *et al*., 2010). One of the mandatory actions for buildings in the EU Action Plan on Energy Efficiency [COM(2006) 545] prompted the Commission to devise a strategy for the uptake of a definition of so-called nearly zero-energy buildings with a view to a more widespread deployment of such buildings by 2020.[3] The European Commission now expects member states to introduce and register nearly zero-energy buildings[4]: this is requested in the recast of the Directive of the European Parliament and

1 One consequence of pursuing the energy efficiency potential is the unavoidable transition to less energy- and resource-intensive building concepts. Von Weizsacker *et al*. call for an integrated improvement in efficiency by, on average, a factor of 4 over 25 years (Von Weizsäcker *et al*., 1998; Raad voor het Milieubeheer, 1996; Reijnders, 1998). Weterings and Opschoor, amongst others, state that eco-efficiency should be improved by a factor of 10 to 20 over 50 years (Weterings and Opschoor, 1994; Jansen, 1997).

2 See for example (PEP, 2008): The term 'passive house' refers to a specific construction standard for residential buildings with good comfort conditions during winter and summer and with no traditional heating systems or active cooling. This normally means excellent levels of insulation and air tightness and good indoor air quality guaranteed by a mechanical ventilation system with high-efficiency heat recovery. The heat load does not exceed the load that can be transported by the minimum required ventilation air. However, space heating does not have to be transported through the ventilation system. The following specifications apply for northern latitudes of 40–60° under the conditions in the PHPP calculation model:

- The annual total energy demand per year for space heating and cooling is limited to 15 kWh/m^2 of conditioned floor area.
- The annual total primary energy use per year for all appliances, domestic hot water and space heating and cooling is limited to 120 kWh/m^2.

A passive house has a high level of insulation with minimal thermal bridges and low infiltration. It utilises passive solar gains and heat recovery to achieve these specifications. The residual energy demand can be met by renewable sources.

3 A time target for new building was set that as of 31 December 2020, new buildings in the EU must use 'nearly zero' energy (ECEEE, 2010). European industry advisory groups have identified research priorities as part of a longer roadmapping exercise for definitions, targeting the year 2050 and encompassing the vision that (EeB, 2009): "By 2050, most buildings and districts could become 'energy-neutral', and have 'zero CO_2 emissions'."

4 When the recast Directive was approved 19 May 2010, the meaning of 'very low-energy building' or 'nearly zero-energy building' was specified as 'a building that has a very high energy performance, determined in accordance with Annex I [of the Directive]. The nearly zero or very low amount of energy required should to a very significant level be covered by energy from renewable source, including renewable energy produced on-site or nearby.'

of the Council on the energy performance of buildings (EPBD, 2010). The European Parliament (2009) recommended a focus on buildings with CO_2 emissions and primary energy use which are low or equal to zero. National, regional or local tax incentives, financial instruments and lower rates of value added tax (European Parliament, 2009: Amendment 102) are expected to support the diffusion. Despite the numerous actions towards zero emission buildings and the excitement of the term 'zero', major challenges need to be met in the development of such regional definitions, in particular in relation to the lack of common understanding (Marszal *et al.*, 2010). Defining nearly zero-energy buildings requires a prescriptive approach with stricter implementation of more ambitious strategies and targets and more policy commitment to market change (Atanasiu, 2010). member states can provide more clarity by defining their expectations in, for example, their building codes and tax legislation.

Meantime, the media coverage and the political attention paid to climate change and to lowering the primary energy demand appear to have sent the housing industry into a kind of 'carbon wild west'. Promoters, developers and communities bandy around words like 'passive' houses, 'climate neutral' living, 'carbon-neutral' streets and 'zero-energy' developments, sometimes without clear definitions, target values or (policy) evaluation procedures. Hence, one major obstacle for the implementation of the recast of the Energy Performance of Buildings Directive (EPBD 2010) seems to be the linguistic, cross-regional and legislative confusion caused by the number and variety of definitions and their historically determined meaning.

9.2 Outline of research

9.2.1 Research goal and reseach question

To speed up the diffusion of the use of highly energy-efficient housing, it is necessary that policy provides visible and widely accepted definitions that help companies and other actors to distinguish themselves from the competition. It therefore makes sense to map out an overview of existing marketing and legal definitions for highly energy-efficient housing concepts, particularly with a view to policy adoption. The goal of this research is to identify openings and barriers for the adoption of existing definitions for highly energy-efficient housing concepts in Belgian and Dutch policy, which can also serve as an example for other European countries.

The main research question was: What definitions can be expected to be adopted for nearly zero-energy housing in Belgium and the Netherlands? This question was explored by asking the following subquestions:

1. *What terms have been adopted in relation to highly energy-efficient housing concepts, especially in Belgium and the Netherlands, and by whom?*

2. *What definitions have been introduced in other countries?*
3. *What definitions show favourable innovation characteristics for further diffusion in Belgium and the Netherlands?*

9.2.2 Research methodology

Diffusion of innovation can be driven by communication within a society, which increases the attractiveness of an innovation (Rogers, 2003). In this perspective, it is relevant to frame the study within the innovation diffusion context, i.e. the communication of highly energy-efficient housing concepts.

Based on innovation diffusion theory (Rogers, 2003), the study defined both open and closed questions to examine perceived attributes of existing highly energy-efficient housing concepts. How a relevant interview method can be derived from diffusion theory has been discussed in (Mlecnik *et al.*, 2010). General questions in the interview used in this paper requested information about the existence of nearly zero-energy housing, their market penetration and national and legal recognition, including financial benefits, regional references, education and communication efforts and expert appreciation. Demonstrability questions were developed to document the degree to which nearly zero energy may be experimented with and is recognised by the state or region for incorporation in existing developments. Visibility questions asked about the degree to which low energy, passive house and nearly zero energy is visible to others. Further, compatibility was regarded as the degree to which nearly zero-energy definitions are consistent with the (recast of the) EPBD (2010).

After trial and regrouping, a final questionnaire contained three main groups of questions that addressed the relative advantage, complexity, demonstrability and visibility of highly energy-efficient housing as well as their compatibility with building code development:

1. Questions about low-carbon, low-energy, zero-energy or passive house development in member states or region (directed at commercial actors and networks, change agents and knowledge institutes)
2. Questions about the compatibility of low-energy housing development with the development of building code (for experts only)
3. Questions about the latest development of relevant labels (for label developers only).

To reply to the questionnaire, experts from different countries were identified and addressed. Amongst other, a list of experts was provided by the European Council for an Energy Efficient Economy. Additionally, leading experts from national and regional passive house organisations and known label developers were consulted.

The *Adoption of definitions for highly energy-efficient housing in Belgium and the Netherlands* section addresses the first question by combining research results with literature study on the emergence of highly energy-efficient housing concepts in Belgium and the Netherlands. The findings were reflected with interviews with regional key stakeholders (academic stakeholders, energy efficiency experts) and during discussions in working groups (working group 'close the circle-energy' of the Flemish transition arena sustainable living and construction: Duwobo, 2010). Using the collected data, the adopted definitions were classified in five categories: general terms used, relevant definitions in research, definitions from demonstration projects, definitions introduced for market creation and legal definitions.

The *Experiences in other countries* section deals with question two by examining interviewees' responses regarding existing legal definitions in the light of attaining the European goal of nearly zero-energy housing with a focus (detected from the research results) on zero-carbon and zero-energy definitions. It analyses the recent working definitions to trace if they can be translated into attainable criteria over time in the Netherlands and Belgium.

In the *Definitions with favourable innovation characteristics* section, the diffusion characteristics related to several working definitions are discussed using the theory of innovation diffusion, and question three is answered by analysing the research results in terms of the possible adoption of definitions. This analysis unveils barriers that could potentially obstruct the adoption of some definitions and identifies crosscountry opportunities for removing them.

9.2.3 Limitations of the research

This questionnaire was addressed to 188 member state professionals, some of them involved in the development of labels for low-carbon, low-energy, zero-energy or passive houses. In total, 25 completed replies were received from 15 different countries. The limitations of the small interview sample need to be recognised.

Although the professionals were carefully selected, answers were diverse and reflected the expert's own experience and their view on the state of adoption of highly energy-efficient houses in the country. Some experts or regional representatives showed only limited experience with nearly zero-energy houses or even none.

This research method led to replies, detailed comments, additional references and empirical data from a small sample, but with a good international distribution. Possible knowledge gaps were tackled with further literature search and discussions with leading experts. Since building traditions and practices can vary according to climate and country, the research focussed on western Europe, and Belgium and the Netherlands in particular. It addresses definitions used in countries that are dominated in particular by a heating demand and new housing. It does not specifically address definitions for energy-efficient or energy-positive non-residential buildings, nor districts or communities.

Experience in Belgium can be dissimilar from experience in the Netherlands, but differences in the adoption of highly energy-efficient housing concepts can generate added value when the findings are compared, also with other countries.

9.3 Adoption of definitions for highly energy-efficient housing in Belgium and the Netherlands

9.3.1 General terms used

Historically, energy efficiency has always figured as a theme in regional research and engineering, but most of the time it was confined to conversion processes involving large energy flows (Lysen 1996). Whereas the energy crises of the 1970s rekindled the interest in the field of energy-efficient housing, no statutory low-energy standards for new dwellings were implemented in Belgium and the Netherlands, like in, for example, Sweden and Denmark. This led to various general terms introduced in daily language for communication purposes.

In Belgium and the Netherlands, 'low-energy' buildings are usually defined as buildings, which have been designed with the explicit intention of using less energy than standard buildings. Sometimes specific energy requirements are set out by energy consultants, which then lead to performance-based strategies. For example, in the Netherlands and Belgium, the regional implementations of the European Energy Performance of Building Directive (EPBD, 2002) have occasionally been used for project targets (e.g. an 'E-level' of 40 or 60 in Flanders and an 'EPC' of 0.4 or 0.6 in the Netherlands), but potential problems have also been reported on building controls and performance guarantees (Visscher *et al.*, 2010).

Whilst in Belgium the term 'passive house' has seen a broad market introduction (Mlecnik, 2008), in the Netherlands, the terms 'climate' or 'CO_2 neutral', or 'zero energy' are often used (PEGO, 2009). 'Zero carbon' and 'carbon neutral' are used terms in Dutch marketing, but they can be understood in various ways, with no official definition. In the Netherlands, several authors have proposed local definitions for further use: CO_2 neutral homes or CO_2 emission-free houses (e.g. van Hal, 2007), zero-energy or energy-neutral houses (e.g. Rovers and Rovers 2008) or passive houses (e.g. Mlecnik, 2009). CO_2 neutral is also applied for larger territories within communities (e.g. Roos and Straathof, 2008).

The concept of 'zero-energy' is also subject to different interpretations and frequently occurs in Dutch and Belgian marketing jargon. 'Zero-energy' is generally interpreted as 'net zero energy', i.e. equilibrium between the used and produced energy.

9.3.2 Relevant definitions in research

Since the 1970s, different research models were proposed in different regions. In the Belgian Walloon region, the Passive and Low Energy Architecture movement (Cook, 2002) received considerable interest, and terms such as 'passive solar architecture' emerged as the expression of a design philosophy for low-energy buildings that takes account of the natural environment. In architecture, the term 'climate-sympathetic architecture' subsequently appeared with regard to buildings which, because they are designed along the lines of 'passive solar' criteria, use the building envelope as the primary climate control and make mechanical installations supplementary. The term 'bioclimatic (or sustainable) architecture' was widely disseminated in the Walloon Region and refers to an alternative way of constructing buildings which takes account of local climatic conditions and which harnesses various passive solar technologies to improve energy efficiency; the term 'passive solar technologies' refers to heating or cooling technology that passively absorbs (or protects from, e.g. natural shading) the energy of the sun and has no moving components (Tzikopoulos *et al.*, 2005). In view of its potential for generating significant energy savings and reducing greenhouse gas emissions (Tzikopoulos *et al.*, 2005), bioclimatic architecture has continued to receive a fair amount of attention worldwide in recent years (e.g. Radovic, 1996; Zain-Ahmed *et al.*, 2002; Nahar *et al.*, 2003) and is regarded as an important parameter in contemporary architecture (Donald, 1998), especially in Belgium (see for example UCL, 2010).

Alternatively, the term 'integrated (energy) design' (IED) was more often mentioned in the Flemish Region, especially by energy consultants, which usually refers to a design process that is meant to lower the operational costs of the building, whilst striving for a comfortable indoor climate and lower emissions (see also: Syneffa, 2008). In the Netherlands, Lysen (1996) initiated the 'Trias Energica' – now commonly coined the 'Trias Energetica' (VROM, 2010) – as a research model to frame the merits of putting energy efficiency before using renewable energy. The Trias Energetica now represents an academically acknowledged three-step priority strategy: (1) reduce the demand, (2) use renewable energy sources and (3) solve the residual demand efficiently and cleanly. It is used in official communication, also for highly energy-efficient housing and construction (for example, VROM 2010).

International knowledge exchange had an impact on the further development of integrated concepts in all regions. For example, the work of experts from the International Energy Agency (IEA), within the Solar Heating Cooling (SHC) Programme, led to national guidelines in Belgium and the Netherlands on how to design, construct and evaluate cost-effective, energy-efficient 'passive' solar homes. The currently used research framework of the 'passive house' concept was developed in 1988 by Bo Adamson at the University of Lund, Sweden, from the basic IED strategy for lowering energy use by, for example, reducing transmission, ventilation and infiltration losses and optimising solar gains (Feist and Adamson, 1989). 'Passive houses' were first defined as buildings which, in the central European climate, have a negligible heating energy requirement and therefore need no active heating.[5] Direct and indirect European funding (for example, PEP 2008) enabled the passive house concept also to be introduced to experts[6] and policymakers in Belgium and the Netherlands. The project-based stop-and-go efforts for the dissemination of the passive house concept have led to regional differences in the diffusion of the passive house concept (Elswijk and Kaan, 2008; Mlecnik *et al*., 2010).

Belgian and Dutch researchers developed national guidelines on how to design, construct and evaluate such energy-efficient passive houses in the regional context. Researchers applied realistic technical solutions to translate some of the more general bioclimatic design criteria into specific recommendations for target values compatible with the local climate.[7] Meantime, 'cradle-to-cradle'[8] and 'sustainable' or 'green'[9] houses are attracting some interest in both the Netherlands and Belgium. As a whole, buildings are much more complex than materials or products alone, but this complexity enables them to close energy, water and material cycles through interconnected loops (Van den Dobbelsteen, 2008). Experience of buildings in this domain still has to be gained in projects, but it could breathe new life into a Trias Ecologica approach to sustainable building (Van den Dobbelsteen, 2008).

5 Theoretical proof of the feasibility of such houses was finished by Wolfgang Feist (1993) and indicated that the use of thermal insolation, heat recovery, super-insulated windows and passive solar and other measures to reduce the heat demand could lead to a simplification of the heating system.

6 The development of the passive house was picked up in the Netherlands by architect Erik Franke, who created a limited network of companies for this purpose in 1998 (Stichting Passiefhuis Holland). This resulted in the first Dutch project in 2000. By this time, the development of the passive house had come to the notice of a Belgian engineering firm that specialised in energy efficiency and developed Flemish demonstration projects. In Belgium, regional funding for the stimulation of thematic innovation combined with funding from a European Intelligent Energy Europe project led to extensive dissemination of the passive house concept and many follow-up projects, first in Flanders and later in the Brussels region, Wallonia and the Netherlands as well (Mlecnik *et al*., 2003; Mlecnik, 2004; PHP, 2010).

7 These criteria are:

- Meet the low energy demand for heating: recommended values for thermal insulation of walls, floors, roofs, thermal bridges, glazing, frames.
- Provide good thermal comfort conditions in both winter and summer with attention to the problem of overheating: recommended values for overheating.
- Establish very good air tightness in the building: $n_{50} \leq 0.6\ h^{-1}$.

8 The basic idea, proposed by McDonough and Braungart (2002), is to constantly upcycle materials and only when this is not possible materials can be downcycled to leave nothing but 'food' (in the form of organic waste) at the end of the lifecycle. The buildings that McDonough and Braungart (2002) cite as examples seem to be incorporations of cradle-to-cradle products.

9.3.3 Definitions from demonstration projects

The late 1970s saw the emergence of rudimentary ideas for integrated concepts and experimental minimum-energy dwellings (see Table 9.1 for some experiences in Belgium and the Netherlands). As in many countries, several terms have been used by individual architects and companies in Belgium and the Netherlands by naming experiments and framing demonstration projects. Examples are the 'minimum-energy house' (Kristinsson, 2007), 'energy-balance home' (Remu, 2000), 'energy house' (Kristinsson, 1999) and 'green house' (Groenwoning, 2010).

Since these definitions were developed in only a few demonstration projects, until now these definitions did not find a strong enough response in the mainstream construction industry. However, some of these terms – and related positive and negative (!) experiences: see Table 9.1 – still remain in the collective memory of interviewed experts.

In literature terms like 'EQuilibrium house' (CMHC, 2010), 'active house' (Marszal *et al.*, 2010), 'plus-energy house' (Activehouse, 2010) and 'plushaus' (Wappler, 2000) can also be found, but these terms have not been reported in interviews from Belgium and the Netherlands.

9.3.4 Definitions introduced for market creation

Due to the lack of policy definition for highly energy-efficient houses, different definitions were introduced by business networks and mixed business/ policy networks. In the Netherlands, a general policy-related definition for highly energy-efficient houses is missing.[10] In the Belgian Walloon Region,

9 Different kinds of 'green' building labels are used – such as Leadership in Energy and Environmental Design (LEED) buildings, Green Buildings, Sustainable Buildings (Laustsen, 2008a) – which define sustainable buildings by means of an integrated design strategy and a point scheme that awards credits for building-design features deemed to improve sustainability. These schemes have been explored in detail and compared (Cole, 1998; Crawley and Aho, 1999; Todd *et al*., 2001; Bosch and Pearce, 2003; Fenner and Ryce, 2008; Lee and Burnett, 2008; Birt and Newsham, 2009). Most rating schemes for 'green building' assess the energy footprint of large commercial properties in order to provide owners and occupants with a solid yardstick for the energy efficiency and sustainability of the building. Widely used labels include assessment in accordance with the UK's Building Research Establishment Environmental Assessment Method or the US Green Building Council or the LEED programme. However, the diffusion of green building ratings has been slow so far and application of rating systems in housing is very limited. It has also been reported that lower energy use does not apply in the case of every 'green building' (Birt and Newsham, 2009). Since the European Commission expects a focus on energy issues, 'green building' definitions were not withheld in this study.

10 One could argue that the 'A-label' according to the introduced energy performance certificate for existing housing shows high energy efficiency. However, the achieved energy savings in such cases are lower than that expected of advanced concepts such as the 'passive house' or zero-energy houses.

Table 9.1 Introduction of energy design concepts in experiments in the 1980s: example in the Netherlands and in Belgium

The Netherlands	**Belgium**
Housing demonstration project	
'Minimum-energy house' built in 1982-1983 by architect Jon Kristinsson	'IDEE-house' built in 1984 by the Belgian Building Research Institute
Resulted in	
Designing for investing an additional €4,500	Designing for technology demonstration in a research facility
Airtight house	Air tightness not considered
Insulated on all sides	Introduction of thermal insulation
Solar energy zoning	Heavily glazed south facades, no solar protection
Solar boiler	Solar collector for heating and hot water
Permanently balanced ventilation with heat recovery and heated by air	No controlled ventilation
Lessons learnt	
An integrated concept led to innovations (polystyrene foundation insulation, airtight walls, roofs and windows, balanced ventilation with heat recovery, electronically ignited gas heater with a modulation burner)	Hasty conceptual and construction decisions led to poor quality (poor ventilation, overheating, leaky points,...)
Initial problems with new technologies, but many of the companies that invested in the innovations are still in business	The demonstration programme for this building was abandoned and a follow-up project (PLEAIDE) was not realised until 1994 with predefined performance criteria*
The decline in the gas price prompted the authorities and banks to withdraw from follow-up projects, but the demonstration project is still used to promote the passive house concept in the Netherlands	Until today, a strong emphasis exists in policy on providing a good indoor climate, ventilation and the avoidance of overheating. Indoor climate criteria have been integrated directly in Belgian energy performance legislation

Sources: The Netherlands: Kristinsson (2007); Belgium: Wouters *et al.* (1986); Vlaams Parlement (1998)

* For example, the design criteria for the Belgian reference dwelling 'PLEIADE' were defined by Wouters *et al.* (1993): (1) meet low-energy demand for heating, (2) provide good thermal comfort conditions in both winter and summer with attention to the problem of overheating, (3) establish very good building air tightness ($n_{50} \leq 1h^{-1}$), (4) provide good conditions for indoor air quality, (5) establish an attractive design for the majority of potential clients and (6) use only realistic technical solutions.

low-energy houses were defined with more specific criteria by the regional government within the framework of a clustering initiative (CALE, 2010). In the Brussels Capital Region, energy performance ambition levels were defined in a demonstration programme with associated grants (Leefmilieu Brussel, 2010). The Flemish assembly of environmental non-profit organisations (BBLV, 2010) introduced a charter for defining low-energy houses according to a German model and kilowatt-hour per square metre definition,[11] but it was not accepted in policy initiatives. Flemish architects recently received the proposal to become listed when working on low-energy houses (EA 2010). In paral-

11 For example, in Germany, many projects have been developed and subsidised with the aim of reaching the criterion of 40-60 kWh/m²a, as the maximum total energy demand for space heating (Zick, 2008).

lel, business networks aiming for a higher ambition level introduced a passive house definition and labelling in the Flemish Region, the Brussels Capital Region, the Walloon Region and the Netherlands (PEP, 2008; Mlecnik *et al.*, 2010).

9.3.5 Legal definitions

Next to the previous definitions listed in Table 9.2, in Belgium definitions for the low-energy house, the passive house and the zero-energy house were formalised in federal income tax[12] legislation (Belgisch Staatsblad – Moniteur Belge, 2009; 2010) as shown in Table 9.3. A Royal Decree (Belgisch Staatsblad – Moniteur Belge, 2010) reconfirms these definitions for 2011–2012 and defined that the 'renewable energy' in the 'zero-energy' house should be produced by:

1. A system of water heating using solar energy.
2. Solar panels for the conversion of solar energy into electrical energy.
3. Heat pumps that use energy stored in the form of heat:
   - in the surrounding air
   - under the soil surface
   - in surface water.

The number of kilowatt-hours generated renewable energy had to be calculated with the regional EPBD method provided by the Directive CE/2006/32 applicable on the house. An exception was made when this method did not provide an evaluation of the production of renewable energy. In that case, the conversion efficiency and the ratio between input and output of the systems and equipment for renewable energy had to be valued by means of a European/international procedure.

In the Netherlands, no definitions have been adopted so far in legal references. The Dutch agency for innovation and sustainability policy (Agentschap.nl) has tried to steer the definition process with a report (PEGO, 2009) but without explicitly defining nearly zero-energy houses. Dutch experts argue if energy demand only needs to be lowered on the scale of a house, since energy can also be produced at a higher level such as the site, district or community (Ravesloot, 2005). The term 'energy neutral' is being addressed in the Netherlands by a construction norm, defining the energy performance on location calculation method, which is applied to developments larger than 300 living units and by attributing a maximum score to energy-neutral neighbourhoods (Verlinden *et al.*, 1999).

Recently, a Dutch report (DHV, 2010) also concluded that the term 'climate neutral' should no longer be used for utility buildings: The term 'energy neu-

12 For 2011, the fiscal advantage during 10 years was €420 for low-energy houses, €850 for passive houses and €1,700 for zero energy houses. Note that the federal income tax advantage was cancelled by the recently installed government.

Table 9.2 Definitions used in Belgium* and the Netherlands (status December 2009)

Category**	Energy criteria for homes	Reference
Low-energy house	Under no specified calculation model: The annual total energy demand for space heating should be limited to 60 kWh/m² gross floor area	Flemish charter 2003 (BBLV, 2010)
(Low-energy house)	Under the conditions in the Flemish EPB calculation model: The E-level should be limited to 60	Label for Flemish architects (EA, 2010)
(Low-energy house)	Under the conditions in the Flemish EPB calculation model: The E-level should be limited to 60	Flemish grants from energy providers (VEA, 2010)
Low-energy house	Under the conditions in the Walloon EPB calculation model: $E_w \leq 80$	Baseline for subsidies in the Walloon Region (Energie Wallonie, 2011)
Low-energy house	Under the conditions in the Walloon EPB calculation model: $E_w \leq 70$; $E_{spec} \leq 120$ kWh/m²/year	Label for construction companies and architects (CALE, 2010)
Low-energy renovation	Under the conditions in the PHPP 2007 calculation model: The annual total energy demand for space heating is limited to 60 kWh/m² of conditioned floor area	Project listing for exemplary actors Brussels Capital Region (Leefmilieu Brussel, 2010)
(Very-low-energy house)	Under the conditions in the Flemish EPB calculation model: The E-level should be limited to 40	Flemish grants from energy providers (VEA, 2010)
Very-low-energy renovation	Under the conditions in the PHPP 2007 calculation model: The annual total energy demand for space heating is limited to 30 kWh/m² of conditioned floor area	Project listing for exemplary actors Brussels Capital Region (Leefmilieu Brussel, 2010)
Passive house	Under the conditions in the PHPP 2007 calculation model: The annual total energy demand for space heating is limited to 15 kWh/m² of conditioned floor area; The annual total primary energy use is limited to 45 kWh/m² year for heating, domestic hot water and auxiliary equipment (fans, pumps), excluding lighting and appliances	Exemplary projects Brussels Capital Region (Leefmilieu Brussel 2010; PMP, 2011)
Passive house (including non-residential)	Under the conditions in the PHPP calculation model: The annual total energy demand for space heating and cooling is limited to 15 kWh/m² of conditioned floor area; The annual total primary energy use for all appliances, domestic hot water and space heating and cooling is limited to 120 kWh/m² (the Netherlands) or to a compactness related formula*** (Belgium)	Current definition promoted by Belgian and Dutch business networks: PHP, PMP, Passiefbouwen.nl and research centres in Belgium and the Netherlands: ECN, SBR, BBRI

* Meanwhile conditions have been revised in the Brussels Capital Region.
** The brackets indicate that the term is not specifically used in reference documents.
*** {90 – 2 × Compactness kWh/m²a} where the compactness [compactness=V/A] is a ratio between the building volume (V) and the envelope surface area (A).

tral' is recommended when addressing buildings and 'CO_2 neutral' when addressing the organisational context.

9.3.6 Discussion: the policy challenge of introducing 'nearly zero energy' in Belgium and the Netherlands

The previous research data show that many definitions are already used. Definitions used in individual marketing efforts or demonstration projects

Table 9.3 Definitions of highly energy-efficient houses in Belgium (status December 2009)

Scope	Income tax reduction* for homes situated in the European economic area
Low-energy house	The total energy demand for space heating and cooling should be limited to 30 kWh/m² conditioned floor area
Passive house	The total energy demand for space heating and cooling should be limited to 15 kWh/m² conditioned floor area During a pressurisation test (according to the NBN EN 13829 norm) with a pressure difference of 50 Pa between inside and outside, the air loss should not be more than 60% of the volume of the house per hour ($n_{50} \leq 0.6/h$)
Zero-energy house	Comply with the conditions for a Passive House The residual energy demand for space heating and cooling can be fully compensated by renewable energy produced on site

Source: Belgisch Staatsblad - Moniteur Belge (2009)

* Note from the author: the income tax reduction scheme was deleted in 2012.

are probably not widely diffused. Several experts stated that the knowledge of building experts, the collaborative interests of consultant engineers and research scientists and the lessons of nature and of indigenous architecture should not be ignored in housing. Researchers apparently developed their own research language throughout the years. The 'passive house', born from the research field and adopted by industry, can currently be considered as a state-of-the-art culmination of many of the research efforts in bioclimatic architecture and integrated energy design, whilst using the Trias Energetica.

The Belgian Regions and the Netherlands are (thinking about) tightening the energy performance levels (and the current implementation of the EPBD) towards 'low energy' or 'nearly zero energy', but definitions and level of implementation can vary in different regions. Tables 9.2 and 9.3 show that definitions vary, even for the passive house, and that earlier market definitions can conflict with legal definitions. Some interviewees mentioned that efforts in harmonization are wished for. The findings are in line with the study of Thomsen *et al*. (2008) for 22 European countries: In some countries, official definitions coexist with unofficial definitions.

Compared to the Netherlands, in Belgium, the legal definition supports the 'passive house' as a political ambition to lower energy use in the building sector – see also Dyrbøl *et al*. (2008) and Mlecnik *et al*. (2010) for a European comparison – and as a preferred model for business development – this model is also supported by EeB (2009). This has historical reasons: The introduction of previous grants and tax relief for passive houses in Belgium helped to create a niche market for similar demonstration projects (Mlecnik and Marrecau, 2008; Mlecnik, 2008). This niche market is currently supported by business networks, research centres and a few policy makers. 'Passive house' does not conflict with commonly regionally used research definitions, although researchers prefer to look beyond the energy scope or beyond the building.

The European Parliament recommended to introduce financial incentives and to express the energy performance of a building in a transparent man-

Table 9.4 Possible barriers (relative advantage and compatibility) of definitions of highly energy-efficient houses in Belgium and in the Netherlands, in the framework of the EPBD recast

Definition initiative (reference)	Financial incentives for high energy efficiency?	Tool recommended to calculate primary energy use in kWh/m²a
BBLV (2010)	Not directly related to the initiative	No, Flemish EPB of PHPP can be used
EA (2010)	Not directly related to the initiative	Flemish EPB software
CALE (2010)	Not directly related to the initiative	Walloon PEB software
Leefmilieu Brussel (2010)	Grants for (selected demonstration) projects	PHPP software*
Belgisch Staatsblad - Moniteur Belge (2009)	Income tax relief	Not particularly mentioned, confirmation according to the definition should be proven by means of a certificate**
PEGO (2009)	Not related to a definition of highly energy-efficient housing	No, several possible tools are presented
DHV (2010)	No specific recommendations	Limits acknowledged of EPC calculations: defining the ambition level requires other tools

PHPP: Passive House Planning Package

* The PHPP is a software tool designed by the Passive House Institute Darmstadt for the evaluation of passive houses. For Belgium and the Netherlands, it is available in a regional version.

** A certificate issued by one of the following: (1) an institute recognised by the King, (2) a competent regional administration or similar administration and (3) a competent administration situated in another member state of the European Economic Area. In practice, in 2008 and in 2009, the tax administration relied on PHP and PMP as 'institutes' and on the already developed passive house label.

ner and to include a numeric indicator of primary energy use expressed in kilowatt-hour per square metre per year (European Parliament 2009; Amendment 82). Table 9.4 lists how several definition initiatives are currently related to financial incentives and whether tools are recommended for an expression in kilowatt-hour per square metre per year. Table 9.4 shows that the relative advantage (financial incentives) and/or interregional compatibility with the EPBD recast (tool for calculation of primary energy use) of highly energy-efficient housing definitions can be improved.

The research further notes that the 'integrated energy design' and the 'cradle-to-cradle' discussion were also incorporated in the transition arena on sustainable housing in Belgium. This led, amongst others, to a recommendation to stimulate the further development of energy-neutral housing and to facilitate a positive market climate for passive houses (Dries, 2007). When the definitions are reflected in relation to their historical background, e.g. the definition of criteria for bioclimatic architecture (Wouters *et al.*, 1993), it is noted that in the case of 'zero-energy' and 'passive house', there are currently no legal specifications for good indoor climate conditions and an attractive design for a majority of potential clients. Since the recast of the EPBD (2010) offers opportunities to revise definitions, the next section puts a focus on comparing experiences with other countries.

9.4 Experiences in other countries

9.4.1 Zero-carbon in the UK

A 'true' zero-carbon home[13] is expected to emit no CO_2 and does not need to import grid electricity (RAB 2007). Heating loads are minimal and any remaining heating needs are met with renewable fuels and technologies. Similarly, electricity demand is reduced to a minimum and any remaining demand is met with renewable electricity. In reality, the achievement of 'true zero-carbon' is a costly business as energy needs to be stored in order to overcome the mismatch between supply and demand in many renewable systems (RAB, 2007). The alternative is the 'net zero-carbon' home, which emits no net CO_2 on an annual basis, but could be either emitting or offsetting it at any given moment.

The term 'zero-carbon' homes appeared in official UK policy even though the technical aspects still had to be defined. The UK government has pledged to achieve zero-carbon standards for all new government-funded homes by 2016 (Jones *et al*., 2008). In February 2007, the Welsh Assembly announced that all new buildings funded by the Assembly must achieve zero carbon by 2011, but it was reported that it was still to provide a definition of zero carbon and explain how the targets are to be achieved (Jones *et al*., 2008).

In 2007, England adopted the BRE Code for Sustainable Homes (BRE, 2006) as a reference framework. The government introduced the Code for Sustainable Homes (CSH) rating as a first major attempt to define 'sustainability in the built environment'. The CSH rates the sustainability of a development on the basis of nine key criteria, only one of which is energy and CO_2 emissions (Saunderson *et al*., 2008). This initial step also included a first definition of a zero-carbon home.

The latest version of the CLG guide (CLG, 2009:46) defines a home as zero carbon when 'net CO_2 emissions resulting from ALL energy used in the dwelling are zero or better. This includes the energy used in the operation of the space heating/cooling and hot-water systems, ventilation, all internal lighting, cooking and all electrical appliances.'

Dwellings must meet the minimum mandatory energy requirements for CSH Level 5 – which means that that emissions must be zero or better. The definition (CLG, 2009:46) further states that "A 'zero-carbon home' is also required to have a Heat Loss Parameter (HLP) (covering walls, windows, air-tightness and other building-design issues) of 0.8 W/m^2K or less, and net zero

13 This definition of zero carbon is similar to the definition of 'autonomous' as in 'autonomous house': The evolution, significance and implications of the definition of 'autonomous' over the years has been reviewed by Brenda and Robert Vale (Vale and Vale, 2002).

CO_2 emissions from the use of appliances and cooking in the home (i.e. on average over a year)." According to the UK definition, off-site renewables can only be used if they are directly supplied to the dwellings by private wire.

Further, a zero-carbon house is also defined in the Stamp Duty Land Tax SDLT (UK Government, 2007) as a house that should meet the following criteria: fabric energy efficiency (minimum HLP of 0.8 W/m^2K), space heating demand (up to 15 $kWh/m^2/year$) and carbon neutral over a year. SDLT and CSH version 2 definitions of zero carbon are similar, except for the unregulated energy[14] that is a fixed value for the SDLT (Poveda, 2010).

9.4.2 'Zero-energy' definitions

The term 'net zero energy' first appeared in US law, but it was defined for commercial buildings. On 19 December 2007, the US Administration passed the Energy Security and Independence Act outlining plans for 'net-zero-energy commercial buildings' and stating that all new commercial buildings should attain net-zero-energy status by 2030 (USC, 2007). In Section 422 (a) (3) (USC, 2007:113), 'zero-net-energy commercial building' is defined as a high-performance commercial building that is designed, constructed and operated in such as way that:

- it has a much-reduced energy requirement;
- it meets the residual energy needs from sources that do not produce greenhouse gases;
- it produces no net emissions of greenhouse gases;
- it is economically viable.

In a number of publications (Torcellini and Crawley, 2006; Laustsen, 2008b; Crawley *et al*., 2009; Marszal and Heiselberg, 2009), authors present the wide

14 Unregulated energy involves energy demand of electrical appliances such as fridge, microwave, TV, radio; both 'white' (kitchen) and 'brown' (entertainment) goods. The unregulated energy is estimated using a formula that accounts for total floor area and a factor for the number of occupants.

15 Net-zero-energy definitions according to Torcellini *et al.* (2006):

- MeetNet zero site energy: A (zero energy building) site produces at least as much energy as it uses in a year.
- Net zero source energy: A source (zero energy building) produces at least as much energy as it uses in a year. Source energy is the primary energy used to generate and deliver the energy to the site. A building's total source energy is calculated by multiplying the imported and exported energy by site-tosource converters.
- Net zero energy costs: The amount the utility pays the owner of the building for the energy exported to the grid is at least equal to the amount the owner pays the utility for the energy services and the energy used over the year.
- Net zero energy emissions: A net-zero-emission building produces at least as much emission-free renewable energy as it uses from emission-producing energy sources.

variety of zero-energy working definitions and highlight the significance of these definitions in the framework of final design and actual performance. Torcellini *et al*. (2006) have defined 'net zero site energy' and 'net zero source energy'.[15] 'Net zero site energy' means that a site produces at least the same amount energy that it uses in a year, regardless of energy type. 'Net zero source energy' refers to a system whereby imported and exported energy is multiplied by a primary energy converter, which allows for some degree of flexibility in the use of heating fuels. Hernandez and Kenny (2010) attempted to introduce a further element in the definition of zero-energy buildings, viz. the embodied energy[16] of the materials used for the construction of the building and its systems. 'Energy-positive' buildings are defined as buildings that are able to produce more energy than they use.

Discussions are still underway at international level (IEA SHC Task 40, 2010) to determine whether these definitions should be evaluated on an annual or on a seasonal basis to reduce the energy mismatch. The 'Source' definition is difficult to interpret since there are no readily available data on the location, source and conversion (Torcellini and Crawley, 2006). 'Site' can also be difficult to define, e.g. does it refer to the building site or the total ground surface? Building owners are primarily interested in obtaining verification that their building has 'net zero-energy cost' status, but this is difficult to determine in practice because of the non-transparent structure of energy rates (Torcellini and Crawley, 2006). Sartori *et al*. (2010) developed a series of criteria that need to be evaluated in order to achieve a sound zero-energy definition.

There are many unanswered questions. For instance, there is no standardised way of making zero-energy calculations (Voss, 2008; PEGO, 2009). The problem is not so much the lack of a definition but rather the need for appropriate analysis and representation methodologies to reveal differences and commonalities (Voss, 2008). As evaluations of zero-energy projects are usually based on calculations, decisions need to be taken on which units to use (final energy, primary energy, non-renewable share of primary energy, CO_2, CO_2 equivalent etc.) (Voss, 2008; PEGO, 2009).

9.4.3 Discussion: relevance for Belgium and the Netherlands

The research detected only a few additional legal references considering the definition of zero-energy or zero-carbon buildings (see Table 9.5 for an overview). The starting point for all common definitions is a far lower level of energy use than standard. 'Zero carbon' or 'net zero energy' has not been de-

16 Embodied and operational energy was also studied for solar houses and passive houses; see, for example, Sartori and Hestnes (2007).

Table 9.5 Legal references and key requirements for nearly zero-energy buildings (status December 2009)

Definition initiative (country)	Legal reference: key requirements
Zero-energy house (Belgium)	Belgisch Staatsblad - Moniteur Belge 2009: The annual total energy demand for space heating and cooling should be limited to 15 kWh/m² conditioned floor area; During a pressurisation test (according to the NBN EN 13829 norm) with a pressure difference of 50 Pa between inside and outside, the air loss should not be more than 60% of the volume of the house per hour ($n_{50} \leq 0.6h$); The residual energy demand for space heating and cooling can be fully compensated by renewable energy produced on site.
Zero-carbon home (UK)	Code for Sustainable Homes (Level 5): Energy-related net CO_2 emissions from a dwelling over a year (emissions from energy required for heating, hot water, lighting and ventilation as well as appliances and cooking) ≤ 0; Heat loss parameter ≤ 0.8 W/m²K; Equivalent renewable energy generation capacity must be installed to reduce CO_2 emissions to zero. All installations for the generation of renewable energy must be located within the curtilage of the development or directly connected. In the case of electricity installations this means a private wire connection.
Zero-net-energy commercial building (USA)	US Congress (USC 2007:113) Section 422 (a) (3): A high-performance commercial building that is designed, constructed and operated in such as way that: ■ it has a much-reduced energy requirement ■ it meets the residual energy needs from sources that do not produce greenhouse gases ■ it produces no net emissions of greenhouse gases ■ it is economically viable.

fined in official Belgian or Dutch policy although the above-mentioned discussions have been acknowledged by the Dutch policy body responsible for the energy transition (PEGO, 2009). Belgium opted for another legal approach to the 'zero-energy' house (see Tables 9.2 and 9.5).

The implementation of the UK 'zero-carbon' definition can be considered as a regional implementation. Regarding the specificity of the Belgian and Dutch context, it could inspire in particular the Netherlands, where the term 'carbon neutral' is often used in marketing. However, the use of an assessment method for zero-carbon homes, such as the Code for Sustainable Homes with its emphasis on point scoring, may cause people to see higher complexity and sustainability as add-ons, rather than integral elements in housing design (Jones *et al*., 2008). Also, many players in UK industry expressed concern at the inclusion of the private wire connection (Saunderson *et al*., 2008).

Terms like 'zero carbon' and 'zero net energy' were coined to simplify the issue and make it more 'accessible', but these simplifications may themselves be to blame for constraining debate and stifling innovation (Saunderson et al., 2008). It can therefore be questioned whether introducing such new definitions, next to the already existing research, marketing and legal definitions in Belgium and the Netherlands, will improve innovation diffusion.

Table 9.6 Examples of how definitions used can have an impact on the adoption of highly energy-efficient housing concepts, using Rogers' innovation diffusion characteristics (2003)

Perceived attribute of an innovation and relation to rate of adoption	Example of interpretation for nearly 'zero-energy' houses
Relative advantage	
The greater the perceived advantage, the more rapid the rate of adoption	When in Belgium a more important tax reduction is given for a 'zero-energy house' than for a 'Passive House' and a 'low-energy house', the adoption of more energy-efficient housing concepts is expected to increase.
Complexity	
Simpler innovations are adopted more rapidly	A simple definition can be easily communicated. A complex evaluation procedure can evoke opposition. Example: Initially, the idea of 'zero-carbon buildings' met with a favourable reception from UK industry, but when the detailed requirements were unveiled many businesses found them unrealistic and unnecessarily complicated and either down-scaled their ambitions or abandoned projects altogether (Saunderson *et al.*, 2008).
Demonstrability	
Opportunities for education and hands-on learning and innovation trials on a partial basis could improve the rate of diffusion	The industry is concerned that, even under favourable conditions many homes may be unable to generate sufficient electricity on-site [to reach net zero energy] due to physical restrictions alone (RAB 2007). This can decrease the diffusion rate of 'zero-energy'.
Visibility	
The easier it is for individuals to see the innovation and its results, the greater the likelihood that they will adopt it	An independent institute (e.g. for grant control) can certify the definition of 'Passive House'. The official certificate can serve as a marketing tool and certified projects can be made public in a database (Mlecnik, 2008). This appeal is currently further enhanced by independent appraisal (Belgisch Staatsblad - Moniteur Belge 2009): confirmation according to the legal definition should be proven by means of a certificate issued by one of the following: ■ An institute recognised by the monarch ■ A competent regional or similar administration ■ A competent administration situated in another member state of the European Economic Area.
Compatibility	
Incompatibility will not lead to adoption unless a new value system is embraced; this is a relatively slow process	The research efforts relating to defining zero-energy buildings focus primarily on local energy generation (integrating for example massive PV, micro-generation...) without taking too much account of some integrated energy or bioclimatic design aspects (popular in Belgium) like lowering the operational costs of the building whilst striving for a comfortable indoor climate. In discussions on net-zero-energy buildings the first and third step of the Trias Energetica are often conflated.

9.5 Definitions with favourable innovation characteristics

9.5.1 Relating definitions to innovation diffusion

The goal in the Netherlands and Belgium is to increase the adoption of highly energy-efficient housing (PEGO, 2009; Dries, 2007). Within this framework, zero-energy or ‘zero-carbon’ housing can be considered an innovation for Belgium and the Netherlands, in addition to the ‘passive house’. Clear definitions of highly energy-efficient housing concepts geared to attaining ‘nearly zero-energy’ homes are expected to bring this goal closer and promote innovation in housing.

In this paper, definitions of such innovations are seen as a communication tool in a changing economic and legal landscape. Innovation diffusion theory examines the processes whereby an innovation is communicated through certain channels over time amongst the members of a social system (Rogers, 2003). Mobilising resources and creating legitimacy are two basic functions that innovation systems need in order to develop (Alkemade and Hekkert, 2009). Clear definitions can create legitimacy and associated resources can form a basis for the development of market infrastructure.

Rogers (2003) identifies five perceived attributes of an innovation that can help to explain the rate of adoption of an innovation: relative advantage, complexity, trialability (in this paper ‘demonstrability’ is used), observability (here ‘visibility’ is used) and compatibility. Table 9.6 gives examples how these attributes can be interpreted for our previous discussion.

9.5.2 Opportunities and barriers in the Netherlands

The energy transition platform for the built environment has put forward several definitions for use and evaluation in the Dutch market and wanted to define further requirements for energy-neutral and CO_2 neutral building projects relating to, for example, maximum energy use per square metre (PEGO, 2009:43). Therefore a ‘carbon-neutral’ approach appears to be most compatible with the current market and policy situation. However, it should be noted that, when the term ‘zero carbon’ was first introduced in the UK and prototypes were developed, case studies within this framework showed that an integrated energy design can offer a total package of both passive and active measures to achieve zero carbon (Jones *et al.*, 2008). In this perspective, defining more precisely the integrated energy design and the Trias Energetica approach can also result in zero carbon solutions for the Netherlands. Regarding the market support, this might also result in ‘passive house’ as a preferred term. A strategy for formulating any definition is still needed, as well as appropriate calculation tools and a study to determine compatibility with the new regulations on the energy performance of buildings.

The market appeal of terms for highly energy-efficient housing in the Netherlands is currently limited because no definitions have been adopted so far in legal references. However, demonstrability is high and the Dutch agency for innovation and sustainability policy (Agentschap.nl) has tried to steer the definition process and acknowledged the complexity of the transition process. Many definitions are currently in circulation, not least in the application files of the subsidy programme for demonstration projects (in Dutch: ‘Unieke

Kansen Regeling' or 'UKR').

At present, a definition of 'low energy' based on the Dutch energy performance legislation has the highest visibility in official websites, whilst 'zero carbon' is often used in projects. Both might have low compatibility with the desire of the European Parliament to express indicators of primary energy use in kilowatt-hour per square metre per year (see Table 9.4). In the meantime, 'passive house' is used by industry networks and a few communities and housing associations.

At present, no specific relative advantage has been attributed to certain definitions – for example, in the form of grants or tax benefits, or social prestige for the market players. This might lead to low visibility and market confusion. The Dutch 'Unieke Kansen Regeling' programme allows communities to apply for grants for demonstration projects for very-low-energy houses. A continuation of this programme potentially offers a trial of grants for certain (prescribed) definitions. Experiences from the previous call for projects can lead to defining favourable definitions for a next call. Also, other countries, like Belgium, might provide experiences from a more advanced policy situation.

9.5.3 Opportunities and barriers in Belgium

In Belgium, definitions for the low-energy house, the passive house and the zero-energy house have been formalised in tax legislation (Belgisch Staatsblad – Moniteur Belge, 2009; 2010), which created attractiveness to use these definitions and gave an opportunity to reduce complexity. The tax law provided a clear framework plus income tax relief incentives which enhanced the market appeal by creating a clear relative advantage. The tax benefits based on energy performance made people perceive a higher energy performance as superior to other alternatives possibly leading to a faster rate of adoption.

The introduction of the low-energy and zero-energy category, in addition to the already existing passive house category, has been perceived as allowing demonstrability consistent with the existing regional value of the 'passive house'.[17] It would therefore be reasonable to expect that past experience and

17 'Net zero carbon' is relatively rarely used in Belgium. In contrast, the non-profit organisations Passiefhuis-Platform and Plate-forme Maison Passive in the Belgian market have counted more than 150 companies that use the term 'passive house' in their marketing. In contrast with the Netherlands, the definition for 'net-zero-energy' in Belgium has no significant basis as yet in market infrastructure or in regional policy. Compared with other definitions, the 'passive house' has an obvious advantage in that the related criteria and instruments are readily available. Since space heating accounts for the majority of the total energy use of households in the European Community, a policy focus on definitions that stand for a substantial reduction in the demand for space heating is compatible with the desire to reduce the primary energy demand and achieve political ambitions. Nevertheless, calculation procedures should be carefully revised when introducing any definition of nearly zero-energy housing, so that a reality-based estimate of energy use can be provided.

Table 9.7 Grants for new low-energy housing categories in the Flemish Region, according to E-level (building energy performance level) for building applications from 1 January 2010 (VEA, 2010) and in the Brussels Capital Region (Leefmilieu Brussel, 2010)

Housing category	Grant	Possible additional grant
E60 Dwelling (Flemish Region)	€1,000	+ €40 per E-level point below E60 + €300 solar boiler
E40 Dwelling (Flemish Region)	€1,800	+ €50 per E-level point below E40 + €300 solar boiler
E60 Apartment (Flemish Region)	€400	+ €20 per E-level point below E60 + €300 solar boiler
E40 Apartment (Flemish Region)	€800	+ €30 per E-level point below E40 + €300 solar boiler
Passive house (Brussels Capital Region)	€100/m² floor area for houses up to 150 m² and €50/m² floor area for houses above 150 m²	+ first blower-door test + €/m² for several 'sustainable' options (e.g. roof insulation, wall insulation, environmentally friendly insulation materials, Forest Stewardship Council labelled wood window frames)

the needs of (potential) adopters will be more readily adopted.

In this context, the visibility of uniform definitions to potential adopters can be considered a key factor in diffusion. This visibility is built up by, amongst others, business networks, mixed policy/business networks and promotion by the federal government taxation services (for example, at building fairs).

However, the tax law and market definitions are currently not compatible with the regional EPBD (2002) implementation. The diffusion of these definitions might therefore be hindered by current regional initiatives promoting other or previous EPBD-related definitions. For example, Table 9.7 shows the additional grants available under the energy performance regulations in the Flemish Region and in the Brussels Capital Region (Status December 2009).

The Brussels Capital Region offers a specific situation. The Flemish Region and the Brussels Capital Region are pursuing the same strategy to increase the relative advantage for a better energy performance by buildings. In the Brussels Capital Region – in contrast with the Flemish Region – the definitions of the passive house are maintained for grants, regardless of the legislation on the energy performance of buildings. This is largely due to the good visibility and compatibility that the definition provides within the framework of the policy programme for demonstration buildings in the Brussels Capital Region. Moreover, the calculation tools for passive houses must be used for evaluation, which is compatible with the design practice of passive houses. In the Brussels Capital Region, the passive house is the only category to be rewarded with grants for new houses. 'Very low energy' (≤30 kWh/m^{2}a) and 'low energy' also receive grants, but only for renovation.

EPBD incompatibilities should be solved when introducing the EPBD recast (EPBD, 2010). Previous research has shown that the current energy performance standard can lead to 'lock-in' effects by encouraging only incremental innovation and techniques that reflect the principles in the energy performance policy (Beerepoot, 2007: 204). It is recommended to avoid penalising

Table 9.8 Innovation characteristics that can influence the rate of adoption of definitions of nearly zero-energy housing concepts in the Netherlands, the Flemish Region and the Brussels Capital Region (Status December 2009)

Attractiveness	Demonstrability	Visibility	Compatibility	Complexity
the Netherlands				
Lack of legal definition = lack of attractiveness	High but current (UKR) demonstration programme does not distinguish definitions	High for 'carbon neutral', emerging for 'passive h ouse'	'passive house' compatible with IED and Trias Energetica	Platform Energy Transition tries to reduce complexity
The Flanders Region				
Marketing makes 'passive house' solutions attractive	'passive house' important trial area; 'zero-energy' new trial area	High for 'passive house', emerging for 'zero-energy house'	Federal Decree compatible with 'low energy', 'passive house' and 'zero energy', less compatible regional interpretations	Transition network reduces complexity with information and education
The Brussels Capital Region				
Policy and market embraces 'passive house'	Current demonstration programme allows trials for different building typologies	High for 'passive house', involved actors are listed by official demonstration programme	Compatible Federal (Royal) Decree	Company clustering and facilitators reduce complexity

techniques that break with convention and that are needed for the transition to nearly zero-energy housing, e.g. some experts noted that 'passive houses' are systematically penalised for fictitious overheating in Flemish EPBD implementation.[18]

9.6 Discussion

Table 9.8 presents a summarised interpretation of the discussion to show how definitions can influence the rate of adoption for nearly zero-energy housing in three regions. Table 9.8 shows that the policy interpretation of 'nearly zero energy' into workable local definitions might differ from region to region, depending on the adoption history of highly energy-efficient housing concepts and the existence of specific policy programmes which have already introduced certain definitions. Where necessary, the relative advantage, demonstrability, visibility and compatibility of favoured definitions can be enhanced by energy policy initiatives to increase the rate of adoption.

18 Due to historical reasons (compare with the negative experiences in Table 9.1), the regional EPBD expresses energy performance in a non-dimensional parameter and also includes an indoor climate appreciation. Fictitious overheating often appears and is penalised in calculations for passive houses.

9.7 Conclusion

Definitions for highly energy-efficient housing have been introduced through general terms and demonstration projects and have been adopted and refined by innovators, researchers, business networks, mixed business/policy networks and policy developers. In search of defining nearly zero-energy dwellings, international researchers are currently proposing prominence of the terms 'net zero energy' and 'net zero carbon' in addition to 'low energy' and 'passive house', in order to enable compatible regional market infrastructure development and innovation diffusion. Although definitions can have a different meaning in different regions and are poorly integrated internationally, a few countries have already adopted definitions in their building or fiscal policies.

The analysis shows that in Belgium and the Netherlands, 'passive house' cannot be neglected as a useful term, offering market and some policy acceptance, for the realisation of net zero-energy or zero-carbon definitions in the future implementation of national energy policies. A clear definition compatible with the regional context is necessary to increase attractiveness and demonstrability. Though the reduction or offsetting of energy and/or emissions in nearly zero-energy definitions seems fairly straightforward, the complexity when examined in detail and when integrated in building energy performance regulations can be reduced.

An important challenge to avoid market confusion is that targeted definitions are clearly formulated and used consistently at all political levels, national and regional. Whilst the research shows that new terms have been easily introduced, a huge effort lies in providing – and reducing the complexity of – associated evaluation procedures and in improving compatibility with local legislation and the recast of the energy performance of buildings directive. The Belgian situation provides an example of a legal framework, compatible with the required EPBD recast, in order to reward better energy performance for passive houses and zero-energy houses. It shows that early fiscal tools can be used to reduce market confusion and to try out or enforce definitions for highly energy-efficient houses.

A challenge now remains in providing a system of appraisal, especially with regard to compatibility with market initiatives and regional grant schemes, regional implementation of the recast of the EPBD, administrative control of tax relief and other energy-related issues (e.g. calculation of relevant energy indicators and tools, indoor climate appraisal and so on). These quality appraisal systems will be an important subject of future research.

Acknowledgements

The author wishes to thank the members of the International Energy Agency joint SHC Task 40/ECBCS Annex 52 task force for fruitful discussions. The author also wishes to thank Shady Attia (Attia and De Herde, 2010) of the Université Catholique de Louvain-la-Neuve (Architecture & Climat) and Stefan Van Loon of Passiefhuis-Platform vzw for providing useful comments and clarifications.

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10 Barriers and opportunities related to labels for highly energy-efficient houses

Published as: Mlecnik, E., H. Visscher & A. van Hal, 2010, Barriers and opportunities for labels for highly energy-efficient houses, ***Energy Policy 38*** *(8), pp. 4592-4603, http://dx.doi.org/10.1016/j.enpol.2010.04.015, http://www.sciencedirect.com/science/article/pii/S0301421510002892*

Abstract

Promoting energy efficiency in the building sector is essential if the agreements of the Kyoto Protocol are to be honoured. Different initiatives for energy labelling of highly energy-efficient residential buildings have emerged throughout Europe as an essential method to stimulate market demand, to control grants or to ensure the quality of demonstration projects with excellent energy performance. The paper identifies the barriers and opportunities for the further diffusion of labels for highly energy-efficient houses. A model based on the theory of the diffusion of innovation is developed to analyse perceived attributes of existing European labels. The paper investigates the innovation characteristics of existing labels in Europe, with a focus on advanced countries. The question of compatibility with the development of the European Energy Performance of Buildings Directive (EPBD) is examined in detail.

The study found that the diffusion of emerging and already existing voluntary European labels for highly energy-efficient houses is needed. Their complexity can be lowered and relative advantage, trialability, observability, and compatibility can be increased. EPBD calculation procedures should be able to receive highly energy-efficient houses. In the framework of the recast of the EPBD, official recognition of existing voluntary labels is recommended.

10.1 Introduction

Europe's buildings remain a large energy user comprising 40% of final energy use and 36% of EU CO_2 emissions (ACE *et al.*, 2009; Itard *et al.*, 2008). There are considerable differences between the various European countries, but on average the residential stock, comprising households, is responsible for 30% of total final energy use (Itard and Meijer, 2008). On average, tap water and space heating are responsible for over 60% of the final energy use in both residential and nonresidential stocks (Itard and Meijer, 2008). These findings clarify that more significant reductions in residential primary energy use and space heating in particular, can have a direct and major impact on achieving climate change and energy efficiency objectives. The eventual aim in terms of energy reduction in the building sector is to mitigate climate change, and reducing energy use in the building sector is considered one of the most important and affordable means to this end (IPCC, 2007).

The European Energy Performance of Buildings Directive, in short EPBD

(EC, 2002), determines the framework for European countries to develop regulations for the energy efficiency of buildings. Energy performance standards and certificates are important instruments. Apart from this directive, many countries developed in the past years methods for the definition of houses with a very low energy use, of which the passive house concept is a widespread concept. To assure that the defined performances are met, specific certification schemes have been developed. In this paper we discuss the examples of such certificates in some countries and we explore the opportunities and barriers of a further dissemination of these instruments, and the relations with the (recast of the) Energy Performance of Building Directive.

Section 10.2 presents the questions and the methods that were used in the research. Section 10.3 highlights the development of certificates and labels in the framework of the EPBD, very low energy concepts and the passive house concept. In Section 10.4 the study develops a model based on the theory on the diffusion of innovation to examine the innovation characteristics of existing European labels. The study uses this model in Section 10.5 to collect expert's opinions on labels for highly energy-efficient houses. This leads to an understanding of the current status of marketing and diffusion of labels in European member states. In Section 10.6 the research examines the proposed recast of the EPBD as an opportunity or a barrier for improved diffusion of these labels. In Section 10.7 the study discusses and examines the research results with the theoretical innovation model, focusing on the most advanced European countries. In Section 10.8 conclusions are drawn on how European member states can improve the diffusion of labels for highly energy-efficient houses, and how they can integrate existing labels in the recasting of the EPBD in such a way as to promote the further diffusion of these labels.

10.2 Research question and method

10.2.1 Research question

The main question addressed in this paper is to identify the barriers and opportunities related to labels for highly energy-efficient houses. The study examines the diffusion of these labels for houses and then looks at the following subquestions:

1. *In order to improve the diffusion of the labels, what can be expected of theoretical backgrounds and the applied theory of innovation diffusion?*
2. *From expert's experiences in Europe what can be expected that will improve the diffusion of the labels?*
3. *How does the development of labels relate to the development of the EPBD in member states?*
4. *What barriers and opportunities are identified for advanced existing labels in member states?*

Examining the perceived innovation attributes of labels from the theoretical perspective, and from the commercial and energy policy perspectives, leads to conclusions on how member states can integrate labels when recasting the EPBD in such a way as to promote their improved diffusion.

10.2.2 Research method

A very important drawback of R&D into low energy and sustainable building design, is that it still seems to be carried out very much in isolation between different countries (Morbitzer, 2008: 23). The paper therefore puts a strong focus on comparing experiences from different European countries, more than on the collection of hard empirical data. To consult in this issue, experts from different countries were identified and addressed. Amongst other, a list of experts was provided by the European Council for an Energy Efficient Economy (ECEEE) and addressed with a questionnaire. Additionally, leading experts from national and regional passive house organizations, and known label developers were consulted. This research method led to replies, detailed comments, references and empirical data from a small sample, but with a good international distribution. Possible knowledge gaps were tackled with further literature search, presentation of intermediate results on conferences (Mlecnik, Kaan and Hodgson, 2008; Visscher and Mlecnik, 2009), and action-based research to develop passive house certification in one country (Belgium), involving discussions and working groups with leading experts from general building industry and research organizations.

In this paper, the first subquestion is mainly addressed through a literature search on the diffusion of innovation. Comments from experts in Belgian working groups led to an interpretation for labels.

To answer the second subquestion, the study uses the theory of diffusion of innovation to develop an internet questionnaire, directed at selected energy experts, with both open and closed questions, examining the perceived attributes of existing labels for highly energy-efficient residential buildings.

To answer the third subquestion an additional literature search and interviews were performed, focusing on international differences in critical issues such as the definition and scope of the energy labelling scheme and the implementation in practice in relation to developing the EPBD.

Research to answer the fourth question was limited to countries that have already implemented an active labelling system for residential buildings with very low energy use, during at least two years: additional literature search and interviews provided detailed insights.

In the next section the study first highlights the development of energy performance certificates and labels.

10.3 Energy performance certificates and labels

10.3.1 The European Energy Performance of Buildings Directive (EPBD)

The European Council Directive 93/76/CEE (SAVE, 1993) presented energy certification as one of the cornerstones for achieving energy efficiency in buildings. This directive states that the certification should consist of a description of the energy characteristics of the building and should provide information for prospective users about the building's energy efficiency. Being non-mandatory and riddled with ambiguities, implementation of the directive was not particularly successful throughout member states (Pérez-Lombard *et al.*, 2009). The Energy Performance of Buildings Directive, EPBD, also known as Directive 2002/91/EC (EPBD, 2002), was introduced a number of years later and also included the compulsory introduction of energy performance certificates for buildings in member states. However, this directive did not spell out the methodology the member states were to use. The European Standard EN 15217 (EN, 2007) has now been developed, and it describes methods for expressing energy efficiency and building certification. Amongst other things, this standard requires an overall energy performance index (EPI) in terms of energy use, carbon dioxide emissions or energy cost per unit of conditioned area to facilitate comparison between buildings. We note that energy use in the residential sector is indeed proportional to the useful floor area (Itard and Meijer, 2008).

In the follow-up of the European Commission's *Action Plan for Energy Efficiency: Realizing the Potential* (EC, 2006) the European Parliament (EP, 2009) has called for the provisions of Directive 2002/91/EC to be strengthened, and for a 20% energy efficiency target in 2020 to be made legally binding on member states. Member states should draw up national plans for increasing the number of net zero energy buildings and/or the number of buildings of which both carbon dioxide emissions and primary energy use are low or equal to zero, and regularly report on them to the Commission. The Council recently took on board Parliament's amendments that require member states to draw up national plans for increasing the number of practically zero energy buildings. Member states are expected to set targets for the minimum percentage these buildings must constitute of the total number of buildings in 2020, and present their results in relation to the total useful floor area (EP, 2009). National, regional or local initiatives to support measures to promote these buildings such as fiscal incentives, financial instruments or reduced VAT, are also expected of member states. The simplest solution to redraft energy performance policy and to add incentives for improved energy performance would be to introduce labels that indicate improved performance (Beerepoot, 2007: 205).

10.3.2 Labels for highly energy-efficient residential buildings and passive houses

In parallel with the development of official EPBD certificates for houses, there has been widespread development of labels for residential buildings with improved energy performance. Different initiatives have emerged throughout Europe as an essential method for stimulating market demand and for ensuring the quality of demonstration projects with excellent energy performance. There are many different kinds of low energy building labels such as ‘Certified’ Passive Houses, LEED buildings, Green Buildings, Sustainable Buildings and Zero Carbon Buildings (Laustsen, 2008). There are also several ‘green building’ ratings that assess the energy footprint mainly of large commercial buildings, and they may provide owners and occupants with a solid yardstick for the energy efficiency and sustainability of properties. For example, widely used labels include assessment in accordance with the United Kingdom’s Building Research Establishment Environmental Assessment Method (BREEAM) or the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design, LEED programme. However, the use of green building ratings has so far been limited, and the global diffusion of rating systems is relatively slow (Eichholtz *et al.*, 2008). It is also reported that a reduction in energy use is not necessarily the case for every ‘green building’ (Birt and Newsham, 2009). It therefore makes sense to study the barriers and opportunities for the further diffusion of labels, particularly those with a proven correlation with very high energy efficiency of residential buildings, and those that are compatible with international and EU objectives.

The vision of the International Energy Agency was presented at the G8 Summit in Heiligendamm. It states that zero energy buildings are feasible but they are still more expensive than traditional buildings, even over the full lifetime of the building, while so-called ‘passive houses’ are becoming economically attractive because of the reduced costs for heating and cooling systems (Laustsen, 2008). In general, it is recommended that schemes be devised that include high insulation and building air tightness levels, and passive solar strategies, while preventing overheating (Beerepoot, 2007). In practice, passive house performance criteria are translated into principles and solutions that address these specific issues (Leonardo Energy, 2006). Many countries already see a ‘passive house’ level as a long-term political ambition to reduce energy use in the building sector (Dyrbøl *et al.*, 2008).

A passive house is designed from a very specific energy performance target. A large number of ‘passive house’ demonstration projects throughout Europe define a limited target energy demand for heating of less than 15 kilowatt hour per square meter net floor surface and per year (kWh/m^{2}a) and a total primary energy demand of less than 120 kWh/m^{2}a (CEPHEUS, 2001; Kaan *et al.*, 2006; PEP, 2008). These specific design criteria for the energy use of buildings, originally made popular in Germany as 'passivhaus' criteria, have shown good correlation with real energy efficiency for residential buildings (Schnieders, 2003; Schnieders and Hermelink, 2006; Berndgen-Kaiser and Frey, 2006). Although the German credentials are high, potential and possible performance problems need to be carefully considered during design and construction. Amongst other, specific design challenges are the low heating capacity required for a passive house and the energy use and good operation of ventilation systems to assure moisture removal and indoor air quality (Morbitzer, 2008). German assessment guidelines (Feist, 1999) reveal the importance of integrated planning to achieve passive house target values. Precise attention must be given during planning and construction to avoiding thermal bridges, to air tightness and to the efficiency of heat recovery by the ventilation system. For heating, ventilation and air conditioning systems, it has been observed that incorrect dimensioning can lead to deficiencies in functioning and in the calculated energy balance. Also, careful attention must be given to avoiding overheating and adapted overheating calculations (Van Loon and Mlecnik, 2007).

Consequently, several routes have been developed for labelling passive house projects: project labelling, technology labelling, a passive house professional's accreditation scheme, and improving codes for sustainable homes (Mlecnik, 2006; Bähr and Sambale, 2009). The criteria have led to related quality assurance schemes and associated labels in many western and northern European countries (Elswijk and Kaan, 2008; Mlecnik, Kaan and Hodgson, 2008).

As basis for the introduction of net zero energy buildings or low carbon buildings in the framework of the EPBD recast, it is interesting to study the existing building labels with a focus on energy performance levels comparable with the passive house level. The elements that could either stimulate or hamper the further diffusion of these labels in the framework of the EPBD recast are studied here.

10.4 Model development: innovation diffusion theory applied to labels

10.4.1 Theory of diffusion of innovation

Energy policy studies often examine the pros and cons of regulatory and economic instruments in terms of a detailed study of environmental effectiveness, economic efficiency, dynamic technological incentives and administrative feasibility, as for example in Beerepoot and Sunikka (2005) and Murakami *et al.* (2002). When digging into diffusion research, many different views can be detected that are similar to focus issues in energy policy studies.

In the theory of diffusion of innovation, the communication perspective is often the most popular perspective, and defines diffusion as the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). Some energy policy authors view communication instruments as useful when it comes to addressing information problems, but they consider them to be supplementary, and not substitutes for economic or regulatory instruments (Ekelenkamp *et al.*, 2000; Kemp, 2000; Sunikka, 2006).

Mobilizing resources and creating legitimacy are indeed some of the basic functions of innovation systems in order for them to develop (Alkemade and Hekkert, 2009). However, some communication instruments – for example quality labels – can also be the basis for creating legitimacy and mobilizing resources. We can observe that labels for highly energy-efficient houses have been developed as a communicative instrument in order to establish initial market demand (IEA SHC Task 37; Mlecnik, Kaan and Hodgson, 2008). Sometimes, only in a later stage following market introduction by innovators, have such instruments been linked with economic incentives or regulation (Mlecnik, 2008).

Three popular perspectives in diffusion research (Brown, 1981; Miller, 2009) explain diffusion by focusing on economic improvement, affordability or communication, respectively. These perspectives have some similarities with the most frequently used typology for energy policy studies: direct regulation, economic instruments and communicative instruments – for example, see Kemp (2000), Murakami *et al.* (2002), van Hal (2000), Sunikka (2006), and Beerepoot (2007). The fourth perspective in diffusion research is often neglected in energy policy studies: the market infrastructure perspective (Miller, 2009) pays more attention to the availability at or near the location of the potential adopter. Indeed, without availability, the person involved or household would not have the option to adopt in the first place. In practice, agents can bring about a necessary change (Miller, 2009; Rogers, 2003): this could be an entrepreneur, a non-profit organization, a specific change agency, government, etc. The emergence and diffusion of an innovation are clearly affected by societal subsystems, actors, institutions and economic structures that affect the rate and direction of change in society (Edquist and Lundvall, 1993; Nelson and Nelson, 2002).

The theory on the diffusion of innovation has only occasionally been applied to the diffusion of demonstration projects (van Hal, 2000), or the diffusion of energy saving or environmental technologies (Alkemade and Hekkert, 2009; Dieperink *et al.*, 2004; Egmond *et al.*, 2006; Tambach *et al.*, 2010).

The study regards labels as a communication instrument in a changing economic and legal framework. At the same time, the study provides insights in the development of market infrastructure and related instruments. Below, a description is given of the characteristic of labels from a communication perspective on innovation diffusion.

Table 10.1 Perceived attributes of innovative labels that can explain the rate of adoption

Perceived attribute of an innovation and relation ito rate of adoption according to Rogers (2003)	Interpretation for labels
Relative advantage	
The greater the perceived advantage, the more rapid its rate of adoption	The degree of relative advantage of labels may be measured in economic terms, for example, the availability of associated financial benefits. But social prestige factors, convenience and satisfaction are also important factors.
Complexity	
Simpler innovations should be adopted more rapidly	It is important to make labelling procedures as transparent as possible, providing simple procedures with the available procedure documents, good examples, documented reports, and education.
Trialability	
Providing the opportunity for education, to learn by doing and to try out an innovation on a partial basis could improve the rate of diffusion	Documenting emerging labels and international experiences can reduce complexity for other actors.
Observability	
The easier it is for individuals to see the innovation and its results, the more likely they will adopt	The visibility of a label will often be determined by the availability of, for example, a plaque for the building, project leaflets, easily accessible internet information, media campaigns and the explicit mentioning of the associated actors and change agents in listings and documentation.
Compatibility	
Incompatibility will not lead to adoption unless a new value system is embraced, and this is a relatively slow process	Important factors are improving compatibility of the label with the EPBD development and the availability of a legal or instrumental framework for the introduction or diffusion of labels.

10.4.2 Perceived attributes of labels from the communication perspective

What can be expected to improve the diffusion of labels from the theoretical communication perspective on innovation diffusion? Rogers (2003) defines five perceived attributes of an innovation that can help explain the rate of adoption of an innovation: relative advantage, complexity, trialability, observability, and compatibility. Table 10.1 shows how these characteristics can be interpreted for labels (results from working group discussions in Belgium). Table 10.1 illustrates that what matters is not so much the 'objective' advantage of a label, but whether an individual perceives the label, as advantageous.

There is ongoing debate about labels for highly energy-efficient houses: less complex procedures might be more cost effective, but more complex procedures might be a better guarantee of energy performance (Visscher and Mlecnik, 2009). Labels are currently considered difficult to understand and use. Labels are also difficult to experiment with on a limited basis.

Otherwise, market actors can be expected to be proud of their label – when it has a high visibility – and to be willing to demonstrate it to other actors – when low complexity allows for it.

10.5 Marketing and diffusion of labels in European member states

10.5.1 Internet questionnaire

Based on the theory described above, the research defined both open and closed questions to examine perceived attributes of existing labels per member state. General questions (11) requested information about the existence of labels, their market penetration and national and legal recognition. Relative advantage questions (3) asked about financial benefits and regional references on energy cost and comfort appreciation. Complexity questions (10) investigated the degree to which the labelling system is made clear through education and communication. Trialability questions (6) were developed to document the degree to which the label may be experimented with and is recognized by member states for incorporation in existing developments. Observability questions (2) asked about the degree to which the label is visible to others. Further, compatibility was regarded as the degree to which the passive house label is consistent with EPBD development (8 questions).

After trial and regrouping, a final questionnaire contained 3 main groups of questions that addressed the relative advantage, complexity, trialability and observability of low energy housing labels as well as their compatibility with building code development:

1. questions about low carbon, low energy, zero energy or passive house development in member states or region (directed at commercial actors and networks, change agents and knowledge institutes);
2. questions about the compatibility of low energy housing development with the development of building code (for experts only); and
3. questions about the latest development of relevant labels (for developers only).

This questionnaire was addressed to 188 member state professionals, some of the involved in the development of labels for low carbon, low energy, zero energy or passive houses. In total 25 completed replies were received from 15 different countries. The limitations of the small interview sample need to be recognized. Although the professionals were carefully selected, answers were diverse and reflected the expert's own experience and the state of adoption of highly energy-efficient houses in the country. A few countries showed only limited experience with highly energy-efficient buildings or even none with labels. Verification of sources and answers was done by interviewing other country experts by telephone and at European dissemination events and workshops.

In the following paragraphs the results from these questionnaires, are regrouped in perceived innovation characteristics, to illustrate what experts expect that will improve the diffusion of labels.

10.5.2 Increasing relative advantage and observability

Existing voluntary labelling initiatives and associated benefits vary in different countries. Countries and regions, and even municipalities, have developed various ways to support the market development of labels for highly energy-efficient houses. Support is currently offered in nine countries with long-term low-interest credit, direct national or regional grants and/or tax deduction. A few countries, regions and municipalities have developed financial aid to support specific 'passivhaus' criteria.

The labels for highly energy-efficient houses currently mainly address innovators: companies wishing to gain competitive advantage by having an advanced market position. For these actors, giving their details in the dissemination of information on labelled projects is seen as an important advantage. Some countries recognize this issue and provide, besides information about demonstration projects, listings of specialized designers, contractors and installers. However, different experts from the same countries have varying opinions on the general availability of this information.

Passive house technologies have been successfully promoted by companies in order to establish a serious and innovative image (Mlecnik, Kaan and Hodgson, 2008). Market actors consider the label to be an advantage. For companies to be recognized as market leaders – whether local, regional, national or international – the aim is to demonstrate that their product differs from that of their competitors. Labels of passive house projects that have been completed provide credentials for companies. Some specialized networks provide databases of labelled passive house projects with project files with references to the actors involved, thereby providing a promotional tool for market actors.

Although market actors are in favour of labels, clients are often unwilling to pay for a label for a house with improved energy performance unless a clear advantage can be identified. Passive house labels appear to be most successful when they are linked with a financial incentive with limited administrative burden. Some passive house networks suggest improving observability by providing information about the labels in the initial consultancy phase when working with clients, e.g. by banks when a loan is applied for, by notaries when a contract is registered, or by specialized networks when energy advice is requested.

10.5.3 Reducing complexity

Labelling passive houses, and associated technologies, has its origin in the verification and prediction of a restricted energy demand. Passive house project labelling is not focused on issues such as stability, safety, or more general environmental performance, but simply on energy demand for heating buildings, thereby simplifying the number of criteria applied.

Table 10.2 Barriers and opportunities for labels for highly energy-efficient housing: reducing complexity of verification

Barrier	Possible solution
Passive houses comprise very complex energy systems	Design and analysis requires appropriate energy analysis, design and construction tools and related education.
Lack of know-how with EPBD assessors	Additional training and qualification of the administrative party involved.
Extra administrative burden to assess verification	Some governments rely on the already developed and specialized knowledge available in existing institutes and networks.
Grants require control and marketing	Some municipalities, for example Hanover in Germany (proKlima, 2009), have taken the initiative to externalize grant control in institutes they create in cooperation with local market actors.
Labels are only developed for new housing. Existing calculation procedures are often not adequate enough for evaluating the design of, for example, renovations and technical systems in offices and school buildings	New fields such as refurbishment and non-residential buildings require further development of more specific labels and associated quality assurance procedures. Compliance in line with evaluation using building simulation software is suggested as an additional instrument for labelling.
Southern European countries (Bulgaria, Croatia, Cyprus, FYR Macedonia, Greece, Portugal, Romania, Serbia, Slovakia) and the Baltic States report that they have no form of labelling or market infrastructure development for low energy buildings or passive houses	Some countries have their first demonstration projects labelled by independent institutes from abroad. Labelling by another country has been reported for projects in Ireland, Poland and the United States. Nordic countries (Denmark, Norway, Sweden, Finland), central European countries (Germany, Austria, Switzerland, Czech Republic, Slovakia, Poland, Hungary), western European countries (UK, Ireland, Belgium, the Netherlands, France) and Spain have set up a network of passive house professionals and institutes to get the passive house market under way.

In relation to the introduction of the more stringent energy performance criteria, verification of energy performance is seen to be complex. Table 10.2 shows some of the barriers and solutions mentioned by experts.

Less advanced countries suffer from a lack of market infrastructure. Some passive house assessors have registered as a label provider with the Passive House Institute Darmstadt. Assessors are required to pay a fee to the institute. To date, 16 international companies or institutes have registered with this system, and four institutes are not registered (PHI, 2009). Almost all assessors prefer to work with specialized software, some with regional adaptation. Besides the availability of appropriate assessors and designers, the results demonstrate that the availability of experienced contractors and installers is a bottleneck in many countries. The use of specialized calculation tools implies a considerable degree of qualification or education of a member of the building team, but this is also recognized as a potential bottleneck in the implementation of the EPBD.

The active involvement of the government in setting up and maintaining knowledge transfer can highly influence the rate of diffusion of labels. For example, Austria (Haus der Zukunft, 2009; Klima:aktiv, 2009) reported strong market increase due to government-induced active guidance for single-family houses, and for the education of professionals for planning and construction, both for new built construction and refurbishment. Many countries would benefit from increased involvement in knowledge transfer activities, since non-involvement of the government can lead to slower diffusion of the innovation. For example, passive houses have been subsidized in Luxembourg by Decree ever since 2001. However, the first subsidy programme did not provide for knowledge transfer to the then inexperienced market, which resulted in only a few demonstration projects because of a lack of experienced contractors (Mlecnik, 2004). In most advanced countries, educational programmes for specific target groups were introduced at the same time as labelling systems were brought in. Experiences in Germany, Austria, Switzerland, Belgium, Luxembourg, and Italy illustrate that quality assurance of passive houses is preferably related to the provision of passive house education initiatives.

10.5.4 Trialability and re-invention

Some European countries are still in the demonstration phase for passive houses. Many European countries still have no labelling or certification system in place for dwellings with improved energy performance. Most existing initiatives are still voluntary labels. Nevertheless, where labels have been implemented, the procedures have been developed in line with regional needs.

Labels for highly energy-efficient houses have been introduced in several countries by different actors: national or regional governments, knowledge institutes, business networks, non-profit organizations or individual companies. Passive house labels are viewed in many countries as a market mechanism whose main objective is to promote energy performance standards that are higher than the regulated ones. Experts from eight different countries report that a 'passive house' can now attain a commercial label. While initial marketing started in Germany, passive house labels have now also been introduced in several western, central and northern European countries. Most southern and eastern European countries are still developing passive house demonstration projects and are not yet involved in the development of passive house labels.

The majority of experts consider labels for passive houses to be an important European development, but with a different value interpretation by different experts. Experts in many countries with emerging low energy housing development are considering developing a national or regional label or certificate for highly energy-efficient houses, subject to specific energy performance requirements. The German 'passivhaus' concept is now designed so that it is particularly difficult for a lot a diffusion agencies in many countries to re-invent it. In some regions, this type of labelling has proved to have become an accepted way of demonstrating quality and conformity with predefined standards, but this is largely due to continuous knowledge transfer efforts on the part of specialized networks or government programmes.

Sometimes regional re-invention – in this context change or modification of the label in the process of its adoption and implementation – has occurred. This is not necessarily a bad thing since it can improve the rate of diffusion

(Rogers, 2003). National or regional adaptation can lead to better consistency with existing values, past experiences and needs of potential adopters.

In some cases leading actors re-invent the leading example of the German 'passivhaus' criteria, with some regional adaptations. For example, in 2008, the official standardization body in Norway started to develop a national standard for low energy and passive houses (Andresen and Dokka, 2008). The Czech Republic also recently introduced national standards TNI 73 0329 (single-family houses) and TNI 73 0330 (multi-family houses) to define the passive house (Barta *et al.*, 2009).

For some experts, the exact 'passivhaus' criteria have not been preserved for future development, in favour of other specific low energy, zero energy, low carbon or zero carbon criteria. For example, Slovenia gives financial support for building residential buildings with 'low energy or passive technology' in the framework of the Eco Fund – Slovenian Environmental Public Fund (Barta *et al.*, 2009). Sweden has a national passive house programme to support building demonstration projects in accordance with a Swedish version of the passive house standard (Barta *et al.*, 2009). Much attention is given in the United Kingdom to the definition and development of zero carbon houses since this term has now been made official. However, the passive house concept is also recognized as one route towards achieving higher levels of the UK codes for Sustainable Homes and building regulations (BRE UK, 2009; Mlecnik, Kaan and Hodgson, 2008). In South Tyrol in Italy, a certification system was developed based on the decision only to certify some of the energy use in housing, as it assumed that a gradual approach would facilitate better understanding and acceptance from the public (Überbacher and Burke, 2009).

10.5.5 Conclusion

The already existing passive house labels form an interesting opportunity for trial. A label should be transparent to the market actors involved. Efficient educational initiatives, partnerships and knowledge transfer initiatives are needed to reduce the assumed complexity involved. Relative advantage can be increased if national, regional or local governments and financial incentives are directly involved. The energy saving value system introduced should be easy to communicate and should preferably be compatible with existing or future EPBD development. This is discussed in the following section.

10.6 Compatibility of labels with EPBD development

Assessing the energy performance of new dwelling design is becoming mandatory in many countries and regions as part of the process to demonstrate compliance with the energy performance required. As a consequence of the implementation of the EPBD, requirements are set for the energy performance of most buildings that have been granted a building permit. However, from the viewpoint of the experts, the existing structures for energy performance evaluation, developed in the framework of the EPBD, are today not sufficient to guarantee the quality and control of the definition of highly energy-efficient houses.

The leading Passive House Institute in Germany recommends the use of PHPP (PHPP, 2007) as a calculation and verification tool for passive houses. The PHPP software tool is basically an Excel software tool used to verify compliance against a predefined passive house standard. The German 'quality proofed passive house' label confirms the 'as built' design of a building in accordance with this specialized software. Limit values for passive houses are validated in this software tool. In practice, what is assessed is whether the values for total energy demand, total primary energy and air tightness fulfil predefined passive house requirements (Beedel *et al*., 2007; Elswijk and Kaan, 2008).

In many other countries, mainly as a result of passive house business networks, the specialized PHPP software is now also used as a basis for calculation and for labelling passive houses. Although it is a privately developed software tool, it does have several advantages for other countries. The tool was developed independently of German building legislation and the German implementation of the EPBD. The accuracy of the PHPP tool as a predictor for energy use has been validated on several demonstration projects (Schnieders, 2003; Schnieders and Hermelink, 2006), which means passive house experts rate the tool highly. Its main advantage compared with other design and evaluation tools is that is has been specifically created as a design and certification tool for passive houses and that it regularly incorporates new research results in its calculation procedures.

PHPP is accepted or even required in some Austrian provinces as an alternative to regional standards. In Belgium, both EPBD and PHPP calculations have to be performed for passive houses: a quality assurance form based on PHPP is required when applying for tax reduction. In some other countries there are also discrepancies between PHPP and EPBD calculations. This has sometimes led to the situation where a building team has to perform two different calculations for the same building. These kinds of situations are neither cost-efficient, nor desirable, and are to be avoided. In practice in many countries, the regional implementation of the EPBD is also accepted for grant control.

The definition of passive house related energy criteria may vary according to the country involved and, in some cases they are even linked with non-energy-related criteria. What is striking is the difference in the use of net or gross floor surface area in the definition. This part of the definition is also often obscure for emerging labelling initiatives. From the point of view of the future development of building energy labels and certificates, it would be logical to clarify an energy statement as a function of the effectively sold or rented surface, i.e. the net floor area. Definitions of net floor area may differ in different countries since there is no uniform European standard, and national standards apply. International harmonization of floor area definitions is recommended.

Different European countries have a different embedding phase and related market penetration of labels for highly energy-efficient houses. Some countries – the UK, Ireland, the Netherlands, etc. – are still starting up initiatives, while others – Germany, Austria, Switzerland, Belgium, France, etc. – provide a framework for grants, cheap loans and tax reduction and associated quality control procedures. The passive house standard in most countries is still a voluntary standard, while certain regions and municipalities in Central Europe are already developing initiatives to include the passive house standard as a legal instrument or obligation for new construction.

Labelling passive houses usually also includes an air tightness test of the building, which means a specific performance test during construction. In some cases, the functioning of technical systems and its effect on indoor climate is also directly or indirectly, through evaluation by PHPP, considered. In some regions a differentiation in low energy definitions has been introduced, for example in the South Tyrol Klimahaus CasaClima programme. Some energy policy programmes link the energy performance criteria with other sustainability criteria. In addition to the PHPP calculations, some countries express the need to include comfort criteria (for example Belgium) or health criteria (for example UK, Austria). The UK and Belgium tend to include confirmation of the correct commissioning of the mechanical ventilation unit in certification. The Austrian provinces include many other criteria. Some experts express the wish that passive house labels should be better linked with other labelling systems such as those for green or sustainable building. However, because energy efficiency is the main focus in Europe, many experts recommend first improving and harmonizing neutral energy-related criteria, suitable for the evaluation of passive houses and net zero energy buildings.

10.7 Learning from advanced regions

10.7.1 Introduction

We noticed from our theoretical model that the rate of adoption and diffusion of labels can be improved by

- a better perceived relative advantage of a label (for example, by providing financial stimuli or social prestige factors);
- lowering a label's complexity;

Table 10.3 The labels examined in five advanced European regions

Country/region	Germany	Austria	Belgium	Italy/South Tyrol	France
Label name	Passivhaus	Klima:aktiv haus	Passiefhuis/ maison passive	KlimaHaus/ CasaClima	Effinergie
Driving actor	Research institute	National government	Private non-profit	Provincial government	Private non-profit
Voluntary since	1997	2005	2005	2001	2007

- allowing experimentation on a limited basis;
- improving the observability of a label; and
- providing better compatibility (for example with EPBD development).

The previous section introduced some of the barriers and opportunities of the existing labels for energy efficiency of residential buildings in member states. This section discusses and examines the research findings with the theoretical innovation model, focusing on five advanced European regions (see Table 10.3). The following discussion leads to conclusions on how member states can integrate labels in the recasting of the EPBD in such a way as to promote their better diffusion.

10.7.2 Germany

Germany is the foremost nation in passive house development, currently leading to an important national and European observability of German technologies, services and systems. Nowadays the German Information Community for Passive Houses estimates that there are over 10,000 passive houses in Germany, also including refurbishments and non-residential buildings (Barta *et al.*, 2009).

Considering that only a small fraction of passive house projects also have passive house quality assurance from the Passivhaus Institut (Passive House Institute), one might question the associated innovation attributes. Project certificates are often applied for by innovators, and for project demonstration purposes in particular. In practice, companies are often more eager to apply for market differentiation of their own product, service or system. The Passive House Institute Darmstadt and selected partners seized on this opportunity and now also provide companies with labels for market differentiation of specific passive house technologies (glazing, frames, heat recovery systems, building systems, etc.). The proposed product labelling facilitates establishing and comparing energetic qualities. In future, the Passive House Institute also plans to differentiate passive house building actors. A label for, and a listing of, labelled passive house planners will make it easy to find a planner with substantiated knowledge of passive houses (Bähr and Sambale, 2009).

The fact that financial benefits are not directly linked to the passive house label plays a role in the rate of diffusion. In the German Free State of Saxony the passive house standard is stimulated through subsidies (IG Passivhaus, 2009). However, the main economic driver for the construction of passive houses in Germany is the provision of a beneficial loan for the construction of low energy and passive houses by the German state bank KfW. Loan approval depends on the calculated primary heat demand according to the Passive House Planning Package (PHPP, 2007) or EnEV (German building regulations, implementation of the EPBD) calculation methods. Since PHPP calculations also have to be performed for a passive house label, many actors prefer to limit their effort to the EnEV calculation.

Perceived complexity is still high since the calculation must be made by an accredited expert. KfW inspects the calculation, but only in rare cases is the building verified with the accredited expert remaining responsible for the accuracy of the calculation (Barta *et al.*, 2009). In practice, German municipalities often facilitate in reducing complexity and can therefore play an important role in increasing the rate of diffusion. For example, following a ten-year focus on the regional knowledge transfer and development of passive houses, the passive house standard has now reached a penetration rate of at least 8% for new built construction in the Hannover region (IG Passivhaus, 2009). In some cities the innovation diffusion effort has even led to full acceptance. For example, in Frankfurt, Leipzig, Kreis Lippe, the passive house standard is now required for the construction of buildings that are owned by the municipality (PHP, 2009).

We note that the limiting energy values are sometimes difficult to achieve cost-efficiently for small houses (Rongen, 2008) or are diminished for refurbishments (IEA SHC Task 37, 2009; Schulze-Darup, 2008). However, the advantage observed for the further development of the PHPP private tool is that calculation procedures and boundary conditions are not influenced by political considerations and special interests of stakeholders and the rapid integration of new research results is possible (PEP, 2008). The official German building energy performance calculation procedure for buildings is included in PHPP to avoid additional work for planners. However, existing German norms (e.g. DIN EN 12831 for heat load calculations, integrated in the regional implementation of the EPBD) are currently perceived as a barrier for correct passive house calculation (Elswijk and Kaan, 2008).

10.7.3 Austria

Observability of the passive house is also high in Austria. Although the passive house market development was initiated in Germany, Austria proved to be a fast adopter of this innovation with a self-acclaimed 1,000,000 m^2 surface area of passive houses already implemented (Barta *et al.*, 2009). Compared with Germany, national government can be seen to be playing a more active role in supporting the diffusion of the passive house concept.

Since 2005 the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management has supported the dissemination and implementation of minimum criteria for the energy performance and ecological quality of newly built residential buildings within its klima:aktiv haus programme (Klima:aktiv, 2009). Considering national policy, the Programme of the Austrian Government for the period between 2007 and 2010 is to be cited as a major market driver, where the Austrian government defines the passive house standard for the first time. The direct and active participation of the Ministry and the Austrian Energy Agency in the klima:aktiv programme allowed standards to be set for newly built constructions and refurbishment by means of a criteria catalogue, in order to be in a position to estimate the energy saving potentials at an early stage and to define specific objectives for 2015. The pioneering federal state in Austria was Vorarlberg, where, in early 2007, the federal government legislated that the passive house standard be compulsory for new buildings of public housing associations. In 2008 the city of Wels signed a declaration to build all future municipal buildings to the passive house standard (IG Passivhaus, 2009).

Relative advantage is high since all Austrian provinces have special subsidies or low-cost credits for passive houses, originating from national investment sources. In general, the better the energy performance of a building, the higher the subsidy.

However, the complexity of the criteria is high. Subsidy can also relate to additional criteria such as family size, income, use of renewable energy, security, green materials and accessibility. Some communities provide additional subsidies, and tax reduction is being discussed (Barta *et al.*, 2009). Austria has nine different housing grant schemes, so verification is likely to differ by region. Criteria for so-called klima:aktiv passive houses have now been defined in the klima:aktiv haus programme. These houses must be free of thermal bridges and be airtight, their heat energy demand and their total primary energy demand must be verified by the PHPP. The houses must also be equipped with energy-efficient ventilation systems with heat recovery and water saving fittings. Furthermore, they must not be built of materials containing HFCH or PVC and they must fulfil summer suitability requirements.

Observability for market actors is high. Online information platforms and databases of exemplary demonstration projects are stimulated. The programme also provides active guidance for single-family houses, and for larger projects, and training for professionals for planning and construction, both for new build and refurbishment. Therefore the structure in most provinces is, in practice, often centred in the provincial institutions that also verify the EPBD documentation, leading to less regulation and more involvement in knowledge transfer activities.

Compatibility with EPBD is addressed by providing a dual opportunity for verification of the standard. When it comes to housing grants, passive houses in Austria are generally certified by means of the Passive House Planning Package or the Austrian methodology in line with guideline no. 6 of the Austrian Institute of Construction (OIB). There are some differences between the

Austrian OIB methodology and PHPP, particularly on surface area definition. Very optimistic default values for internal heat gains and shading of the OIB methodology have been criticized, while PHPP shows good validation (Elswijk and Kaan, 2008).

10.7.4 Belgium

The observability of the passive house standard is maintained in Belgium by two regional non-profit organizations whose initial remit was to stimulate thematic innovation in the building sector using the German passive house standard (Mlecnik, 2008). The first organization introduced passive house labels in 2005, similar to the German passive house labels (Cobbaert, 2005). In practice, demonstration projects in the initial phase were provided with know-how and were assessed by the non-profit organization. In contrast to the German situation, there was an element of reinvention in order to lower complexity: a limitation on primary energy demand was not retained as an assessment criterion, but as a recommendation, mainly because the Belgian construction sector was unfamiliar with these kinds of extensive calculations.

The German PHPP software was translated and adapted for the Belgian climate. An initial quality assurance form was based on the verification of PHPP calculations and the results of a building pressurization test to determine air tightness. The relative advantage of the associated passive house label has gradually increased. The penetration of the passive house concept and calculation tool is high in Belgium due to consistent effort made by the non-profit organizations to stimulate both supply and demand. Special grants for passive houses we re given on a regional level. Twelve Flemish cities provided additional grants for passive houses. A reduction in real estate tax was also in the pipeline (Barta *et al.*, 2009; PHP, 2009). Since 2007, a ten-year federal income tax reduction has been implemented to stimulate the development of passive houses (Ferdinand, 2007). To obtain the federal tax reduction a passive house quality assurance form provided by the non-profit organization was required (Van Loon and Mlecnik, 2007). Federal tax reduction for passive houses referred to the necessity of submitting a passive house quality assurance form, provided by independent experts and verified by the organization. Nevertheless, the rate of diffusion of the label remains low. Compared with the number of passive houses constructed, still less than 10% have asked for passive house quality assurance.

Complexity is increased because of incompatibility between various regional initiatives, and different implementation of the EPBD in different regions (implementation in the Flemish, Walloon and Brussels regions also include indoor climate requirements). Some actors in the Flanders Region also provide grants for the energy efficiency level (E level) defined according to regional EPBD calculations, although it was demonstrated that there is no direct relationship between achieving the passive house standard and reaching a certain – level (Van Loon and Mlecnik, 2007).

The Belgian situation is characterized by some trialability, but it is limited bearing in mind that the German passive house criteria form the basis. The passive house label referred to in the federal tax reduction was made official every year by royal decree. In 2009, an effort was undertaken by the non-profit organization to update the labelling procedure for indoor climate issues that are also part of the EPBD implementation (PHP, 2009). PHPP is still a basis for certification, but additional compulsory notes are included for interpreting PHPP in the framework of the Belgian building tradition, expectations and normalization. As a result of experiences with observed quality in demonstration projects (Mlecnik, van Loon and Hasselaar, 2008), the quality assurance procedures have also been reviewed to include the critical issues of summer comfort and air quality (PHP, 2009). Considering trialability, the passive house concept is more widely seen as an important driver for other related topics: the nature and symbolic value of the passive house building concept have also facilitated the integration of other areas such as water management, the use of sustainable materials and urban integration, as well as health and comfort issues (Marrecau and Clerfayt, 2009).

As things stand at the moment, PHPP is incompatible with EPBD calculation tools: the EPBD reporting has to be undertaken by trained reporters using required official EPBD software and online registration tools. In 2007, passive house projects were validated with the then commonly used software for Flemish EPB calculations, the regional implementation of the EPBD, showing several shortcomings in the official calculation tool to evaluate passive houses (Van Loon and Mlecnik, 2007). A good coupling of the passive house concept with the EPB is still to be obtained and requires substantial research effort. PHPP is used by passive house specialists and is currently not accepted as an alternative to EPB calculation. Both calculations have to be performed (Elswijk and Kaan, 2008; PEP, 2008). The cost of an extra 'certificate' in addition to the legal energy performance certificate is considered to be a bottleneck for the effective development of future energy labelling in the framework of the EPBD recast.

10.7.5 Italy, South Tyrol

Increased relative advantage is provided by official authorities being directly involved. The labelling was first a voluntary measure. Since the label was introduced, more and more municipalities made the system compulsory, until 2004, when local government decided to establish the programme also at provincial level (Überbacher and Burke, 2009). Since September 2004, due to the success of the first years and the new availability of specialized planners and craftsmen, the regional government has required a maximum space heating requirement of 70 kWh/m^{2}·a for new buildings and the Klimahaus CasaClima labelling procedures can be used as documentation (Schmitt *et al*., 2007). The labelling programme is based on controlled calculations. The 'Department for air and noise' of the Province now conducts examinations on site and where necessary also conducts a building air tightness pressure test, both free of charge within the province.

Compared with the strict 'passivhaus' criteria, complexity has been reduced. The core of this labelling programme is the classification of better performance of buildings in accordance with their space heating requirement. Klimahaus Casaclima classifies buildings according to their annual space heat requirement in Gold: ≤ 10 kWh/m^{2}a; A: ≤ 30 kWh/m^{2}a; B: ≤ 50 kWh/m^{2}a (KlimaHaus, 2009). All of them are considered to be low energy buildings. Passive houses are considered to be in the KlimaHaus Gold category. The calculation code is less detailed, so that this criterion does not correspond exactly with the requisites for a passive house under the PHPP.

Trialability of the label is good and further development is expected. To underline the fact that not only energetic aspects are crucial for sustainable development, the option of having a building certified as 'CasaClima+' was established. This applies to those buildings where ecological aspects, such as ecological construction materials and renewable energy sources for heating, are used (Schmitt *et al*., 2007).

Considering observability, it was reported that promoting the Klimahaus initiative has cleared away many prejudices against low energy houses and stimulated interest in energy-efficient construction, both in South Tyrol and in the rest of Italy (Franzelin, 2007). Media-adapted staging was also reported as one of the success factors: the Klimahaus insignia became a status symbol coveted by contractors, planners, craftsmen and politicians alike (Franzelin, 2007).

Compatibility with EPBD development is better in the northern Italian province of South Tyrol. The originally voluntary Klima-Haus CasaClima labelling programme was introduced in 2001 (Überbacher and Burke, 2009), before the European EPBD (Franzelin, 2007). The scheme is further expected to serve as the implementation of the EPBD for the autonomous province of South Tyrol (Schmitt *et al*., 2007).

10.7.6 France

Initial expectations were that the relative advantage of the passive house concept would also be high in France. The passive house concept was introduced in France in 2005 by three different non-profit associations and has indeed received considerable attention in legislation development in the 'Grenelle de l' Environnement' (round table on the environment). A French label (Effinergie, 2009), a Swiss standard (Minergie, 2009) and the German passive house standard (La Maison Passive France, 2009) are all used and they all define criteria for low energy construction. However, since each organization had its own definition and procedures, increased complexity was the result. An effort was undertaken to reduce complexity by declaring only one label official at national level. The 'Bâtiment Basse Consommation' (BBC)-Effinergie label, developed by the Effinergie society, has been accepted as the official promotion label for low energy buildings ('bâtiment basse consommation énergé tique BBC 2005', decided 8 May 2007, published 15 May 2007). Reducing the number of labels also meant that relative advantage was limited to the actors involved with this label. The government has given up the interest in passive houses that it declared in the 'Grenelle de l' Environnement' (round table on the environment) in exchange for increased support for Effinergie houses with fewer strict requirements. For example, only Effinergie buildings are eligible for specific loans at zero interest rate (Effinergie, 2009). Only Effinergie certification has been made official and is now conducted by four official certification institutes specialized in different subsectors and recognized by the state.

The associated procedures are still perceived as complex and require specialized training. The label limit value can vary from 50 to 70 kWh/m^2a, according to the climatic region (square meter gross floor area). Effinergie buildings also have to comply with certain air tightness values, which differ for individual and collective housing. Certification includes technical verification of the project prior to construction, on site control, detection of errors and delivery of the label.

Trialability of advanced criteria might be higher for other labels. For example, the Swiss Minergie-P and Minergie-ECO-P standards are also used for passive houses in France (Minergie, 2009). Minergie-P sets higher performance levels for comfort and energy use. Energy use for heating, hot water, ventilation and cooling is limited to 30 kWh/m^2a (square meter gross floor area). Minergie certification is issued by two different associations and also includes advice to the architect and the client and a thermal check. A Minergie standard for zero energy buildings is already being developed.

Compatibility with EPBD was guaranteed since the French Réglementation Thermique 2005 would define the limits for primary energy demand for heating, cooling and hot water production. Compatibility with the vision to reach a low carbon society might be lower: the advent of a general low energy movement has led to a possible threat for the already existing development of a market for passive houses and zero energy houses, since benefits are solely attributed to Effinergie houses.

10.7.7 Conclusion

To steer the innovation-decision process of clients towards highly energy-efficient houses it is important to relieve barriers in the persuasion phase. Specific actors will be necessary to show relative advantage, to reduce complexity

Table 10.4 Differences in actors involved in the diffusion of labels for highly energy-efficient houses in five European regions

Country	Innovation driver	Innovation actor	Early adoption actor
Germany: *Passivhaus*	Private (Passivhaus Institut Darmstadt)	Bank	Local and regional governments
Austria: *klima:aktiv passivhaus*	Private (Energieinstitut Vorarlberg)	National government	Regional governments
Belgium: *passiefhuis/maison passive*	Private (Passiefhuis-Platform vzw)	Companies	National, regional and local governments
South Tyrol/Italy: *KlimaHaus, CasaClima*	Private (Agenzia CasaClima srl)	Regional government	Province
France: *Effinergie*	Private (Effinergie)	National	National certification institutes

Table 10.5 Some perceived attributes that can influence the diffusion of labels for highly energy-efficient houses in five different European regions (D: Germany; A: Austria; B: Belgium; I: Italy; F: France; for labels: see Table 10.4)

2009: Early adoption labels for highly energy-efficient houses		Country				
Perceived attribute	Targeting	D	A	B	I	F
High relative advantage	Clients' decision	+	+	+	+	+
Low complexity	Quality assurance	0	0	0	0	0
High compatibility	National (EPBD)	-	+	-	-	+
High trialability	Regional market development	0	+	+	+	-
High observability	Companies' direct involvement	+	+	+	0	-

and to increase trialability, observability and compatibility. The main actors can be different in different European regions as illustrated in Table 10.4.

The analysis confirms that regional re-inventions of low energy and passive house standards are common and that diffusion actors can be different in different regions. This can either be a barrier or an opportunity depending on the availability of market infrastructure to support change. Labels without relative advantage can get stuck in the innovation phase. Table 10.5 illustrates a general evaluation based on the questionnaire's results of perceived attributes of labels in the regions discussed.

All regions have provided relative advantage through financial incentives to support the label's transition from innovation to early market development. Labels with high complexity, low compatibility, low relative advantage and low trialability risk staying in an early adoption phase. Most countries still have some problems defining the most cost and market effective quality assurance procedures. Low complexity can stimulate market development, but can also be a barrier to future opportunities such as introducing improved energy performance or sustainability criteria, particularly when trialability is limited. Apparently, labels developed prior to the EPBD suffer less from achieving compatibility with EPBD. This leads to the general recommendation to develop new labels (for example labels in less developed regions or labels for zero energy houses) or use existing labels prior to the introduction of the national recasts of the EPBD.

10.8 Conclusion

Due to the lack of experience of many designers, contractors and installers with building according to the much more rigorous requirements of highly energy-efficient houses, there is potentially a high risk of unsuccessful adoption of labels for highly energy-efficient building. It is essential to maintain a high level of quality assurance and companies' involvement in the energy labelling scheme implemented. To differentiate relevant experience, some form of quality control is recommended, for example by means of a project label or certificate. Passive house project labelling is already popular throughout Europe and closely related to the project-based identity of the building sector, and therefore consistent with the emerging development of demonstration projects with improved energy performance. Alternatively, or in addition, requiring experience guarantees of the architect, the building contractor and the installer may help ensure that the users involve self-educated parties and finally get the energy-efficient and comfortable house they had in mind.

Labels have been introduced in many European regions as a market mechanism to promote a higher energy performance standard than the one required by the EPBD in the member states. For many less advanced countries, the development of specific labels for highly energy-efficient houses might suit both current market demand and implementation of the EPBD recast, and lessons can be learnt. Labels for passive houses have been introduced in many European countries as an option for clients to introduce more user influence in a market that suffers from weak demand. The adoption of labels has benefited from strategic niche development by private actors, and from support by governments, banks and/or companies. National, regional and municipal authorities can facilitate in reducing complexity and can therefore play an important role in increasing the rate of diffusion. An important success factor in the diffusion of labels is the (increased) involvement of national governments in knowledge transfer activities and recognition of expertise. Educational programmes for specific target groups are needed at the same time as labelling systems and quality assurance procedures are brought in. Labels that are perceived as having more relative advantage, compatibility, trialability and observability and less complexity will be adopted more rapidly than others.

Current EPBD calculation procedures have, in many countries, still not been adapted for highly energy-efficient houses, which might provide an opportunity for further development. How practical coupling of EPBD and labels should be done is very country-specific and possibly subject to re-invention. Existing EPBD procedures might even not be suitable or recommended for evaluating passive houses and it should be avoided that two types of calculations need to be done for such houses. Existing labels at least determine specific energy-related parameters and thus complement information for the required EPBD building certificates. Referring to the European Standard EN 15271 (EN, 2007) and the amendments of the European Parliament for the EPBD recast (EP, 2009), the recommendation is for the energy performance of a building to be expressed in a transparent manner and to include a numeric indicator of primary energy use, preferably expressed in kWh/m^{2}a, as also suggested by Casals (2006), and referring to the floor area sold or rented. Combining existing advanced labels, for example 'passive house', with the energy certificate scheme of the EPBD is recommended.

On a long-term perspective, zero energy building, passive houses or other ultra low energy using buildings will be the target of the recast of the EPBD. An option for redrafting member state energy performance policy can be to adjust the current energy performance standards by adding labels and incentives for improved performance and integrating conditions for existing labels.

There is a symbiotic relationship between the existence of labels for highly energy-efficient houses, market infrastructure and user finance. Voluntary labels, often established through negotiation between private parties and government or other influential private actors, can be a complementary option to further EPBD development. They are often somewhat easier to enact since they can have the merit of a developed market, and established quality assurance procedures.

Currently there is no direct link between the practical integration of the EPBD recast and passive house labels, since all countries are just starting the recast process of the EPBD. The EPBD recast is now an opportunity to reconsider the role and content of the already existing labels and label providers. For example, the Austrian experience shows that the introduction of a near zero energy standard, by means of a stepped energy performance label in combination with company oriented government marketing, targeted education and progressive economic measures to reward better energy performance levels, offers good diffusion opportunities. In practice, existing voluntary labels already form the experimental case in many countries, regions and municipalities, with prospects for recognition as certification. When voluntary labels are already developed by private parties, label recognition by a national government body is recommended in order to ensure a faster transition to early adoption. Where possible, energy policy initiatives should guide the active contribution, and increase trustworthiness, of existing voluntary labelling initiatives and networks to speed up market development.

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11 Success factors in the adoption of innovation: the promotion of passive housing

Submitted for publication as: Mlecnik, E, Success factors in the adoption of innovation: the promotion of passive housing, ***Energy Policy*** *(JEPO-D-12-00764, revised)*

Abstract

To achieve a meaningful increase in the adoption of project-based innovation, such as passive houses in the construction sector, it will be necessary to develop operational activities and communication policies that can stimulate both supply and demand. To examine this issue, this study presents an innovation adoption perspective based on insights from innovation diffusion theory, transition research and theory on environmental behaviour.

An analysis was conducted of the promotional activities of a network in Belgium dedicated to the market development of passive houses. Data were gathered during the first years of this network's life via participatory observation and analyses of activities. The qualitative analysis discusses the activities used to steer client decisions and to stimulate innovation in businesses and compares the approach of the network with an integrated model.

The findings reveal that a coherent set of activities can be geared to the adoption of systemic innovation and to continued knowledge generation in networks. The activities should target various customers and businesses and should regularly adapt to changing conditions. Furthermore, activities should provide solutions that guide businesses and customers alike from each step of the adoption decision process to the next. Communication policy should focus on reinforcing conditions and activities that support innovation-decision processes.

11.1 Introduction

It is acknowledged in the construction sector that an increase in the uptake of systemic innovation beyond demonstration projects is essential in order to meet the challenges of a changing climate and European policy objectives. For example, one of the key spearheads in the recast of the European Performance of Buildings Directive (EPBD, 2010) is the uptake of nearly zero-energy buildings and more widespread deployment by 2020[1]. The European Commission expects member states to create a market infrastructure and demand for such buildings by, for example, introducing national, regional or local tax incentives and financial instruments and/or by lowering VAT (EPBD, 2010).

However, there is a growing awareness that it will take more than financial benefits or cost-optimal measures to develop a market infrastructure

1 Generally, the diffusion of energy-efficient housing is progressing but at a much slower rate than expected.

and customer demand and to achieve innovation in the construction sector; the situation calls for a more holistic approach (European Commission, 2010). Supply and demand need to be created for the uptake of innovation. Given that businesses and customers will have to develop and share information in order to jointly create a market, effective strategies will be important for policy development, especially those that define operational activities that eliminate innovation adoption barriers. For example, companies and society at large do not know enough about existing innovative and highly energy-efficient housing concepts such as the passive house[2] (Pass-net, 2011). At the regional level, the customer might encounter insufficient availability of market players, a lack of market infrastructure and limited competencies (Pass-net, 2011).

Innovation studies on sustainable housing and passive houses have previously pointed to the need for specific know-how retrieval centres (Ornetzeder and Rohracher, 2009) and new approaches to systemic innovation in businesses (Mlecnik, 2012). It was found essential to enhance the visibility of relevant product, system and service innovations (Mlecnik, 2011). At the same time, a consistent flow of information must be in place to avoid the regeneration of innovation deficiencies which have already been detected in new projects (Femenias, 2004)[3]. A clearer understanding of innovation theory and practical approaches is required, on the basis of which businesses and customers can be persuaded to adopt systemic innovations such as passive houses. Deeper insights into the diffusion of innovation and ways of stimulating the development of emerging markets could prove particularly useful. Taking the passive house as an example of innovation, it would be useful to specify the activities that know-how retrieval centres should engage in to stimulate the adoption of such innovation. It should be noted that such cen-

2 Several studies in the European framework have already confirmed the existence of demonstration projects and vibrant business opportunities for so-called passive houses (for example: IEA SHC Task 28, 2006; PEP, 2008), ultra-low energy houses in which the necessary heating can, but must not, be provided by controlled ventilation systems, thus avoiding additional space heating systems. In order to perform properly, passive houses require a high insulation level (glazing, and insulation for window frames, walls, roofs, floors, connections, etc.), good airtightness, careful use of passive solar gains and appropriate technical systems. A wide range of passive house innovations is already available on the European market, such as triple glazing with improved window frames, improved insulation systems, building airtightness solutions, integrated heating and ventilation systems, construction systems, design tools, calculation software, and more. Service innovations can also be found, such as integrative planning using energy experts, quality assurance services and passive house project labels and certificates for components (Mlecnik *et al*., 2010; Mlecnik, 2011).

3 Although communication about highly energy-efficient housing has been developed from experiences in demonstration projects, important challenges remain in order to 'diffuse' solutions beyond the demonstration project phase (Femenias, 2004; van Hal, 2000).

Table 11.1 European networks with a mission to promote the adoption of passive housing

Country	Network	Website
Austria	IG Passivhaus Österreich	http://www.igpassivhaus.at
Belgium (Flanders)	Passiefhuis-Platform vzw	http://www.passiefhuisplatform.be
Belgium (Wallonia)	Plate-forme Maison Passive asbl	http://www.maisonpassive.be
Czech Republic	Centrum pasivního domu	http://www.pasivnydomy.cz
Europe	Network of Passive House Promoters	http://www.pass-net.net
France	La Maison Passive France	http://www.lamaisonpassive.fr
Germany	IG Passivhaus Deutschland	http://www.ig-passivhaus.de
Hungary	Passzívházépítok Országos Szövetsége	http://www.passzivhazepitok.hu
Ireland	Passive House Association of Ireland	http://www.phai.ie
The Netherlands	Stichting Passiefhuis Holland	http://www.passiefhuis.nl
The Netherlands	Stichting Passiefbouwen.nl	http://www.passiefbouwen.nl
Nordic countries	Passivhus Norden	http://www.passivhusnorden.org
Poland	PIBP Polski Instytut Budownictwa Pasywnego	http://www.pibp.pl
Slovakia	PassivnyDom Slowakia	http://www.pasivnydom.sk
Spain	Plataforma Edificación Passivhaus	http:// www.plataforma-pep.org
Switzerland	IG Passivhaus Schweiz	http://www.igpassivhaus.ch
United Kingdom	Passivhaus Trust	http://www.passivhaustrust.org.uk

tres already exist in the form of various networks. Some of these are listed in Table 11.1[4].

These organisations promote passive housing by applying a coherent set of communication tactics that target construction firms as well as customers. An analysis of these tactics might help to identify important success factors for the promotion of project-based innovation in fields such as the construction sector and aid the definition of activities that lead to market transformation and the development of communication policy. The main research question was therefore: *What are the tactics and success factors for stimulating the adoption of project-based innovation, as determined from a study of the activities of an innovation-oriented passive house network?*

11.2 Research strategy

In anticipation of the implementation of European energy policy (EPBD, 2010), the aim of this study was to gain a deeper understanding of the important factors in communication strategies that promote project-based innovations such as passive housing in the construction sector. The study first developed a theoretical perspective (Section 11.3) with possible wider applications in innovation research, reflecting on Rogers' theory of innovation adoption (Rogers, 2003). This theoretical section also integrates various elements from the liter-

4 In addition to these, there is an International Passive House Association, recently initiated by Passivhaus Institut, a Passive House Alliance in the US and several initiatives in countries in Asia, as well as in Australia and New Zealand.

ature on transition research, the theory of innovation diffusion and the theory on environmental behaviour change in order to raise a number of relevant points about operational activities concerned with the communication of innovation. These points were incorporated into a model proposed for the study of network activities that stimulate project-based innovation.

With this in mind, the study identified some success factors based on the activities of a successful passive house network in relation to the adoption of innovation and the stimulation of regional supply and demand. Particular attention was paid to single-family housing – with SMEs as the suppliers and owner-occupants as the customers – and the adoption of the passive house. In the light of the proposed model, Section 11.4 reflects on the activities of an innovation network in Flanders (Belgium) that led to the successful development of demand and market infrastructure for passive housing. Compared with other networks, for example in Austria (Ornetzeder and Rohracher, 2009), there was a strong focus from the start on directly providing SMEs with knowledge and assisting them to develop innovation opportunities. Since 2003, the network in question – Passiefhuis-Platform vzw (PHP) – has developed various activities equivalent to 2.1 FTE, with a four-year grant from an SME innovation support programme under the auspices of the Flemish Agency for Innovation by Science and Technology (IWT, 2007; PHP, 2007). The definition of these activities resulted from a dialectic process of group facilitation, collecting information about possible and real communication activities in task group meetings, and regularly reflecting on the learning cycles with a growing number of enterprises and customers. The author has been involved since 2001 as an innovation project facilitator, assisting the network to define innovation promotion activities by applying the principles and processes of group dynamics. The qualitative data described are thus a result of participatory observation and group facilitation by the author, mainly during the period 2002-2006, and an analysis of activity reports. It should be noted that innovation diffusion activities tend to have very specific emergence histories closely related to the local context and social conditions and this may therefore limit the prospects of transference to another regional or social context. The activities discussed here focused on developing the market for single-family owner-occupied homes in a region where most of the housing market consists of single-family homes commissioned by the owner and built by SMEs.

Section 11.5 reflects on the success factors identified, with the aim of further developing the model, while the research question is addressed in the conclusion (Section 11.6). At this stage, the study does not attempt to give a full representation of the many agents implicated in any systemic transition of a region, or to deal with various aspects of transition research. The study does not attempt to conclusively determine the best available communication activities for networks or the construction sector. The primary goal was to review and integrate theory and experiences which could help to define opportunities for the promotion of highly energy-efficient housing in relation to the urgently needed development of market infrastructure and demand. The theory development brought in new elements regarding research on activities that promote the adoption of innovation, particularly those that result from project-based approaches such as those found in the construction sector. However, the reader should bear in mind the limitations of the theory development since it mainly focused on activities which were only illustrative for one network. This suggests a need for future research to test whether this approach to promoting innovation adoption is successful for other types of projects and other technologies in various sectors.

11.3 Theory development

11.3.1 Operational activities facilitating transition

The author acknowledges that there is a well-established strand in transition research (see for example Elzen *et al.*, 2004) aimed at providing a theoretical approach to institutional and technological change, drawing in turn upon communication theories and found across a large range of disciplines (sociology and political sciences, geographical clusters theory, knowledge management, evolutionary economics, technological change theories). When looking at specific niche development, most research focuses on descriptive case studies in various sectors, such as sanitation (Hegger *et al.*, 2007), biomass (Raven, 2005; Verbong *et al.*, 2008), energy systems (Hendry *et al.*, 2007; Verbong *et al.*, 2008; Woei, 2007), public transport systems (Weber *et al.*, 1999), electric vehicle transport (Hoogma, 2000), eco-housing (Smith, 2007) and eco-friendly food production (Roep *et al.*, 2003; Smith, 2007). What is apparent from this strand of research is that socio-technical experiments or innovation journeys only evolved into actual technological or market niches in a few cases. Researchers detected an important need for the articulation of expectations and sustainability visions, learning processes with multiple dimensions, and the building of multiplayer networks (Hegger *et al.*, 2007; Elzen *et al.*, 2004; Kemp *et al.*, 1998; Caniëls and Romijn, 2008; Raven, 2005; Weber *et al.*, 1999). In this framework, communication in market niches – using multiplayer networks – is considered particularly effective (Caniëls and Romijn, 2008; Schot and Geels, 2008; Hegger *et al.*, 2007; Elzen *et al.*, 2004; Kemp *et al.*, 1998; Verheul and Vergragt, 1995). Which activities within these multiplayer networks successfully lead to market development is not well understood. Within networks, decisions and strategies are developed, negotiated and implemented, leading to changes in societal structures, which in turn structure governance patterns (Loorbach, 2010). Researchers (Van der Brugge and Van Raak, 2007; Loorbach, 2007, 2010) have identified four different types of governance activities that are relevant to societal transitions: strategic (vision-related), tactical (regime-related), operational (innovation-related) and reflexive (monitoring-related). Strategic and tactical activities operate in the long-term and mid-term respectively, and therefore it is often difficult to determine their success due to the necessary long period of observation. However, operational activities, experiments and actions that have short-term horizons can be more readily identified.

The present study therefore focused on success factors in activities defined by one network, with the aim of determining communication practices and operational activities at a policy level that could in turn filter through and transform structures, culture and routines at the regime and landscape levels, particularly with respect to innovation/communication policy. Since operational activities are often concerned with finding suitable ways to adopt an innovation, literature on innovation diffusion was also further explored.

11.3.2 Adoption of innovation

From the perspective of the innovator/enterprise

An underlying thesis of this study was that operational activities can be hosted within networks to spread knowledge about available innovations[5]. In the theoretical framework on innovation, nearly zero-energy housing, particularly passive housing, is recognised as system innovation (Jochem, 2009; Mlecnik, 2011) and as a radical innovation (Mlecnik, 2011)[6]. A communication perspective on the diffusion of innovation has been under development since the 1950s. An early milestone can be found in the work of Rogers (1962, 2003), who defined the diffusion of innovation as the process whereby an innovation is communicated through certain channels over time among the members of a social system[7]. Amongst other things, Rogers (2003) defined five attributes which help to explain the adoption of an innovation (relative advantage, observability/visibility, compatibility, complexity, trialability/demonstrability). Various studies have shown that each of these attributes is relevant for decision-making on energy use in housing (Wilson, 2008). Rogers (2003) also highlighted the important role played by 'change

5 Rogers (2003) defined 'innovation' as an idea, practice or object that is perceived as new by an individual or other unit of adoption.

6 'System innovations' are characterised by the integration of multiple independent innovations that must work together to perform new functions or improve performance as a whole (Cainarca *et al.*, 1989). 'Radical' innovations are characterised as scientific and technological breakthroughs that can change the very nature of an industry (Marquis, 1988).

7 Diffusion is a kind of social change, defined as the process by which alteration occurs in the structure and function of a social system (Rogers, 2003: 6).

agents' in organising the communication of innovations.

Attention should also be paid to the sectoral context. One persistent problem in the construction sector is that the communication of innovation stops short at demonstration projects (Silvester, 1996; van Hal, 2000; Femenias, 2004). It is generally acknowledged that innovation in the housing sector can be slowed down by high levels of management and coordination in project-based environments (Harty, 2005). Communication about innovations can be ineffective because of the ad-hoc nature of the generation of knowledge and networking in the construction sector (Femenias, 2004; Harty, 2005). Moreover, cooperation that is based on temporary contracts between changing constellations of players tends to complicate communication processes and thus slows down the uptake of innovation (Ivory, 2004).

From the perspective of the adopter/customer

Another underlying thesis of this study was that, within networks, activities that spread knowledge about available innovations to customers need to be determined. The EPBD recast (EPBD, 2010) seems to suggest that financial incentives and cost-optimality could be key to communicating about nearly zero-energy housing to customers. However, EPBD economic policy instruments and more effective communication strategies should develop in tandem. For example, researchers in behavioural economics (for example, Ariely, 2009) have questioned the usefulness of communication strategies based on cost-optimality, arguing that there is a need to develop the market through an interplay of supply (enterprises), demand (inhabitants) and intermediary facilitators (governments) (Boerbooms *et al.*, 2010).

The Dutch policy programme 'More with Less' (Boerbooms *et al.*, 2010) suggests using customer segmentation approaches in the communication of information concerning highly energy-efficient housing. Research indicates that customer segmentation approaches based on environmental concerns[8] are more stable than approaches based primarily on demographic criteria (Straughan and Roberts, 1999; McDonald and Oates, 2006). Peattie (1998) has identified two factors that are considered highly significant for green purchases by users (see also McDonald and Oates, 2006): the degree of compromise and the degree of confidence[9]. A study by Defra (2008) indicated ways to improve policy designed to bring about change in environmental behav-

8 For example, Zimmer *et al.* (1994) suggested factors – beginning with a list of 57 distinct environmental concerns, statistically reduced to seven – on which marketeers can realistically focus.

9 Compromise can take a variety of forms, such as having to pay more or travel further in order to purchase a green product. It can also mean that purchasing a green equivalent might involve a sacrifice in the performance of the product. The degree of confidence is how certain the user is that the product addresses a genuine issue and that it represents an environmental benefit.

iour: increase awareness/knowledge, develop participant skills, promote tangible benefits, offer enabling and exemplifying activities, promote community engagement and choice editing. Jones and De Meyere (2009) also illustrated the relevance of such an environmental behaviour approach to passive houses, thereby using key terms related to influencing customer behaviour: 'enable', 'encourage', 'exemplify' and 'engage'.

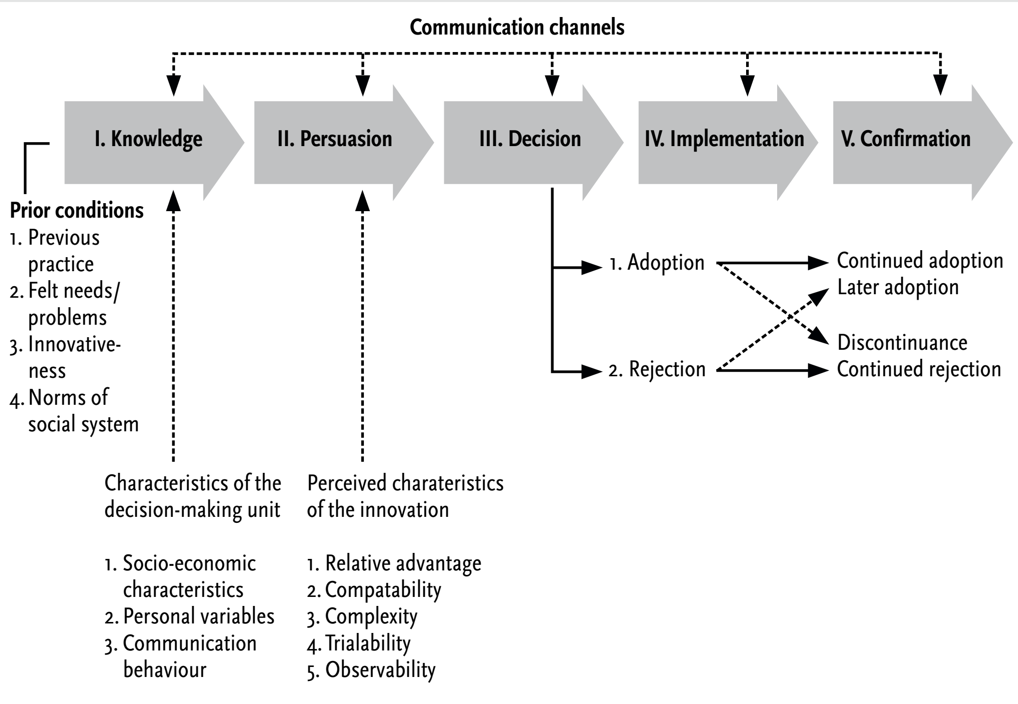
Such insights from research on changes in behaviour towards the environment provide guidance on elements that influence communication strategies. One common pitfall is that the notion of economic rationality is often overvalued at the expense of confidence and compromise. Moreover, as shown in the previous subsection, a system focus and sectoral particularities are often neglected in communication. The following subsection integrates the various issues detected into a sectoral model for studying communication tactics in relation to the promotion of systemic innovation, both to businesses and customers.

11.3.3 Revisiting Rogers' innovation adoption model

Rogers (2003) developed an innovation adoption model to determine how an adopter could be reached through communication channels. Figure 11.1 shows this model as a timeline through which an individual (or other decision-making unit) passes from initial knowledge of an innovation to forming an attitude towards it (persuasion), to a decision to adopt or reject it, to implementing the innovation, and to confirming its customer value.

According to Rogers' model, adoption can be influenced by prior knowledge and conditions. The characteristics of the decision-making unit are important and communication channels (e.g. formal and informal social networks, cues, mass media, etc.) can exert an influence at each step of the decision-making process. Rogers sees knowledge as a starting point in innovation adoption, whereby he distinguishes awareness as a precursor to 'how-to and principles knowledge'. The perceived characteristics of an innovation play an important role in the persuasion phase. Note that parties who decide to adopt might change their minds if they fail to find suitable players for the implementation (see Figure 11.1). It might prove useful to critically reflect on the innovation-decision model on the basis of some research findings on innovation diffusion and environmental behaviour. Kaplan (1999) argued that Rogers' model (Figure 11.1) did not specifically emphasise motivation, experience, and familiarity as critical influences. Other researchers also highlighted the need for the presence of 'market infrastructure' when knowledge is introduced (Brown, 1981; Miller, 2009; Rødsjø *et al.*, 2010). Miller (2009) contended that innovation is impossible without entrepreneurial competencies and resources. From the demand perspective, Jones and De Meyere (2009) suggested a circular model that articulates the need for learning cycles. Based on

Figure 11.1 Five steps in the innovation-decision process



Source: Rogers (2003)

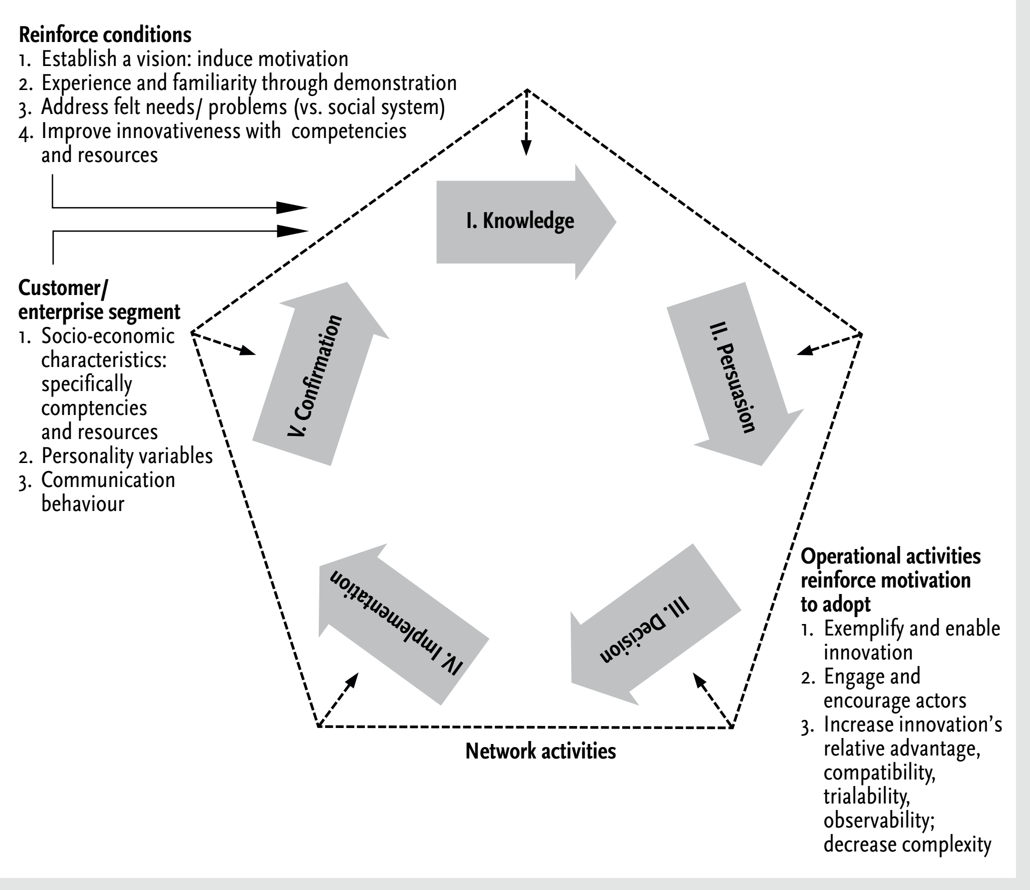
demonstration projects this need was similarly confirmed for the construction sector (e.g. van Hal, 2000; Femenias, 2004).

Compared to many other technologies, buildings are often produced at a relatively high cost, over a longer time span and as a one-off or a limited number, which limits possibilities for rapid knowledge generation and innovation development. Market development also depends on customer acceptance and broader 'confirmation' of demonstration projects, with such confirmation also an input to or incentive for 'knowledge'. For example, Jensen *et al.* (2007) noted the importance of the quality of the building energy certification scheme in increasing enterprise knowledge in Denmark. It would therefore make sense to connect 'knowledge' to 'confirmation' and present an innovation adoption cycle, since innovations 'confirmed' in demonstration projects are a source of new knowledge for new projects (in potential new customer segments). This would also emphasise the need for a 'learning cycle' as detected in transition research.

Figure 11.2 displays an alternative model of network activities that influence adoption processes, incorporating the notion of learning cycles. This model maintains the relative parsimony promoted by Rogers while adding new and enhanced features, specifically for examining network activities in relation to market development and pro-environmental behaviour.

There are clear similarities with the conventional model, but also differences. The five steps in the adoption decision-making process remain, but the pro-

Figure 11.2 Integrated model for analysing network activities, from the perspectives of project-based innovation adoption, using closed learning cycles and stimulating pro-environmental behaviour (e.g. in the construction sector)



cess has the structure of a closed loop – which can be built upon in the next learning cycle – to emphasise the need for learning processes with multiple dimensions (transition research) and the need to continuously increase awareness/knowledge and develop participant skills. The prior conditions which enable the adopter to learn without possessing a great deal of attribute information remain in place, but the model shows the need to add other prior conditions and the need to reinforce these prior conditions based on the experiences of customers or enterprises in previous adoption processes. The articulation of expectations and sustainability visions is considered an issue regarding prior conditions, as found in transition research. Knowledge is a product of motivation and context, as suggested by Kaplan (1999), and experience and familiarity are also included, based on innovation diffusion research (van Hal, 2000), where the path of demonstration was shown to lead to experience and familiarity. The need for competencies and resources to establish innovativeness is also emphasised in these conditions. The social system is seen as influencing felt needs and problems, but the latter can also influence the former.

Adopter characteristics such as socioeconomic characteristics, personality variables and communication behaviour are also included, but the importance of addressing both the enterprises and the customers is emphasised, as well as the need for competencies and resources. As mentioned above, customer segmentation is important, with respect to which – and possibly related to characteristics of the demonstration project – the target enterprises for innovation might also differ. Once sufficient experience is gained in innovation-decision processes for one segment (or demonstration project), the adopter might want to gain experience in another segment (or demonstration project).

In Figure 11.1 Rogers emphasises that parties who decide to adopt might change their minds from the decision phase onwards. However, this is a confusing attribute for project-based innovation in the construction sector as a change of mind might occur at any stage of the process. In project-based adoption processes for passive houses, potential adopters can heavily rely on complementary actors, who provide knowledge, encouragement (in the form of persuasion), assistance in their decisions and implementation, and confirmation. If these actors are not found in the market infrastructure, the adoption process may be discontinued. Therefore, the emphasis on actors changing their minds is removed in Figure 11.2 and more emphasis is placed on the communication channels that should be used to try to avoid discontinuance.

For the purpose of this study, communication channels are interpreted as actively facilitating the movement of the adopter from one step of the innovation-decision process to the next. As mentioned above, various categories of activities could be studied. Here the focus is on one network's short-term activities, possibly resulting from operational instruments introduced at the policy level. Such activities aim to increase the adoption of innovation – by influencing perceived innovation characteristics – and to reinforce environmentally conscious behaviour by exemplifying and enabling relevant innovation and engaging and encouraging actors and their collaboration. On the demand side, such a network should particularly consider exemplifying existing innovation by promoting tangible benefits, assisting customers in their choice editing and promoting community engagement (Defra, 2008). On the supply side, mutual learning in multiplayer networks is important, as found in transition research.

The new model in Figure 11.2 fills the gap between knowledge and interest and explicitly identifies causal relationships that have been overlooked by researchers. In short, this model for the analysis of network activities combines experiences from various theoretical backgrounds which can assist in identifying potential improvements. For example, to bring about the desired environmental behaviour, communication policy should focus more on maintaining learning cycles by 'reinforcing prior conditions', exemplification (effective use of experiences from demonstration) and on engaging, enabling and encouraging customers and enterprises who might need further compe-

Table 11.2 Communication activities of the PHP in the period 2003-2006

Target group	Communication activities	Number of actions 2003-2004	Number of actions 2005-2006
Companies and clients	Visits to companies and demonstration projects	70	67
	Technical publications	7	37
	Lectures/seminars	22	45
	Newsletters	8	12
	Promotional publications	5	43
	Website actions	1	6
Mainly companies	Networking actions for companies	18	16
	Actions for membership	1	4
	Larger innovation networking initiatives	4	7
	Technology watch (innovation support)	2	8
	Innovation studies	4	7
	Stimulating international cooperation + partner search	5 + 2	10 + 2
	Grant application support	2	9
	Guidance of innovation projects	4	4
Mainly clients	Answering technological questions	300	450
	Guided question transfer	100	60

Based on: IWT 2003; PHP 2007

tencies and resources to actually develop or adopt innovation.

The following elaborates on this model, with the next section providing an example which highlights the validity of the main features of this conceptual framework.

11.4 Activities of a passive house network

Taking the passive house as an example of innovation, one possible form of communication channel influencing innovation decisions and the adoption of such innovation (e.g. activities of know-how retrieval centres) will now be explored. The research presents the activities already undertaken by a passive house network to illustrate various elements of the models in Figures 11.1 and 11.2. First, the various activities addressing both customers and businesses are listed for the network. Second, the prior conditions (as defined by Rogers) are described in relation to the activities of the network. Third, the network's activities are discussed according to the steps in Rogers' model in Figure 11.1 and repeated in Figure 11.2, starting from Step 1 (Knowledge) to Step 5 (Confirmation). Fourth, Step 5 activities are discussed as the key to 'closing the loop', as shown in Figure 11.2. Finally, the importance of the additional elements in Figure 11.2 (Segmentation and Reinforcing conditions) is discussed.

11.4.1 Various activities addressing both customers and businesses

The network investigated engaged in various activities to address innovation in businesses, stimulate market demand and build up market infrastructure (with limited personnel, equivalent to 2.1 FTEs). Table 11.2 provides an overview of the activities in 2003-2006. In 2003-2004 the PHP carried out 155 actions for groups of companies and potential clients. These activities included the preparation of publications and newsletters, company visits, project visits, website campaigns, networking, cooperation in preparing and conducting innovation studies and activities in a wider perspective. It also answered about 400 technological questions from clients. In 2005-2006 this rose to 277 actions for companies/clients, as well as addressing 510 technological questions from clients. At the same time, the uptake of innovation by businesses was addressed and efforts were made to convince potential clients or businesses to adopt a passive house demonstration project or passive house technologies. In the following subsections we look at how these activities fit into the models.

11.4.2 Prior conditions

The Passiefhuis-Platform (PHP) was formally established as a non-profit organisation in the Flemish Region in October 2002. It brought together market players with the aim of 'diffusing knowledge about highly energy-efficient building', preferably via the passive house concept[10]. In this framework, the 'knowledge' starting point was the same as addressed by Rogers in Figure 11.1. At this time there was a negligible market infrastructure or customer demand for passive houses in Flanders. Regional implementation of the European Energy Performance of Buildings Directive (EPBD) at that time also did not create the prospect that high energy efficiency would soon become standard. In addition, the member enterprises had no or only limited experience with passive house innovation. However, various enterprises and customers were aware that passive houses were clearly defined in neighbouring regions and had been

10 At the core of the expectations was the development of a more appropriate pathway for know-how and technology retrieval from neighbouring countries. For example, in Germany and Austria the passive house concept and technologies were highly developed, while in Flanders they were unknown to companies and clients, except for a few innovators. This created a sense of urgency for innovation learning. A proactive approach was needed, which would spread an attractive vision of energy-efficient innovation in the regional construction industry. To fill existing knowledge gaps about the integrated passive house concept, input would be needed from different players such as architects, engineering offices, suppliers, materials producers, system providers, energy consultants, installers, contractors, possible future owner-occupants and others.

set ambitious energy targets, which raised initial interest in developing similar communication activities as in those regions. Note that knowledge generation starting from a poorly defined subject can differ from knowledge generated from clearly defined concepts. The fact that the passive house concept was already validated through thousands of demonstration projects in Germany certainly helped to establish interest in regional knowledge generation.

Having acquired innovation funding resources, the network was able to attract the competencies that it deemed necessary: an engineer/researcher, a specialist in information technology management for administration and an independent architect for technical consultancy. These employees could also draw on advice from a multidisciplinary management board and on the experience of members of the network. The first market segment for which PHP engaged in activities was the construction of newly built single-family passive houses. This segment choice implied that the majority of enterprises for whom the promotional activities were to be designed were 'innovator' micro- and small enterprises from various fields (architects, engineers, contractors, installers, suppliers). The easiest customers to attract in this segment were highly motivated 'green' families.

In the following the study explores the activities listed as communication channels influencing the steps in innovation-decision processes (see Figures 11.1 and 11.2), starting from the 'Knowledge' step.

11.4.3 Activities leading to awareness, 'how-to' and 'principles' knowledge

The network employees created channels whereby businesses and clients could contact them and share in their expertise and that of the network's members. For example, they attended important regional building fairs, where they provided information on passive houses and first-line consultancy for potential clients[11]. Specific activities offered examples of innovations using workshops, symposia, building fairs and study trips organised by PHP or third parties.

The employees developed specific activities and communication tools (website, digital newsletters, interventions in regular media, technology watch, presentations, concept, project and technology leaflets, database, list of frequently asked questions, programme of requirements, energy calculation software) which were directed at both companies and clients and explained the passive house concept as an integrated concept, the energy performance

11 Notably, at Belgium's largest building fair (Batibouw), the network could benefit from participating in related 'green' seminars and incorporating a green tour, which created a sufficient setting for a royal visit to the network stand, which in turn generated important media attention.

of passive houses, principles on how to achieve the passive house standard and specific technological criteria.

The primary aim of these efforts was to raise awareness of the passive house concept and recent developments in this field. In general, the website turned out to be particularly effective, with significant numbers of visitors[12]. Media such as magazines, newspapers, radio and television were important allies in providing a wider audience with initial knowledge about passive houses.

In this first period, knowledge generation was often influenced by the presence of 'confirmed' innovations, as 'closing the circle' suggests in Figure 11.2. Knowledge, examples of enterprise innovation and 'confirmed' demonstration projects were sought in Germany and Austria to be used as examples for the regional introduction of innovation and demonstration projects. For example, previously validated energy calculation software for passive houses was translated from German and adapted to the situation in the Benelux. Such an approach lowered the threshold from radical innovation in the market at large to incremental innovation in the network itself.

11.4.4 Activities facilitating persuasion

Step 2 (Persuasion) activities are discussed here on the basis of the perceived characteristics of an innovation introduced by Rogers (see Figure 11.1: relative advantage, compatibility, observability/visibility, trialability/demonstrability and complexity).

Communicating relative advantage of the innovation

To convince companies and clients of the added value of the passive house, the network employees invested considerable energy in communicating the deficiencies of mainstream housing, such as insufficient thermal insulation, leaks in the construction, inadequate use of solar energy and health problems due to lack of ventilation, all of which could be eliminated by properly implementing the passive house concept. Clients and businesses were approached mainly with information on how passive houses can offer higher levels of

12 Since its creation in 2003, the popularity of websites such as www.passiefhuisplatform.be – and directly linked websites such as www.maisonpassive.be and www.passivehouse.be – has enormously increased, in particular in the period 2004-2007. At the end of 2007, more than 1000 visitors per day were counted. A Google search in December 2007 provided 42,900 hits for pages from Belgium on the word 'passiefhuis' and about 50,700 hits for pages from Belgium for the word 'maison passive', while these words did not exist in 2002. In the period examined, the PHP website was always at the top of the google.be search. Part of this success might also be explained by a neologism that was introduced for communication purposes to differentiate the passive house concept from unsuccessful passive house interpretations from earlier decades.

comfort (thermal comfort in both winter and summer, air quality, acoustic comfort, lighting quality, healthy indoor environment), better structural quality and more profitability and future value.

Demonstrating market compatibility and increasing visibility and demonstrability

The organisation of the passive house fair and symposium in particular, persuaded businesses and clients that there was a regional market infrastructure for passive houses. Businesses were selected to participate in the fair – the network employees acted as 'gatekeepers' – according to the specific offerings they could contribute to the realisation of passive houses. The exhibition mainly attracted visitors who were looking for knowledge or assistance in their decision to adopt the passive house. Often these visitors would be referred to activities such as regional demonstration projects as a source of information and communication, which helped to convince architects, contractors, suppliers, consultants and clients of the feasibility of passive houses in Flanders. Companies and clients who visited a demonstration project could be persuaded in situ by their peers in their own 'language'. Visits to passive houses were considered a key to persuasion, with realised projects demonstrating the feasibility of the concept for different types of buildings and construction methods.

Reducing complexity

The technical consultant answered questions on the feasibility of potential new projects. Usually, clients were invited to schedule a meeting to discuss draft plans. Furthermore, the PHP website provided direct referral to 'experienced' parties; for example, it integrated an external user forum on eco-housing developed by another non-profit organisation and provided a list of professionals involved in demonstration projects. The first activities enabled people to discuss their doubts about passive houses and facilitated peer-to-peer exchange to solve problems, while the second activity facilitated the engagement of professionals.

The section below discusses why the activities of a network should not stop at the persuasion phase, revealing that the activities concerned with Steps 3 (Decision) and 4 (Implementation) in Figures 11.1 and 11.2 are also important in facilitating continuity in innovation adoption processes.

11.4.5 Activities facilitating decision and implementation

Companies who decided to innovate were assisted by the network employees in applications for Flemish SME innovation grants and finding potential research partners. It was thought that facilitating a decision to sign an innovation grant request would prompt businesses to continue a formalised process of innovation. However, only a few could be assisted at this level. Meanwhile, several SMEs decided to directly adopt technologies from other European countries. The 'knowledge' gained from activities and projects led to an understanding that the threshold for regional radical innovation could be lowered by the importation of 'confirmed' technology. Only at a later stage, when it became possible to sell products in larger quantities, did some companies engage in a formal innovation journey.

The most frequently asked question from clients took the form of requests for a list of players in and technologies for the construction of passive houses. A list of players (architects, energy calculators, suppliers, contractors) was duly compiled on the basis of knowledge gleaned from confirmed demonstration projects. Different web-based databases were created to identify enterprises involved in demonstration projects and technology development.

A telephone consultancy service also addressed any remaining questions that might arise during the implementation phase of a passive house. In addition, enterprises could hire a network employee if they wanted personalised, neutral advice on passive house technologies or assistance in the development or coordination of an innovation journey.

The following addresses how the model in Figure 11.2 provides additional insights compared to Figure 11.1, discussing the coupling of activities that address the confirmation phase, the need for knowledge generation based on 'confirmation', the importance of segmentation and the need to systematically reinforce prior conditions.

11.4.6 Activities concerned with confirmation, closing the loop

Given the vested interest in confirmed demonstration projects and technology developments to source knowledge generation, the network was particularly concerned about the confirmation of the quality of initial regional demonstration projects[13]. The network employees developed specific activities[14] for this purpose, and a Belgian[15] 'quality assurance declaration' for passive houses. This development framework prompted the managers of various en-

13 In this period, media reported the destruction of recent sustainable building demonstration projects in the neighbouring Netherlands due to poor quality of execution.

14 Certain services – for example energy calculation and airtightness testing – are crucial for obtaining quality in the implementation of a passive house project in the framework of such certification. Such activities were not developed by network employees, but offered by network members. The employees would communicate the importance of such quality-assurance services in order to boost the quality of demonstration projects.

15 This voluntary label was first granted in October 2005 to seven single-family housing projects by the State Secretary of Sustainable Development and Social Economy.

ergy distribution networks and local governments (communities and cities) to set up grants for passive houses.

Furthermore, the network created the necessary peripheral conditions for endorsing enterprises with expertise and for confirming demonstration projects. Knowledge and players from 'accepted' projects were the most important basis for knowledge generation for future builders, enterprises and the general public, thus providing a loop of input to different activities aimed at the diffusion of knowledge. Projects with quality assurance were used as a knowledge source for new customers. Participating businesses were allowed to contribute as knowledge providers in networking events. These procedures endorsed the closure of the information loop.

11.4.7 New segments and reinforcing conditions

The 'confirmed' information generated was also meant to address new segments of enterprises and customers. After a first loop generating general interest in the innovation, it became clear that only a limited target group of well-off, double-income innovator clients committed to green issues had been reached and that supply merely followed demand and technology available in other regions. The characteristics of the first customer segment, confirmed Rogers' view that clients who seek contact with change agents usually have a higher socioeconomic status, engage in more social participation, have higher formal education and favour cosmopolitanism (Rogers, 2003: 382). A subsequent loop focused on the learning cycle of the supply side, first addressing the segment of designers and architects – who usually help the customer in the persuasion phase – and later the segment of contractors and indoor climate engineers. This segmentation proved useful, since it led to the detection of a need for specific activities to reach various target groups. Architects appeared to be in need of a design handbook, while heating engineers, for example, had become wary in the wake of popular communication about 'houses without heating' and needed specialised design and energy calculation tools. Additional resources to improve enterprise innovativeness were brought into the network to develop activities in these fields.

While innovator green families could be convinced by sustainability visions and energy savings, for other customer target groups it became apparent that this focus should shift towards proven comfort and/or financial benefits. Customer segments were gradually expanded from well-off green families to comfort- and health-valuing families and motivated project developers. Again this led to the defining of new activities by the network. For example, project developers had a greater need for cost-based analyses. The project development learning cycle also resulted in the first spin-off demonstrations for office buildings, public service buildings, schools and daycare centres, amongst others, thus bringing in new customer segments (workers, facility managers, students, elderly people, children). A demonstration project for various building typologies allowed various target groups to gain experience and familiarity through demonstration.

Norms of the social system also changed due to the influence of demonstrations of passive houses, which also influenced network activities. For example, many requests for technology started to come from neighbouring regions (Brussels Capital Region, Wallonia), where there were no such initiatives. This created a need for multilingual communication and the establishment of an independent network for the French-speaking part of the country. The combined regional interest led to influence at the national policy level. When income tax reduction for passive houses was introduced by policymakers, there was suddenly an urgent need for an adapted confirmation tool and discussion arose about the compatibility of passive house related activities with projected EPBD developments. Today there is the prospect that the passive house standard will be obligatory in the Brussels Capital Region by 2015, which implies the development of a rapid transition to customers with various psychographic profiles. This merely illustrates that networks have to continuously define and redefine their activities according to changing conditions and learning experiences.

It is not the intention of this study to discuss the further evolution of the network activities in detail. Suffice it to say that the activities were adapted to changing conditions for various segments, leading to network growth in terms of employees, members, projects and activities. Accordingly, it is time to identify the success factors in the communicative work of the PHP and define opportunities for communication policy.

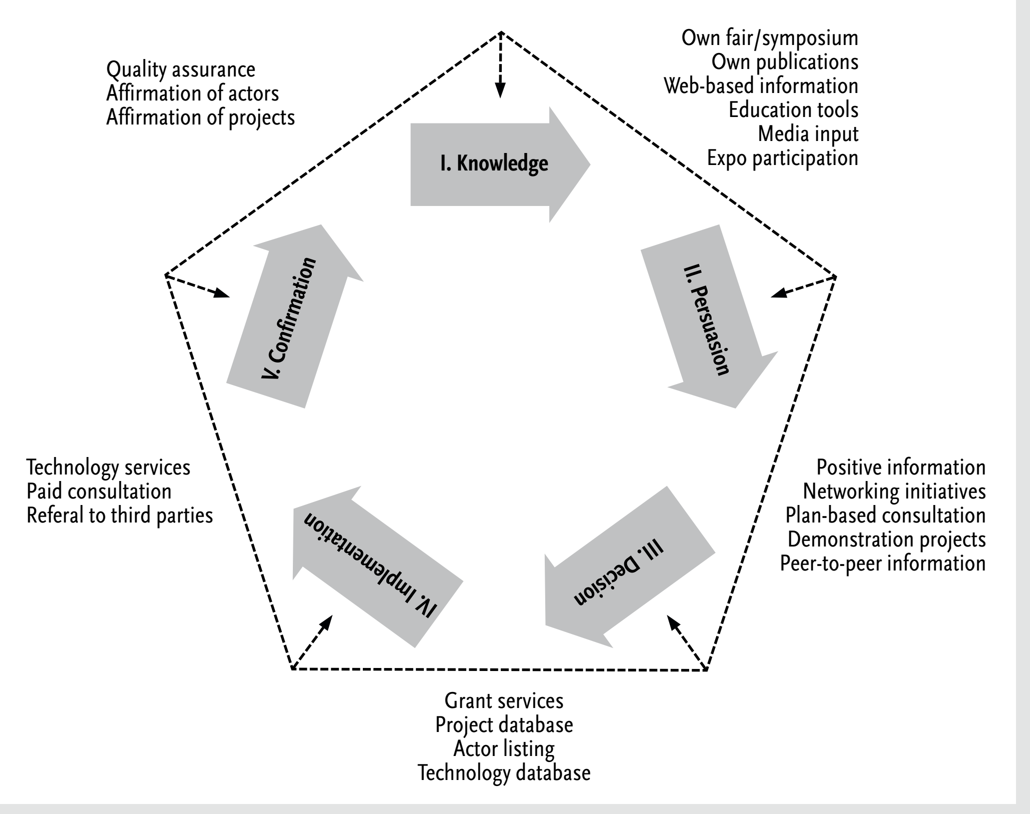
11.5 Success factors for the creation of customer demand and market infrastructure

11.5.1 Adapting to changing prior conditions and market segments

This study of one network has clarified that an important success factor in the development of market infrastructure and customer demand for project-based innovation such as passive houses is that prior conditions are initially favourable. The network had a formal goal to diffuse knowledge and could use competencies and resources in order to encourage the adoption of innovation. Gaining knowledge from confirmed innovation in other regions lowered the threshold for radical innovation within single enterprises to incremental innovation within a network.

This study also showed that a high degree of coordination was required to continuously revise activities based on changing prior conditions and seg-

Figure 11.3 PHP activities guiding innovation adoption processes



ments. The decision to endorse frontrunners in various segments (businesses as well as clients) and to introduce a system of recognition into the social system, were important aspects that influenced the conditions for subsequent innovation and learning cycles. At the same time, providing information to both the supply and the demand sides in various segments reinforced the position of the network employees as neutral players and strengthened the motivation of enterprises and customers to engage in network activities.

11.5.2 Network activities reinforce each step of the decision process

Another important success factor was the emphasis on concerted action and the creation of synergies (see Table 11.2) rather than innovation in individual enterprises. Figure 11.3 shows the various communication activities of the network at the various steps of the model from Figure 11.2.

It seems that one of the strengths in the definition of network activities was that in order to reinforce adoption, communication initiatives were organised to provide answers at each step of the decision-making process. This meant that businesses or clients could count on an appropriate response, with predefined communication activities from the network employees, regardless of the innovation-decision phase in which they found themselves. The network produced enterprise-related information materials and undertook activities that mainly assisted in the evaluation of opportunities for innovation. In terms of perceived innovation characteristics (Rogers, 2003), it was observed that activities were defined in such a way as to significantly reduce the perceived complexity. The various activities enhanced the attractiveness and improved the availability of innovations, which led to the building up of an emerging market infrastructure and demand. Compared to group actions (see Table 11.2), there was only limited attention paid to 'engaging' individual enterprises in innovation journeys and 'enabling' them to find competencies and resources, which was one of the weaknesses in the definition of activities. Nevertheless, the exemplification of some innovation paths improved the visibility of specific opportunities for technological and service innovation for individual enterprises.

11.5.3 Linking confirmation activities with knowledge generation

The study showed that a passive house network's activities could increase the level of confidence in adopting innovation (in this instance, the passive house). This confirms Peattie's proposition (1998) that the degree of confidence is significant for green purchases by users. In practice, the degree of confidence was increased by developing and communicating a confirmation system linked to knowledge generation. Innovations made visible in confirmed demonstration projects convinced enterprises that they could benefit from innovative technologies and activities, using them as a framework to promote their own specific products, systems and services. In turn, this led to the acquisition of knowledge within these enterprises and a visible development of new supply. Similarly, positive experiences of customers in projects – or with innovations – were used as new knowledge to create confidence in aspiring customers.

The development of its own performance requirements, consultancy and quality assurance services allowed the network to play an important role in the continuation of 'knowledge' diffusion and market development. Setting conceptual standards that express relative advantage was used as a recognition barrier and exclusion mechanism. The network agents were in fact both gatekeepers of the standard as well as innovation diffusion accelerators. In addition, expressing relative advantage, the network increased trialability through its explicit focus on demonstration projects. It increased compatibility and reduced complexity by defining activities for various segments.

This approach paved the way for the closing of each learning cycle and the opening of new innovation paths centred around demonstration projects, which resulted in both market infrastructure development and new customer demand. Enterprise and customer confirmation of the innovation even led to spill-over to other segments. Thus, one of the strengths of the model in Figure 11.2 is its focus on linking activities in the confirmation phase with activities in the knowledge phase. It can generally be recommended that closing each information loop will feed new innovation-decision processes regularly and consistently.

11.6 Conclusion

Returning to the research question: What are the tactics and success factors for stimulating the adoption of project-based innovation, as determined from a study of the activities of an innovation-oriented passive house network? To address this question, the study began by developing theoretical insights and a model to analyse the activities of innovation-oriented networks. This was used to analyse the activities of a successful passive house network from the perspective of the diffusion of innovation, increasing environmentally aware behaviour and stimulating market transition. The research findings point to reinforcing conditions, operational activities and success factors that can increase the level of adoption of innovation, essentially by using learning cycles more effectively, particularly in project-based fields such as the construction sector. An analysis of the activities of a successful passive house network revealed a broad range of potentially interlinked activities, which not only targeted the development of customer demand but, more specifically, the uptake of innovation by businesses.

An important success factor related to the successful uptake of innovation was the systemic approach to defining network activities that address the specific characteristics of the project-based sector and various enterprise and customer segments. These activities focus on the development of customer adoption and enterprise innovation in different technological subdomains, while offering the promise of market transition. Specific competencies and resources are needed to coordinate such activities. A set of coherent communication activities can be defined to realise the diffusion of innovation by focusing on behavioural change and by creating synergies to produce identifiable innovation outcomes.

Another important success factor was that both customers and businesses were supplied with appropriate information at each step in the innovation-decision process. Learning, vision development and network formation are important. However, more importantly, short-term activities must be defined in detail to persuade potential adopters and assist them in their decision to adopt an innovation. The study revealed a need for dedicated professionals to provide suitable responses at each step of the decision-making process, both for businesses and clients. In this framework, a possible role was detected for passive house networks as both 'change agents' and formal gate-keepers between innovation-push and demand-pull.

Other success factors were identified from the perspective of stimulating environmentally aware behaviour. In this framework, the importance of segment-oriented activities and peer-to-peer positive communication to boost confidence and ease perceived compromises should not be underestimated. Enterprise and customer confidence can be enhanced and perceived compromises can be eased by nurturing motivation, increasing availability, highlighting attractiveness and using confirmed innovations as new knowledge. Activities that address the confirmation of an innovation are very important, as these can assuage the lack of confidence and feed knowledge, thus leading to learning cycles. Introducing a mechanism of recognition into the social system is also important, but it should be recognised that this can also influence prior conditions for subsequent innovation and learning cycles. Networks should be wary about continuously changing prior conditions when defining or redefining activities for various segments.

The model developed and the success factors identified can be used to improve innovation theory and to develop communication policy to stimulate regional supply and demand, particularly for nurturing project-based innovation such as that found in the construction sector. In general, the policy should integrate experiences arising from the diffusion of innovation and theory on changing environmental behaviour. A policy focus on improving the affordability and competitiveness of highly energy-efficient housing is not recommended while the market infrastructure is still being developed. To encourage environmentally-aware behaviour, communication policy should focus more on exemplification (effectively using experiences from demonstration projects) and on engaging, enabling and encouraging clients and businesses. Businesses also need the right capacities and resources to develop innovation. In this respect, innovation funding for the creation of synergies and the development of communication activities would be useful. Furthermore, innovation policy could strengthen regional and other networks where appropriate. Funding is needed to improve the availability and attractiveness of systemic innovation that targets different customer and business segments, particularly during market introduction.

A model relating to the diffusion of innovation and changing environmental behaviour was introduced and explained in the theoretical framework. Future research could reflect on this model to target different technologies and other market segments and for the further development of policy. Given the time frame that is required to study the development of network activities, only one network could be investigated, with a limited perspective concerning the development of one specific innovation (the passive house) in only one region. Therefore, the theory should be considered with care and within the limitations of this study, while future research is required to confirm the validity of the model.

Acknowledgements

The author would like to thank the two anonymous reviewers as well as colleagues Anke van Hal and Henk Visscher (OTB TU Delft) for their valuable comments, and PHP for making it possible for the author to develop this study.

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12 Conclusions

12.1 Introduction

The debates about climate change and the security of energy supply, perceived opportunities for a 'greener' economy and policy developments like the Energy Performance of Buildings Directive have all revived interest in energy efficiency and related innovations. Significant potential has been recognised for reducing energy use, especially in such energy-intensive sectors as (residential) buildings. Achieving the current policy objectives related to climate change and energy will require significant carbon reductions in residential buildings, particularly with regard to energy demand for space heating. For this reason, this study investigated innovation opportunities and challenges related to the adoption of highly energy-efficient housing concepts.

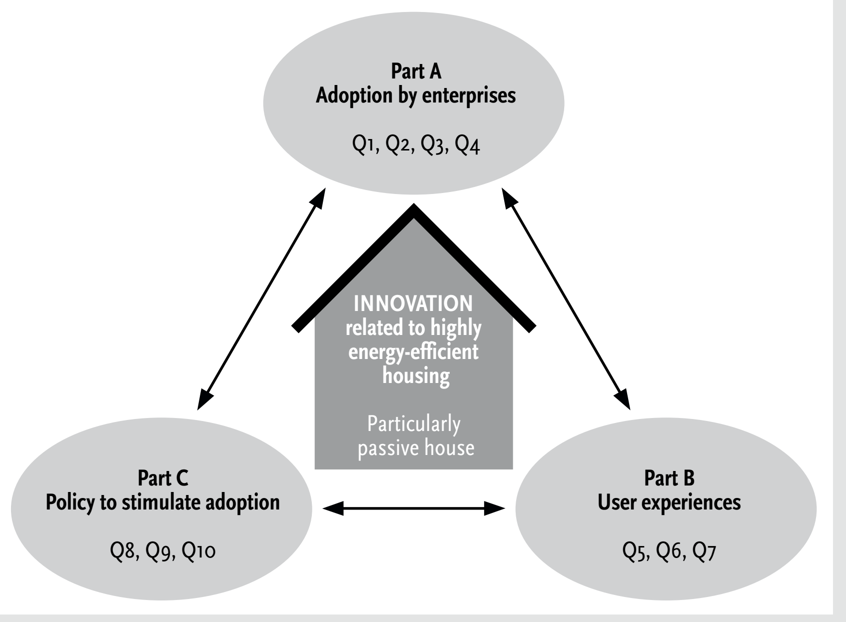
Of various housing concepts, the passive house concept – which focuses on largely reducing the demand for space heating – developed relatively fast alongside the increasing public interest in energy efficiency in the framework of sustainability. After a market introduction phase the passive house has shown the potential to grow beyond a singular focus on space heating demand and initiate structural changes in society. This holistic process of generating impact on companies, end-users and policy makers was considered worth exploring. Therefore, passive houses were taken as a case concept to study innovation opportunities and challenges related to the adoption of highly energy-efficient housing concepts, with the understanding that such a study might have broader implications, for example related to the adoption of various sustainable building concepts.

In practical terms, this research aimed to identify innovation opportunities and challenges related to highly energy-efficient housing concepts, particularly passive houses. The theoretical objective involved the development and interpretation of innovation theory drawing upon an approach to the adoption of concepts. The main research question was formulated as follows:
Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses?

To structure the research in relation to the applied theories and key concerns regarding market development, the main research question was subdivided into three primary questions (each analysed in a separate part) and ten subquestions (each analysed in a separate chapter), as follows:
Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses (main question), as observed from the supply side (Part A), the demand side (Part B) and the policy side (Part C)?

Analysing demonstration projects involving single-family housing, the first part of the study identified innovations that enterprises associate with pas-

Figure 12.1 The research defined the 'innovation' and studied its adoption by enterprises (Part A), end-users (Part B) and policy (part C), defining multiple research questions in each part



sive houses and other highly energy-efficient housing concepts. Innovation theory was then developed further through the examination of the innovation-adoption process of a supplier, in order to explore systemic innovation opportunities. The path of collaboration between enterprises was further explored for an emerging market (advanced housing renovation) and by examining opportunities and barriers for the transition from an innovator market to early adoption, using the experiences of a passive house enterprise network.

The second part of the study addressed the viewpoint of the demand side by examining the innovation-adoption experiences of end-users, based on post-occupancy evaluation research for various categories of newly built nearly zero-energy homes in the Netherlands. To ascertain the need for quality assurance and for improving passive house certification, this part of the study also drew upon the experiences of end users with certified passive houses. To support the emerging market for advanced renovation, the decision processes of owner-occupants regarding innovation adoption involving highly energy-efficient renovation were addressed.

The third part of the study aimed specifically to derive lessons from European policies and initiatives that could stimulate the adoption of highly energy-efficient housing concepts. To this end, it studied the definitions of nearly zero-energy houses that are contained in the policies and networks of European member states, with particular emphasis on the adoption of labels in governmental policy. In addition, opportunities for increasing innovation adoption through various communication channels were explored, as exemplified by the activities of the previously discussed passive house enterprise network.

Several research methods were used to explore the issues mentioned above, depending upon the specific research question addressed. In addition to literature study, data were collected from existing Belgian and Dutch residential demonstration projects in order to identify innovations and end-user experiences in newly built, passive and nearly zero-energy houses and renovations. Additional empirical data were collected through questionnaires directed towards companies, end-users and policymakers, along with database and web searches, and interviews with demonstration project stakeholders (e.g. end users, architects and enterprises). Lessons were also derived from action-based experiences with innovation guidance for enterprises, the establishment of a passive house network and the development of the market for passive houses in Flanders, northern Belgium. Like the Netherlands, Belgium began relatively late with the adoption of the passive house concept, although it nevertheless managed to achieve faster market introduction than the Netherlands. These experiences therefore provided an interesting basis for exploring questions related to adoption.

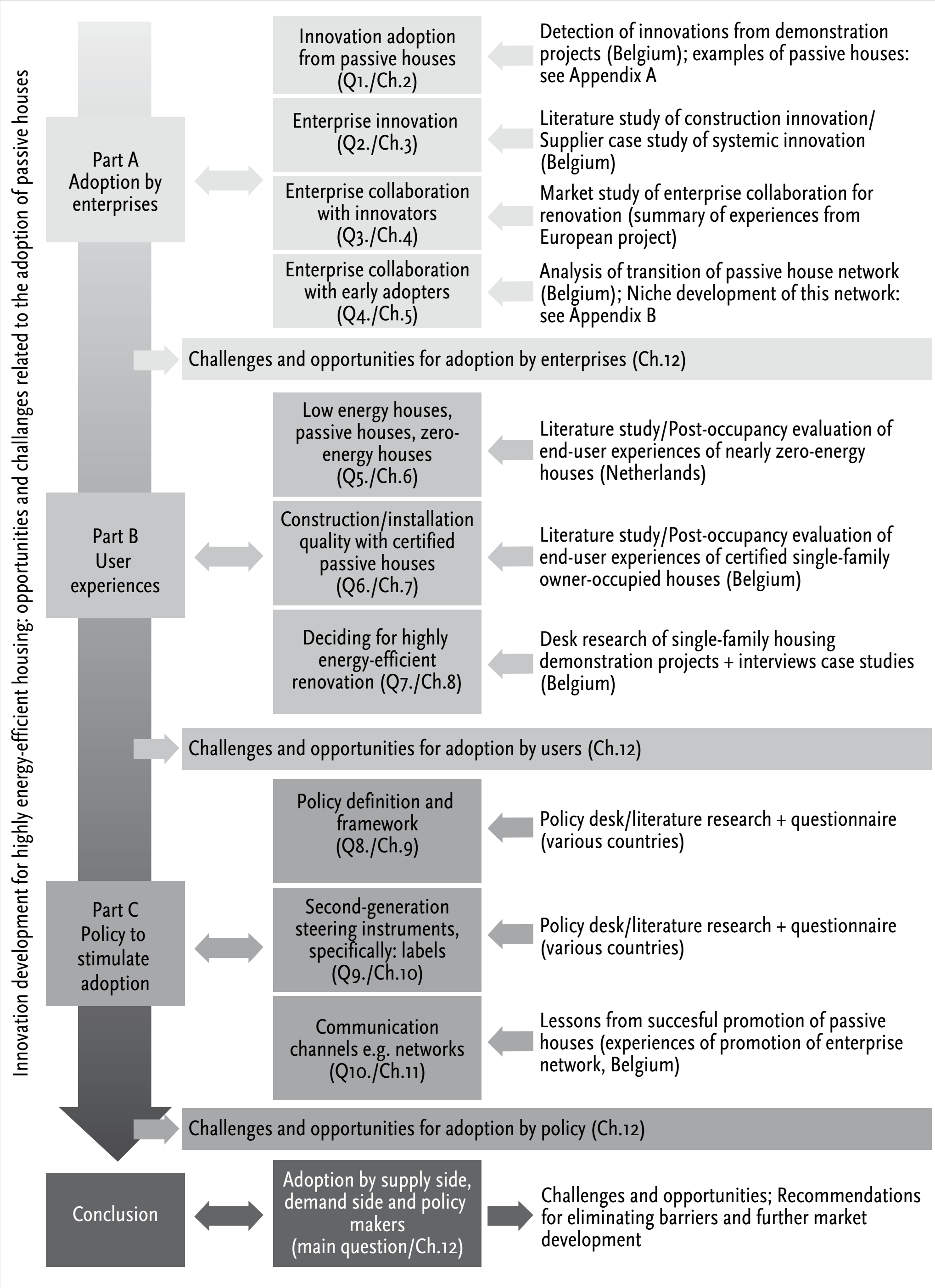
The general research approach is illustrated in Figure 12.2.

The study focused on highly energy-efficient housing and related innovations in countries where domestic energy use is dominated by space heating. The identification of innovations from enterprises and the examination of enterprise-network experiences and end-user experiences focused on single-family and/or owner-occupied housing in Belgium and the Netherlands. The conclusions should be seen in light of the limitations described in each chapter, taking into account the fact that building traditions and market development can differ across countries and that learning effects identified by studying selected demonstration projects and innovation trajectories can be limited. Conclusions and recommendations are also bound in both space and time, and they are subject to the availability of information during the time of the research.

12.2 Opportunities and challenges related to the adoption of highly energy-efficient housing

This section begins by answering the various sub-questions with regard to innovation adoption, as defined during this research. As illustrated by these answers, many elements are needed in order to answer the main question, and a variety of factors and recommendations have the potential to increase the rate at which highly energy-efficient housing concepts (e.g. passive houses) are adopted by businesses, customers and policymakers.

Figure 12.2 The three main parts in the book, the main themes covered in the ten studies, the research input used in each chapter, and the research output expected from each part



12.2.1 Challenges and opportunities for adoption by enterprises

Q1. *Which innovations are likely to be adopted in accordance with the passive house concept?*
An integrated architectural approach can result from stimulating the passive house concept, and enterprises associate this concept with a multitude of technologies, services, systems and architectural innovations (possibly clustered into various combinations). One advantage of the passive house concept is that it can be easily translated into generally recognised principles. Enterprises relate these principles to specific requirements, thus introducing various technological innovations in such fields as thermal insulation, building airtightness, high-efficiency mechanical ventilation with heat recovery, passive solar and light gains, and additional heating and renewable energy systems, as well as various combinations of these innovations. In addition to generating technological innovations, passive house projects introduce innovations involving systems, service and architecture. The promotion of newly built passive houses is also likely to stimulate the integration of new technologies in existing housing and the development of standard protocols.

The main conclusion of this part of the study is that the communication of 'concepts' (e.g. 'passive house') leads to the adoption of multiple innovations.

Q2. *Which opportunities exist for eliminating barriers to supplier-led innovation in highly energy-efficient housing?*
Suppliers in the house-building sector often lack the competency, expertise and resources that are required for systemic innovation. Suppliers that do engage in innovation may find that various players in the construction sector are inhibited by a preference for loose collaboration and a project-based approach characterised by the ad hoc generation of knowledge. The results of this study show that it is nevertheless possible for suppliers to lead systemic innovation and to offer a coordinated collaborative approach that allows risk sharing between the different stakeholders.

The most important opportunity for suppliers involves the realisation that their innovation journeys are not necessarily subject to policy directives or specific phases in a demonstration project, as coordinated collaboration can be planned as far in advance as the conceptual-design phase. Suppliers should move away from an incremental vision of innovation to embrace modular innovation as a vehicle for incorporating architectural and system innovation in demonstration projects. When embarking on such an innovation journey, it is essential to establish and develop a network around the innovation (whether proposed or actual), as this can contribute to market success: different enterprises in the construction-sector innovation chain have different frames of reference, and they contribute with different kinds of knowledge and competences. Formal structures for innovation collaboration between market players can enhance competencies and resources for innovation journeys.

Specialised agents can direct suppliers towards collaborative approaches to architectural and system innovation. Given the specificity of the construction sector and the innovations for achieving a high level of energy performance, it would be worthwhile to cultivate and develop these agents as intermediaries between suppliers and other players in the construction chain.

The primary conclusion of this research with regard to this question is that the adoption of highly energy-efficient housing is likely to increase as enterprises increasingly engage in systemic innovation journeys. More specifically, suppliers should collaborate with market players and innovation intermediaries.

Q3. Which collaboration opportunities exist with regard to highly energy-efficient housing renovation?

Due to the current level of fragmentation within the sector, with individual small and medium-sized enterprises (SMEs) each performing a fraction of a supposedly integrated renovation, cost escalation and the lack of knowledge and project management are posing important barriers to the advanced energy renovation of single-family housing. One particular challenge involves the need to increase the flow of technical information concerning highly energy-efficient renovation and knowledge about project management between the frontrunners and the many less experienced implementing actors, most of which are SMEs. In addition, actors on both the supply and the demand sides should be informed in a more targeted way.

The results of this study[1] show that housing renovation processes should be reformulated and better collaboration structures should be developed, in order to unburden the client. The study identifies a need to develop a pool of experienced actors for the implementation of highly energy-efficient housing renovation, along with a need to introduce quality-assurance and support schemes for major housing renovations. Supply-chain collaboration would support the necessary market development. Such collaboration could be facilitated through the development of a specific web platform. A 'one-stop shop' web portal could provide information to both groups of actors, suppliers and customers. A major opportunity lies in finding market-proof structures for collaboration and communication, in order to reduce the burden on homeowners, particularly with regard to alleviating financial burdens and burdens related to project management. Ideally, innovators would enter this gap in the market, establishing themselves as project coordinators capable of supporting homeowners throughout the decision-making process.

1 See also:http://www.one-stop-shop.org for additional findings.

The most important finding of this research on this question is that, in order to stimulate the adoption of highly energy-efficient renovation concepts, enterprises should engage in collaboration structures and communication channels in an effort to reduce the burden on homeowners.

Q4. *Which opportunities and barriers exist with regard to enterprise collaboration, particularly with regard to bridging the gap between innovation and early adoption?*
A market for highly energy-efficient homes should be developed relatively rapidly. In reality, however, the volume market cannot be targeted directly. Results from this study indicate the need to develop, characterise and cultivate the various subsequent innovation phases and transitions between phases. For example, in the case of the development of the Flemish market for single-family passive houses, SMEs played the most important role in sparking radical innovation at the regional level, while large companies were slower to adopt innovation through incremental innovation, particularly given the financial incentives that were in place and that targeted a large market. The results identify business-to-business collaboration as the key to the development of innovation in both the market introduction phase and the early adoption phase.

The transition from innovation to early adoption poses a considerable challenge, thus implying the gradual involvement and motivation of a range of enterprises and the attraction of skills and expertise in innovation. While the market introduction of innovation can be facilitated by formal collaboration between regional innovators and foreign suppliers, collaboration between innovators and large companies was identified in a later phase. This type of collaboration proved essential in order to bridge the transition to the early adoption phase.

Collaboration between specific types of enterprises can be facilitated by regional enterprise networks (e.g. for passive houses). The findings show that multi-player networks, which allow for collaboration amongst various types of actors (e.g. architects, installers, contractors and consultants, as well as clients and knowledge institutes), play an important role in eliminating barriers to expertise and in the provision of knowledge and networking opportunities.

The results of this study allow the conclusion that facilitating the transition from the innovation phase to the early adoption phase and increasing the rate of adoption in the early adoption phase will require large companies to collaborate with the regional innovators. Consultation with a specialised network could be one way of achieving this goal.

12.2.2 Challenges and opportunities for adoption by end-users

Q5. *What are the experiences of Dutch occupants with nearly zero-energy houses (e.g. passive houses)?*

Potential residents choose nearly zero-energy dwellings for various reasons (e.g. size, location, neighbourhood and purchase price), but the energy costs associated with a dwelling are important as well. End users living in highly energy-efficient houses are quite satisfied with their dwellings and indicate a high level of comfort. These findings could be used as additional arguments in the promotion of such dwellings.

One barrier to the adoption of nearly zero-energy houses might be the perception that they offer insufficient air quality and/or comfort in the summer, independent of energy category. Design deficiencies (e.g. lack of shading or ventilation bypass) or technical deficiencies in the heating and ventilation systems could be linked to such experiences. These examples illustrate the importance of quality assurance regarding design and execution, in addition to requiring the high level of energy performance associated with nearly zero-energy houses. Careful design and execution, including noise protection, sufficient air-humidity control and odour-removal strategies are critical points for attention in relation to possible improvements in all housing categories. In addition, simplicity and the user-friendliness of control systems are of utmost importance.

To avoid negative end-user experiences, it is strongly recommended that inhabitants be provided with information in addition to that provided in the standard short introduction to the house. At the very least, such information should include operation manuals, and preferably detailed instructions concerning the specific advanced housing concepts they would encounter in the dwelling. It is particularly important for end users who are not involved in the building process (e.g. end users in rental housing) to be provided with user-oriented technical information and/or training prepared by qualified sources.

The most important recommendation resulting from the examination of this question is that, regardless of the type of energy concept, increasing the adoption and diffusion of highly energy-efficient housing concepts will require quality assurance and specific information transfer in order to serve end users.

Q6. *What are recommendations for the improvement of passive house certification, based on end-user experiences?*

The current obligatory requirements for passive house certification (e.g. in Flanders, northern Belgium) do not always enhance end-user appreciation for indoor temperatures, indoor air humidity levels and/or noise levels. Summer comfort could be improved by adding cooling-demand requirement. There is also room for improvement with regard to requirements relating to the design and installation of indoor climate systems. Another very important course of action involves improving the user-friendliness of and information on building services, particularly mechanical ventilation systems.

These recommendations should be discussed within the context of developing widely supported plans aimed at improving the general quality of building services in housing, preferably by involving multiple stakeholders. Such plans should indicate the parts of regulations in which recommendations could be introduced, in addition to indicating which building codes require updating.

It could be concluded that passive house certification should be amended to include quality assurance for building services.

Q7. How were owner-occupants persuaded to apply highly energy-efficient renovation concepts in renovations of single-family houses?

Considering their renovation budgets[2], the promise of structural improvement, increased surface area, and improved comfort appeared to be the strongest factors motivating owner-occupants to adopt highly energy-efficient renovation concepts. Concern for comfort improvement was particularly influential in leading to energy-saving solutions falling within the cluster of comfort-oriented technologies in innovative concepts (e.g. the passive house renovation concept). Owner-occupants were also motivated by a more general concern for the environment and for improved health conditions. In particular, the passive house concept provided an opportunity for owner-occupants to negotiate a well-defined energy performance target with the executing parties.

One recommendation for addressing problems related to the lack of knowledge has to do with social strategies[3], including the establishment of peer-to-peer knowledge-exchange networks for owner-occupants, as well as for architects and contractors. The attractiveness of highly energy-efficient renovations could also be increased by providing reference networks, suitable tools and significant economic incentives for both customers and executing parties in order to improve the relative advantage and visibility of the actors involved.

The main finding with regard to this question is that, in order to increase the adoption of highly energy-efficient renovation concepts, owner-occupants should be given specific information about achievable ambitious energy-efficiency targets for their own renovation situations, in addition to information about the non-energy benefits of achieving such targets. A fully developed argument is needed in order to convince owner-occupants.

2 It should be noted that, in most of the interviews with owner-occupants (e.g. in Belgium), the cost of highly energy-efficient renovation concepts or available subsidies were not identified as strong persuasion parameters. This was largely due to lack of information about additional costs and the lack of substantial subsidies at the time the construction projects were started. In the selected demonstration projects, the owner-occupants (who belonged to the group of 'innovators') demonstrated that they had understood the possibility of additional costs, which they attempted to keep within an acceptable range of their mental budgets. They nonetheless appeared to be persuaded mainly by other parameters with perceived positive effects.

3 See also additional studies of the autor on http://www.lehr.be.

12.2.3 Challenges and opportunities for adoption by government policymakers

Q8. Which definitions of nearly zero-energy housing are likely to be adopted in Belgian and Dutch policy?

Definitions for highly energy-efficient housing have been introduced through general terms and demonstration projects, and they have been adopted and refined by innovators, researchers, business networks, mixed business/policy networks and government policy developers. In the effort to define nearly zero-energy dwellings, international researchers are currently proposing the terms 'net zero-energy' and 'net zero-carbon' in addition to 'low energy' and 'passive house', in order to enable the development of compatible regional market infrastructure and innovation diffusion.

The findings of this study show that 'passive house' is an important and useful term for the future implementation of national energy policies in Belgium and the Netherlands, as it offers market visibility and some policy acceptance. One important challenge with regard to avoiding market confusion is to ensure that definitions are clearly formulated and used consistently at all political levels (i.e. national and regional) and that they are compatible with the recast European Energy Performance of Buildings Directive (EPBD). Government policymakers responsible for energy policy are advised to define and reward better energy performance for passive houses and net zero-energy houses (e.g. through the use of fiscal tools and associated appraisal systems).

The main conclusion of this part of the research is that policymakers could increase the adoption of highly energy-efficient housing concepts by including 'passive house' in developing their EPBD policies.

Q9. Which barriers and opportunities exist with regard to the further diffusion of labels for highly energy-efficient houses?

In many European countries, labels for highly energy-efficient housing had been introduced even before the introduction of the Energy Performance Certificate for houses, which is currently required within the framework of the EPBD. Labels for passive houses have already been introduced in many European countries as an option for clients, in order to introduce additional user influence into a market that suffers from weak demand. Given the lack of experience on the part of many designers, contractors and installers with regard to building according to the much more rigorous requirements of highly energy-efficient houses, demand was weak due to the potentially high risk of unsuccessful adoption of highly energy-efficient building (i.e. the risk that the buildings would fail to achieve the required energy performance). Non-profit actors were most likely to engage in maintaining a high level of quality assurance and organizational involvement in energy-labelling schemes that had been implemented.

For many less advanced countries, the development or recognition of existing labels for highly energy-efficient houses might suit both current market demand and the implementation of the EPBD recast. The utility of the energy-calculation methods currently included in the Energy Performance Certificates has been criticised within the context of highly energy-efficient housing. On the other hand, specific passive house energy-calculation tools do offer reliable energy calculations. Combining existing advanced labels and associated energy-calculation procedures (e.g. 'passive house certificate' and 'PHPP') with the EPBD energy-certificate scheme is recommended. The specific way in which the EPBD and labels should be coupled in practice is highly country-specific and possibly subject to re-invention (e.g. by using a graded energy-performance label). One option for redrafting the energy-performance policies of member states could involve adjusting the current energy-performance standards by adding existing labels and incentives for improved performance and/or by increasing the trustworthiness and acceptance of existing labels in the Energy Performance Certificate programme.

There is a symbiotic relationship between the existing labels/certificates for highly energy-efficient houses, market infrastructure and user finance. The further diffusion of labels (or certificates that integrate them) could benefit from support by governments, banks, companies or combinations of these parties. National, regional and municipal authorities could facilitate the adoption of labels through such efforts as increasing their visibility through knowledge-transfer activities and by recognising the expertise of label providers. In addition, educational programmes for specific target groups are needed at the same time that labelling systems and quality-assurance procedures are introduced.

The main conclusion from the research on this question is that government policymakers could increase the adoption of highly energy-efficient housing by integrating existing passive house labels in their national recasts of the EPBD. The primary benefit would be the simultaneous implementation of a form of quality assurance, as it is already related to existing labels.

Q10. *What are the tactics and success factors for stimulating the adoption of project-based innovation, as determined from a study of the activities of an innovation-oriented passive house network?*

With regard to improving communication policies related to the success factors identified with regard to communication, the findings of this study indicate the necessity of a broad range of potentially interlinked communication activities, with high intensity of communication. Funding is needed to improve the availability and attractiveness of conceptual approaches to highly energy-efficient housing, particularly during the market-introduction phase. Communication should highlight innovative concepts (e.g. passive houses), as this would allow innovation in various technological sub-domains while offering a plausible technology and the promise of organisational innovation. This communication should be neutral, positive and peer-to-peer, addressing various customer and business segments. One very important point is that customers and businesses should be guided through the provision of appropriate information at each step of their innovation decision-making processes.

Customer confidence should be enhanced, and perceived compromises should be eased by cultivating motivation, increasing availability, highlighting attractiveness and guaranteeing quality. A policy focus on improving the affordability and competitiveness of highly energy-efficient housing is not recommended while the market infrastructure is still being developed. To induce environmentally conscious behaviour, communication policies should focus more on exemplification (i.e. the effective use of experiences from demonstration projects), as well as on engaging, enabling and encouraging clients and businesses.

In addition to targeting the development of customer demand, communication should be specifically directed towards the uptake of innovation by businesses. A set of coherent communication activities could be defined in order to realise the diffusion of innovation by focusing on behavioural change and by creating synergies to produce identifiable innovation outcomes. Specific competencies and resources are needed in order to guide companies along their innovation journeys.

It can be concluded that government communication policy should facilitate and engage in providing neutral, positive, peer-to-peer communication and systematic guidance for various customer segments and innovators.

12.2.4 Challenges and opportunities, as observed from the supply side, the demand side and the policy side

With the available research and answers to the sub-questions, the results of the study can now be used to formulate a more general answer to the main question:

Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses?

The study approaches this question from three viewpoints: from the supply side (Part A), from the demand side (Part B) and from the policy side (Part C).

Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, as observed from the supply side (Part A)?

The findings identify various barriers to the adoption of innovation related to passive houses by enterprises. The adoption and diffusion of passivehouse innovations by enterprises can be hindered by low demand or by a lack of market infrastructure (Chapter 2). One important challenge for enterprises in both the market-introduction phase and the early-adoption phase involves the need to attract skills and expertise in innovation (Chapter 5) and to develop motivation to adopt systemic and/or radical innovation (Chapter 3). Players within the construction sector may be inhibited from adopting innovations by their preference for loose collaboration and a project-based approach characterised by the ad hoc generation of knowledge (see Chapter 3). One important barrier to adoption by enterprises involves the fact that, because many enterprises in the house-building sector are small, they may lack the competency, expertise and resources that are required for systemic innovation (see Chapters 3 and 4). In addition, the adoption of innovation in housing renovation is hindered by the current fragmentation of enterprise activities, in which each of the many SMEs performs only a fraction of a renovation, as well as by a lack of project management (see Chapter 4). The market for highly energy-efficient homes needs to be developed relatively rapidly. In practice, however, the volume market cannot be targeted directly (Chapter 5). This study has identified various pathways to eliminating barriers to innovation adoption.

First, the findings indicate that focusing on specific target groups of enterprises could be useful for accelerating the rate of market introduction. The results suggest that SMEs from the construction value chain may be particularly capable of introducing technological, system and service innovations in demonstration projects (Chapter 2). With regard to the development of the Flemish market for single-family passive houses, small enterprises played the leading role in sparking regional and radical innovation, while large companies contributed during the early adoption phase through incremental innovation (Chapter 5). On the other hand, Chapter 3 identifies suppliers as a potentially important target group for introducing innovation (through innovation journeys), as well as for developing innovation beyond demonstration projects. The results of the study showed that suppliers have the important advantage that their innovation journeys are not necessarily subject to specific phases in the demonstration project, and that coordinated collaboration for innovation can be planned as far in advance as the conceptual-design phase. The personal commitment of companies is needed for adoption of passive house innovations (Chapters 2 and 3, Appendix B).

The adoption of innovation depends upon convincing companies (Chapters 2 and 3). As highlighted by the results of this study, specialised innovation agents are needed to facilitate market development and innovation adoption. Innovation facilitators appear to be very important for identifying potential innovating companies, stimulating innovation decisions and creating synergies. As shown in Chapter 3, suppliers have a need for innovation management when dealing with various SMEs and when integrating innovation in building projects. They must be guided properly, thus ensuring that their innovation journeys can generate cooperation and learning, in addition to ensuring that formal structures for innovation collaboration are able to increase competencies and resources for innovation processes (see Chapter 3). Chapter 3 provides evidence that innovation agents can help enterprises to identify modular, architectural and system innovations and to formalise the journey in order to obtain grants, in addition to increasing the range of expertise by involving complementary players and sharing information with possible innovation allies. A continuous effort appears to be needed within the construction sector to consult with SMEs regarding opportunities for coordinated collaboration involving highly energy-efficient housing and to facilitate innovation learning, in addition to 'packing' SMEs into innovation journeys. By using emerging ideas derived from innovations (including modular supplier innovation), specialised agents can point the way to collaborative approaches to architectural and system innovation.

The results of this study have shown that enterprise *networking* (Chapters 2 and 3) improves market development. As observed in Chapter 2, such networking could have a peer-to-peer character, centring on projects. Business-to-business collaboration was indeed found crucial to the development of innovation in both the market-introduction phase and the early adoption phase (Chapter 5). For suppliers embarking on innovation journeys, it is essential to develop and cultivate networks around the proposed or actual innovation (Chapter 3). According to the results, multi-player networks involving architects, installers, contractors, consultants, clients and knowledge institutes are important for eliminating barriers to expertise (Chapter 5). Multi-player networks are also important for providing networking opportunities during both the market-introduction phase and the early-adoption phase (Chapter 5).

If an enterprise lacks competencies that are needed for innovation, *enterprise collaboration* is likely to improve market development, as exemplified for the housing-renovation market (Chapter 4). As shown in Chapter 3, different enterprises in the innovation chain within the construction sector have different frames of reference and different kinds of knowledge and competencies. Exchange between enterprises is important when embarking on architectural or system-innovation journeys (Chapter 3). As reported in Chapter 4, collaboration by different categories of actors (e.g. informing, persuading, deciding, implementing and assuring actors) can support the development of emerging markets. Chapter 5 notes that the market-introduction of innovation can be facilitated by formal collaboration between innovators (e.g. regional) and suppliers (possibly foreign). Collaboration between innovators and large companies was identified in a later phase, and this type of collaboration offers an essential bridge for the transition to the early-adoption phase (Chapter 5). The results also indicate that collaboration between specific types of enterprises can be facilitated by regional enterprise networks for passive houses or other innovations (Chapter 3 and 5).

Given the specificity of the construction sector and the facilitators and innovation agents required, it would be worthwhile to cultivate and develop change agents that combine the role of facilitator and innovation agent. Such agents could act as intermediaries between suppliers and other players in the construction chain, in addition to acting as 'niche developers'. It would make sense to position such change agents within existing passive house networks (see also Appendix B). For example, employees of the Flemish passive house network are already supporting innovation journeys from incremental innovation towards system and radical innovation (see Chapter 3). Given the key role of multi-player networks in facilitating enterprise collaboration, innovation policy should specifically support their networking efforts.

The results identify several conditions that are necessary in order to facilitate innovation adoption and market-infrastructure development for enterprises. These conditions include making demonstration projects available, nurturing quality assurance and developing a pool of experienced actors.

As shown in Chapter 2, although enterprises introduce technological innovations in demonstration projects, many companies face challenges to adoption with regard to the needed knowledge about design and expertise regarding construction. Chapter 3 reports that the availability of demonstration projects was very important to the ability of enterprises within the construction value chain to adopt such knowledge and to collaborate with players who could provide the knowledge needed for innovation. Following the realisation of demonstration projects, another important challenge for companies involves attracting future clients. The demonstration projects show availability of innovation and offer clients the opportunity to adopt the innovation (Chapter 3).

Enterprise networking should ideally take place with regard to projects having demonstrated their ability to bridge the gap between future clients and innovating companies (see Chapter 2). Within this framework, the results of this study identify a need defined by enterprises to cultivate quality assurance. In the market-introduction phase, quality assurance can contribute to the recognition of demonstration projects, as exemplified for highly energy-efficient housing renovation (Chapter 4). After introducing innovations in demonstration projects, a confirmation system is needed in order to guarantee the quality of further projects (Chapter 2) and confirm conditions for obtaining grants and support (Chapter 5).

Furthermore, demonstration projects can be used to develop a network of experienced actors during the market-introduction phase (Appendices 1 and 2). As identified in Chapter 4, there is still a need to develop such a pool of experienced actors for the implementation for highly energy-efficient housing renovation. In particular, a specific pool of innovative actors is also needed on the level of renovation processes. While many companies are willing to collaborate, better collaboration structures are still needed in order to relieve the burden on the client (Chapter 4).

In conclusion, from the perspective of the supply side, the most important barriers to innovation adoption, as identified in this study, are as follows:

- The complexity of systemic innovation, particularly for SMEs.
- Low demonstrability: low demand and lack of market infrastructure.
- Insufficient motivation to adopt, as well as insufficient skills and expertise.

The most important opportunities for eliminating these barriers, as identified in this study, are as follows:

- Innovation agents should guide committed SMEs, and particularly suppliers.
- Enterprise collaboration and multi-player networking should be stimulated.
- The quality of demonstration projects should be assured, and a pool of experienced actors should be defined.

In answer to this part of the main question, it can be concluded that multi-player enterprise collaboration plays a key role in the adoption of 'concept' innovation.

Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, as observed from the demand side (Part B)?

Additional challenges and opportunities were identified by studying the demand side. Examples include opportunities for motivating end-users, the need to inform end-users and the need to introduce or improve quality assurance.

As indicated in Chapter 6, energy costs associated with a dwelling might be an important aspect that could encourage potential residents to choose a nearly zero-energy dwelling, along with other factors, including size, location, neighbourhood and purchase price. Results from the study reported in Chapter 8 also indicate that owner-occupants are motivated to adopt highly energy-efficient renovation concepts by the promise of various improvements: structural improvement, increased surface area and improved comfort. In addition, however, owner-occupants can be driven by a more general concern for the environment and for improved health conditions (Chapter 8). These issues should also be addressed in order to increase the adoption of energy-saving innovations, as these criteria are more important for some owner-occupants than is energy saving (Chapter 8). The results indicate high levels of satisfaction for the energy performance and indoor comfort in nearly zero-energy dwellings (Chapter 6) and in certified passive houses (Chapter 7). In theory, these findings could be used as additional arguments in the promotion of such dwellings (Chapter 6). In particular, concern for improved comfort could lead to the adoption of energy-efficient solutions falling within the cluster of comfort-oriented technologies in innovative concepts, as exemplified for the adoption of the passive house renovation concept (Chapter 8). According to the results, emphasis on 'energy efficiency' and efforts to brand the passive house concept are less relevant (Chapter 6).

The provision of detailed information (including, but not limited to, initial oral instructions and written manuals) is of critical importance, and it should not be neglected, regardless of the concept4 being addressed (Chapter 6). One very important course of action involves improving the user-friendliness and information on building services, particularly mechanical ventilation systems (Chapter 7). Inhabitants should be given information in addition to that provided in the standard brief introduction to the house. At the very least, such information should include operation manuals, but it should ideally include detailed instructions concerning the specific advanced housing concepts they will encounter in the dwelling as well (Chapter 6). It is particularly important to provide end users who are not involved in the building process (e.g. end users in rental housing), with user-oriented technical information and/or training by qualified sources (Chapter 6). In particular, in relation to first-time occupancy, the start-up phase for the operation of heating, ventilation and control systems can be critical for optimising performance. Furthermore, the organisation of feedback from occupants could effectively contribute to the identification and elimination of deficiencies (Chapter 6). The perception of poor levels of indoor climate control, dry air in winter and problems related to noise or odour could be eliminated in some cases by providing specialised information.

The results of the study indicate that the careful design and execution of heating and ventilation systems (including noise protection, sufficient air humidity control and odour-removal strategies) are critical points for attention with regard to possible improvements in all housing categories. Quality assurance regarding design and execution is needed, along with requiring the high-energy performance of nearly zero-energy houses. Quality assurance should include the evaluation of comfort in relation to such aspects as indoor climate and thermal comfort during winter and summer, air quality and noise protection, as well as such social parameters as information transfer to and communication with end users.

Potential solutions could involve introducing a quality-assurance system or improving the passive house certification procedures for assessing quality according to predefined requirements. For example, according to the results reported in Chapter 7, end-user appreciation of summer comfort could indeed be improved by maintaining a cooling-demand requirement. Consideration

4 See Chapter 6, which reports on a study of end-user experiences with low-energy houses, passive houses and zero-energy houses.

should be paid, however, to the manner in which requirements are implemented. The current obligatory requirements for passive house certification in Flanders (northern Belgium) have not always led to end-user appreciation of indoor comfort (Chapter 7). In particular, a small percentage of households from certified passive houses were not very satisfied with indoor temperatures, indoor air-humidity levels and/or noise levels (Chapter 7). This passive house certification system still has considerable room for improving the design and installation of indoor climate systems. In addition, questionnaires can be useful tools for identifying unsatisfied end users (Chapters 6 and 7). Unsatisfied end users could then be assisted by eliminating deficiencies in quality and providing the necessary information (see Chapter 7).

In conclusion, from the perspective of the demand side, the most important barriers to innovation adoption, as identified in this study, are as follows:

- The possibility of low perceived relative energy-efficiency advantages.
- The possibility of low satisfaction with indoor comfort.
- The visibility of deficiencies in projects.

The most important opportunities for eliminating these barriers, as identified in this study, are as follows:

- Emphasise non-energy benefits to persuade potential adopters.
- Provide end users with detailed information.
- Guarantee indoor comfort and the satisfactory performance of building services.

In answer to this part of the main question, it can be concluded that the needs and experiences of end users should be used to guide further innovation.

Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, as observed from the policy side (Part C)?

Energy policymakers (e.g. national, regional and municipal authorities) can play an important role in increasing the rate of diffusion of highly energy-efficient housing concepts. While Austria, Germany and Switzerland started by building up a niche market for passive houses in the early 2000s, other countries (e.g. the Netherlands and Belgium) have realised their first passive houses more recently (PEP, 2008). Countries in which the market for passive houses has developed more slowly could learn from other countries and regions with regard to processes that could facilitate adoption by enterprises and users, as well as with regard to policies aiming to stimulate innovation and deployment.

From a long-term perspective, zero-energy buildings, passive houses or other ultra-low energy- buildings will be the target of the recast EPBD (see

Chapter 10). As shown by the study presented in Chapter 9, policy makers in various countries are still struggling to determine which definitions should be applied for highly energy-efficient housing policy. One important challenge with regard to avoiding market confusion involves the fact that targeted definitions should be clearly formulated and used consistently at all political levels (e.g. nationally and regionally). A clear definition that is compatible with the regional context is necessary in order to increase attractiveness and demonstrability. The energy performance of a building should be expressed in a transparent manner. It should include a numeric indicator of primary energy use, preferably expressed in kWh/m^2a, and referring to the floor area sold or rented (Chapter 10). Nevertheless, definitions may have different meanings in different regions, and they are poorly integrated internationally.

Policymakers are also confronted with a lack of knowledge regarding the possible implementation of the concept definitions contained in policies. As shown in Chapter 9, several countries have already adopted housing-concept definitions in their building or fiscal policies. An important challenge (see Chapter 9) remains with regard to providing a system of appraisal. This challenge is especially salient with regard to the compatibility of such systems with market initiatives and regional grant schemes, regional implementation of the recast of the EPBD, administrative control of tax relief and other energy-related issues (e.g. the calculation of relevant energy indicators and tools, indoor climate appraisal). The Belgian situation provides an example of a legal framework (compatible with the required EPBD recast) that rewards better energy performance for passive houses and zero-energy houses. It shows that early fiscal tools can be used to reduce market confusion, as well as to test or enforce definitions for highly energy-efficient houses.

When developing appraisal systems, policymakers should consider the fact that there is a symbiotic relationship between the existence of labels for highly energy-efficient houses, market infrastructure and user finance (Chapter 10). Voluntary labels, which are often established through negotiation between private parties and government (or other mixed public/private actors) can be a complementary option for the further development of the EPBD (Chapter 10). In many cases, voluntary labels are somewhat easier to enact, given that they can draw upon the merits of a developed market and established quality assurance procedures. One option for redrafting the energy-performance policies of member states could be to adjust the current energy-performance standards by adding labels and incentives for improved performance and by integrating conditions for existing labels. As identified in Chapter 10, an important opportunity lies in the provision of a direct link between the practical integration of the EPBD recast and existing labels, e.g. passive house, given that all countries have recently begun the process of recasting the EPBD. In practice, existing voluntary labels are already providing experimental cases in many countries, regions and municipalities, with prospects for recognition as certification. Passive house project labelling is already popular throughout Europe, and it is closely related to the project-based identity of the building sector. It is therefore consistent with the emerging development of demonstration projects with improved energy performance (Chapter 10). For cases in which voluntary labels have already been developed by private parties, label recognition by a national government body is recommended in order to ensure a faster transition to early adoption (Chapter 10).

As shown in Chapter 11, a set of coherent communication activities can be defined in order to realise the diffusion of innovation by focusing on behavioural change and by creating learning cycles to produce identifiable innovation outcomes. Other ways of facilitating the diffusion of innovation include providing guidance to clients or companies throughout the entire decision-making process, with suitable responses at each step. Most importantly, players should engage in persuading potential adopters and helping them in their decisions regarding whether to adopt an innovation. For example, motivated passive house mediators have played a key role in guiding innovation-decision processes towards the implementation of nearly zero-energy housing for both businesses and clients. Businesses also need resources to help them acquire the competencies they need in order to develop innovation. Within this framework, a possible role also emerged for networks (e.g. focused on passive houses) as 'change agents' and formal gate-keepers between innovation-push and demand-pull factors within the single-family housing sector. Innovation policies could strengthen regional and other innovation networks, where appropriate. Such policies should improve the availability and attractiveness of conceptual approaches to highly energy-efficient housing that target different customer and business segments, particularly during the market-introduction phase. Accordingly, innovation funding for the creation of synergies, the development of communication activities and education and the implementation of learning cycles for various customer and business segments has proven useful.

Educational programmes for specific target groups are needed, corresponding to the introduction of labelling systems and quality-assurance procedures. In particular, the adoption of highly energy-efficient renovation continues to require special effort for the deployment of innovation and the development of policy. The attractiveness of highly energy-efficient renovations can still be increased by providing reference networks, suitable tools and significant economic incentives for both customers and executing parties, with the goal of improving the relative advantage and visibility of the actors involved (Chapter 8). As shown in Chapter 8, to date, only a few planners, consultants, building companies and suppliers of building materials have adopted highly energy-efficient renovation concepts. In theory, the adoption problems by architects, contractors and other players can be overcome by increasing the attractiveness, competitiveness, affordability and availability of highly energy-efficient renovation concepts for these target groups. Given that the elimination of barriers requires considerable effort for low-energy renovation concepts, as well as more advanced concepts (e.g. passive house renovation), the focus should be on exemplification by providing competencies and resources for the realisation of highest energy-saving targets for various existing building typologies.

Energy-policy development does not always explicitly correspond to the promotion of innovation or innovation-policy development (or vice versa), despite the evidence provided in Chapter 2 concerning the potential for innovation related to highly energy-efficient housing concepts. In general, collaboration between innovation policymakers/innovation networks and energy policymakers is recommended. The Austrian experience provides a rare example in which the introduction of a near zero-energy standard (through a stepwise energy-performance label combined with company-oriented government marketing, targeted education and progressive economic measures to reward better energy-performance levels) offers favourable opportunities for innovation diffusion (see Chapter 10).

Moreover, as shown in the energy-policy study, one important factor in the adoption of innovation is the adoption and diffusion of labels. It is essential to maintain a high level of quality assurance and corporate involvement in the energy-labelling scheme implemented. One important success factor in the innovation diffusion of labels involves generating or increasing the involvement of national governments in knowledge-transfer activities and the recognition of expertise of architects, building contractors and installers (see Chapters 10 and 11).

The success factors identified through this study could be used to improve energy and innovation policy, as well as to develop a joint communication policy aimed at stimulating a regional supply of and demand for highly energy-efficient housing. In conclusion, from the perspective of the policy side, the most important barriers to innovation adoption, as identified in this study, are as follows:

- Possible low compatibility between EPBD policy development and existing labels.
- Insufficient guidance for enterprises and customers in their decision processes.
- Perceived complexity of concept solutions in emerging markets.
- Complexity of various government policy levels and dealing with the specificity of the construction sector.

The most important opportunities for eliminating these barriers, as identified in this study, are as follows:

- Clearly define a system of appraisal for nearly zero-energy housing, using available passive house labels.

- Provide innovation funding for change agents.
- Provide an educational programme, particularly with regard to highly energy-efficient housing renovation.
- Integrate energy policy and innovation policy for the construction sector.

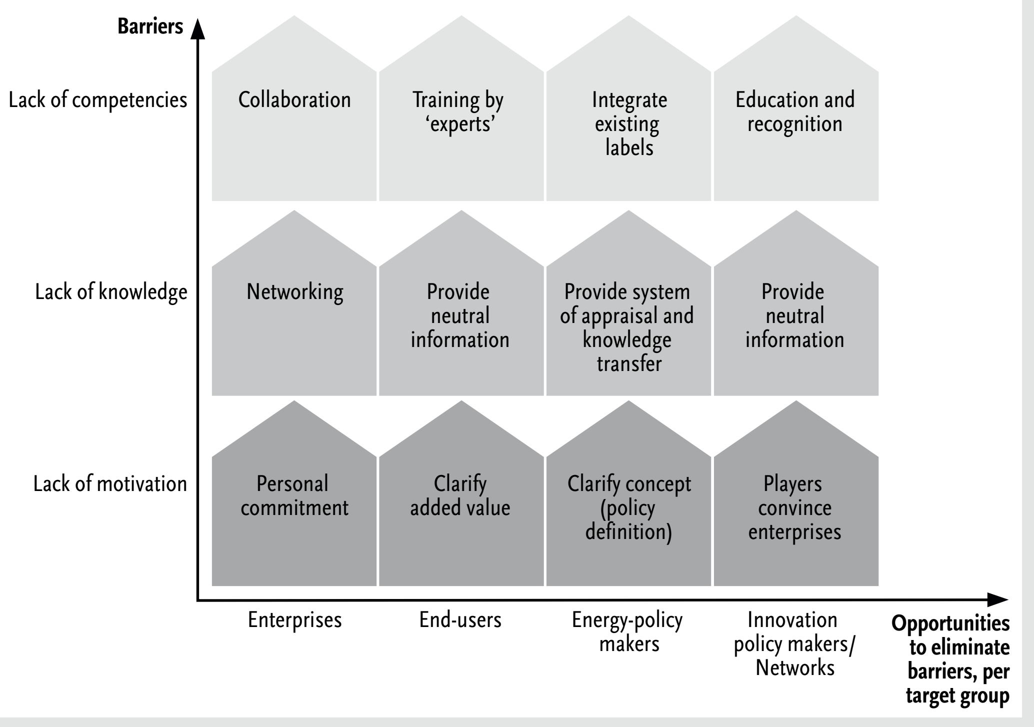
In answer to this part of the main question, it can be concluded that increasing the adoption of highly energy-efficient housing (particularly passive houses) requires an active role on the part of government policymakers.

As the reader can observe, this study has generated many answers to the main question, along with the associated recommendations, depending upon the perspective of the adopter. The results show that innovation adoption is not a process undertaken by individual companies adopting individual technologies. This study highlights the many new opportunities that emerge once the shift from individual technology innovations to innovative concepts has been made. Moreover, most of the opportunities observed in this study became apparent when considering groups of companies, enterprise networks, end-users and policy makers as 'adopters'. From the three perspectives the answer to the main question – 'Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses?' – can be summarised as follows:
- 'Concept' innovation (e.g. passive houses) should be stimulated, and multiplayer enterprise collaboration can play a key role in facilitating adoption of such innovation.
- Further innovation of concepts (e.g. passive houses) is needed, and the needs and experiences of end-users could reveal opportunities in this regard.
- Government policymakers should be engaged in the adoption of 'concept' innovations (e.g. passive houses).

12.3 Discussion: recommendations for further market development

One important finding from this study is that barriers – and ways of eliminating barriers – can be specific to particular phases of market development. There is a need to develop, characterise and cultivate the various subsequent innovation phases and transitions between phases (Chapter 5). During the market-introduction or innovation phase, it is important to target innovation-diffusion efforts towards the specific target group of innovators within specific market segments in the regional context, in order to achieve quality-assured demonstration projects. For single-family housing, the results of this study demonstrate the importance of primarily address-

Figure 12.3 Integrated approach to eliminating adoption barriers for highly energy-efficient housing



ing SMEs (Chapter 2) and suppliers (Chapter 3). Regional differences can be important as well. For example, the study shows that architects played a leading role in the realisation of demonstration projects (Appendix A, Chapter 2) and the achievement of highly energy-efficient renovation (Chapter 8) in Belgium. Although the focus of the study is not on finding adopter categories for end-users, Chapter 7 does illustrate the fact that owner-occupants form an important target group. On the policy side, the findings identify the adoption of highly energy-efficient concepts by the makers of energy policy (Chapters 9-10) and the stimulation of adoption by the makers of innovation policy (Chapter 11, Appendix B).

Throughout the various studies, three reoccurring important barriers for market development of highly energy-efficient housing emerge from various perspectives used to investigate the various target groups, including enterprises (Part A), end-users (Part B) and policymakers (Part C). These three barriers can be summarised roughly as 'lack of motivation', 'lack of knowledge' and 'lack of competencies'. Figure 12.3 reflects on ways in which to break through these barriers, using the solutions identified in this study in order to eliminate the barriers to innovation adoption that were discussed in the previous section. This reflection can be made for various categories of important adopters: enterprises (particularly SMEs and suppliers, as well as enterprise networks), end-users (the importance of owners and occupants was noted) and policymakers (particularly for energy policy and the development of innovation policy).

Figure 12.3 illustrates a pathway for transition. It suggests a way in which to go beyond the demonstration project towards a larger market for highly energy-efficient housing. First, all target groups (enterprises, end-users, energy policy makers, innovation policy makers and networks) should be involved in the realisation of this pathway. They should coordinate their efforts in order to eliminate these barriers. This is necessary, given the need to create market infrastructure (Chapter 5, 11, Appendix B) and customer demand (Chapter 11, Appendix B) simultaneously with the introduction of innovation, in symbiosis with policy development.

One motivated company can make a difference (e.g. Chapter 3 and Appendix B). During the market-introduction phase, the first barrier ('lack of motivation') is the most important. Once this barrier has been eliminated, knowledge can be found with like-minded innovators (e.g. in specialised networks). In order to eliminate the barrier 'lack of competencies', enterprise collaboration is fundamental, as illustrated by the experiences of a supplier (Chapter 3), interviews with supply-side actors (Chapter 4) and the experiences of a passive house network (Chapter 5, 11, Appendix B). Enterprise collaboration facilitates the uptake of the needed systemic and/or radical innovation (Chapter 3).

At the same time that an innovation is introduced, it is necessary to create customer demand and develop market infrastructure. Various innovators (e.g. SMEs, suppliers) need to clarify the benefits offered by the innovation to specific segments of end users. In order to enhance trustworthiness and customer confidence, networks should provide neutral information. Finally, end-users should be provided with specialised information for their own situations.

Enterprises and end users are needed in order to develop initial demonstration projects. These parties can be assisted by frontrunner policymakers. For example, the makers of energy policy can define the requirements for grants, and the makers of innovation policy can help companies by providing innovation agents. These policymakers can currently find sufficient inspiration in advanced countries (Chapter 9, 10) with regard to installing systems of information and appraisal whilst providing additional knowledge to end users and enterprises.

The *transition* from the introduction of an innovation (using demonstration projects) to early adoption poses a considerable challenge. This implies the gradual involvement and motivation of a range of enterprises (Chapter 5). In this phase, demonstration projects provide the basis for eliminating the knowledge barrier: structured information according to building typology, so that potential adopters can test similar concepts and learn from these demonstration projects (Chapter 8). It cannot be expected, however, that demonstration projects alone will guarantee the development of the associated market infrastructure and customer demand. During this phase, the barrier posed by lack of competencies becomes particularly important. In particular, integrated architectural approaches (Chapter 2), greater skill competence (Chapters 3-5, Appendix B) and tighter coordination in the planning and construction phases (Chapters 4, 8) are very important for highly energy-efficient housing and renovation concepts. Targeted dissemination and education are necessary in order to improve skills and competencies (Chapters 4, 8, 11).

Some countries (e.g. the Netherlands) are already developing a combination of government policy measures: market stimulation, target setting in covenants, legislation and support of innovation (Chapter 1). If we are to meet the goals that have been set, we must accelerate the transformation of the energy and housing market significantly, in addition to addressing all barriers to innovation diffusion and early market development simultaneously. In order to eliminate these barriers simultaneously, the continued use of collaborative strategies is highly recommended. As indicated by the results of this study, peer-to-peer knowledge-exchange networks for owner-occupants, architects and contractors (Chapter 8) or multi-player enterprise networks (Chapter 5, Appendix B) could provide neutral information, networking opportunities and a system of appraisal. On the other hand, policymakers bear an important influence on the adoption of innovation (e.g. passive houses) in the wider public. These networks and policymakers should now develop an integrated master plan, including the use of quality assurance systems (Chapters 6, 7, 8), in order to maximise the impact of the knowledge from demonstration projects. These plans should continue to stimulate enterprise collaboration towards systemic innovation (Chapter 3) and the uptake of systems of appraisal in policy (Chapters 9, 10). In addition, these plans should reflect the fact that customer demand should be created more effectively. Customers are not highly motivated to adopt highly energy-efficient housing because of its promises of 'energy efficiency' or terms specific for describing nearly-zero energy housing (Chapter 6). For this reason, both networks and policymakers should seriously reflect on their communication strategies, possibly by putting more focus on construction quality (Chapters 6-8), as well as on comfort and health (Chapters 6). In addition, policymakers should take advantage of the opportunity to integrate the use of existing market definitions (Chapter 9) and voluntary labels (Chapter 10) in order to increase the rate of adoption. For purposes of developing integrated communication plans that go beyond the demonstration project, policymakers could benefit from the experiences of existing passive house networks (Chapter 11).

From this cross-reflection, it can thus be concluded that for various target groups and customer segments, all barriers to innovation adoption should be eliminated. In order to reach this goal policymakers and passive house networks should develop a master plan. In particular, this master plan should focus on two main recommendations derived from this study, with the following related issues:

Master Plan Recommendation 1:
Makers of innovation and energy policy should support specific change agents.

- Energy policy and innovation policy should be integrated for the construction sector.
- Enterprise collaboration and multi-player networking should be stimulated.
- Funded innovation agents should guide committed SMEs and suppliers.
- Funded change agents should guide potential adopters in each step of their decision-processes.
- In some cases, these change agents could also combine their communication activities with the role of enterprise innovation agent.

Master Plan Recommendation 2:
Quality assurance schemes for highly energy-efficient housing need to be introduced or revised

- Potential adopters should be persuaded according to non-energy benefits.
- The quality of demonstration projects should be assured.
- A pool of experienced actors should be developed.
- End-users should be provided with detailed information.
- Indoor comfort and the proper performance of building services should be guaranteed.
- A system of appraisal for nearly zero-energy housing should be defined, using available labels, e.g. passive house.
- An educational programme should be developed, particularly for highly energy-efficient housing renovation.

12.4 Theoretical development and limitations of the research

12.4.1 Contribution to theory development

With regard to theory, this study focuses primarily on exemplifying, interpreting and developing the innovation diffusion theory developed by Rogers (2003). The study does not contribute to the analysis and discussion of specific timelines and lifecycle curves of innovations, nor does it introduce any mathematical diffusion models. Instead, the choice was made to explore Rogers' ideas regarding innovation characteristics, with the goal of identifying additional elements that may still be needed in order to persuade potential adopters to accept concept (passive house) innovation. This choice was made, given the influence innovation characteristics have on the rate of adoption and on the decision process of adoption (as passive houses are still largely in the market-introduction phase). The study has contributed to a deeper understanding and conceptualisation of various issues that could lead to improvement of innovation theory, using practical goals and real market, end-user and policy experiences as a laboratory. The theoretical challenge presented in the exploration of the research questions involved investigating innovation theory beyond the level of individual technologies and towards the concept level. Moreover, the study challenges Rogers' innovation diffusion theory to take more explicitly into account experiences from the construction sector (construction innovation theory) and from related theoretical fields (e.g. enterprise network theory and environmental behaviour research). In addition, this study has broadened the adopter's perspective in order to include groups of enterprises and policymakers.

According to theory, the rate at which companies adopt innovation can be affected by societal, technical, economical, geographical and policy circumstances (see e.g. Rogers, 2003). Nevertheless, there is little scientific literature regarding barriers to effective adoption and opportunities that could lead to effective adoption of highly energy-efficient innovation in construction companies. Scientists have also paid little attention to the reasons enterprises and users have for deciding to adopt and experience systemic solutions (e.g. passive houses). As noted in the previous section, this study uses the example of the passive house concept to explore barriers and opportunities related to the adoption of innovative concepts by various target groups (e.g. enterprises, end users, policy makers). By taking a concept approach instead of addressing individual technologies, the component studies have contributed to innovation theory in several ways. Most notably, they have identified the emergence of multiple innovations, novel opportunities for eliminating barriers that impede supplier-led innovation and opportunities and barriers for enterprise collaboration within the innovation-development phase and the early market-development phase. Consequently, the studies use the analysis of technological, societal and policy factors that can stimulate or hinder innovation diffusion in order to address various issues related to technology innovation, business innovation and policy innovation issues. They also suggest pathways for integrating highly energy-efficient housing concepts as innovations.

Various chapters have illustrated the validity and usefulness of Rogers' innovation diffusion theory for studying highly energy-efficient housing. The results have demonstrated how Rogers' theory can be applied to a relatively new type of innovation (e.g. passive houses). For example, the study reported in Chapter 5 confirms Rogers' hypothesis that larger units of adoption can be slower to adopt innovation. In addition, characteristics of innovations that influence the rate of adoption (as specified by Rogers) are used to discuss the adoption of highly energy-efficient renovation concepts by end-users (Chapter 8) and the adoption of definitions of nearly zero-energy housing (Chapter 9) and labels (Chapter 10) by policymakers. In addition, the research reported in Chapter 8 involves a test of a decision model based on Rogers' innovation diffusion theory on a limited number of case studies involving single-family owner-occupants. The decision model also proved useful for categorising success factors in the promotion of highly energy-efficient housing (Chapter 11).

The five steps in innovation-decision processes (i.e. information, persuasion, decision, implementation, confirmation) are applied and elaborated in Chapters 4 and 11. For example in Chapter 4, this model was tested and used for reflection in various countries (e.g. Belgium, Norway, Denmark, Finland) from the perspectives of both the supply and demand sides. The exercise in Chapter 11 provides an interesting foundation for elaborating Rogers' innovation-decision model into a network activity model that allows studying innovation-adoption opportunities from the perspectives of taking into account learning cycles and changing market segments and conditions. The innovative feature of this model is that it deliberately relates the innovation-decision process to various actor categories and customer values that can influence the innovation-decision phase of homeowners and businesses.

These elaborations have proven useful for discussing and improving communication between market actors and clients, particularly with regard to the identification of collaboration opportunities, as well as the development of web-based communication tools (Chapter 4) and network activities (Chapter 11) that can facilitate innovation-decision processes. The theoretical insights also suggest that, ideally, innovators should establish themselves as project coordinators who can support the homeowner throughout the entire decision-making process (Chapter 4) and networks should establish themselves as facilitators who can support various customer and business segments throughout the entire decision-making process (Chapter 11). It would be useful to investigate these models and hypotheses further, especially with regard to the emergence of 'one-stop shops' for integrated renovation (Chapter 4) and the study of network activities of various enterprise networks (Chapter 11).

Several of the chapters in this study contribute to the improvement of understanding regarding specific problems in innovation diffusion theory, particularly in relation to the transition from one market-development phase to the next (e.g. from innovation to early adoption; see Chapter 5). For example, one persistent problem identified in construction-innovation research is that innovations are not diffused automatically beyond a limited group of innovators or demonstration projects (Femenias, 2004). Although innovators and early adopters are known to have different characteristics (Rogers, 2003), the processes that lead to a transition from innovation to early adoption are not well understood. Researchers speculate that the players involved (and thus the innovation-policy strategies needed) may differ according to whether an innovation is being introduced or targeted towards the early-adoption market (Rødsjø *et al.*, 2010). For example, researchers speculate that companies of different size (e.g. micro-enterprises or large enterprises) adopt different innovation strategies (Rogers, 2003) and that different actors collaborate in different market phases (Rødsjø *et al.*, 2010). Such issues have been investigated within the niche of highly energy-efficient housing. From a theoretical perspective, Chapter 5 offers further elaboration on the experiences of the enterprise network described in the Appendix B, relating these experiences to innovation diffusion theory. In particular, it addresses the relevance of innovation phases, the relevance of company size to innovation and the need for enterprise collaboration.

One major theoretical insight developed in this study is that innovation researchers often tend to address the adoption of individual technologies, paying little attention to concept approaches or systemic innovation. As demonstrated in this study, however, the use of concepts and systemic innovation opportunities are crucial to the diffusion of innovation. As shown in Chapter 2, a concept approach can lead to individual technological innovations, as well as to system, service and architectural innovations (see Chapter 2). A success factor related to the successful uptake of innovation is the systemic approach to communication about innovative concepts (e.g. passive houses; see Chapter 11). Neutral communication on a conceptual level allows innovation in different technological sub-domains, while offering a plausible technology and promise of organisational innovation (Chapter 11). The results of this study thus suggest that the adoption of innovative concepts can more readily lead to adoption of innovation, as well as to the systemic collaboration that is essential for the adoption and diffusion of innovation, as well as for the achievement of energy-efficiency objectives. For example, in this study, renovation projects using clustered innovative passive house technologies generated the lowest energy use (Chapter 8). By breaking innovation down into individual principles (see Chapter 2), the concept approach to innovation led to innovation within the traditionally very conservative construction sector. The adoption of innovations by enterprises was indirectly supported by a high level of company identification with their own products, systems and services within concept-related principles. The application of a concept approach to innovation stimulated the introduction of technological innovations, as well as system, service and architectural innovations (see Chapter 2). Chapter 11 highlights the benefits of exposing individuals (or other decision-making units) to the existence of integrated concepts related to (energy) performance standards, given that the client's motivation to implement an integrated approach can be an important driver for the simultaneous implementation of several innovations.

The study has also demonstrated the potential utility of introducing the use of specific research methods or models to discuss innovation diffusion theory. For example, Chapters 6 and 7 show that post-occupancy evaluation research using questionnaires can provide important insights for discussing the elimination of barriers to adoption and communication. Chapter 4 shows the usefulness of generating business models and using collaboration canvasses in order to identify opportunities for collaboration. Chapter 11 introduces a model relating the diffusion of innovation to environmental behaviour change. Future research could test and use this model to target different market segments and for the further development of policy.

In addition to its connection to innovation diffusion theory, this study contributes to the further development of construction innovation theory. Because the hypothesis that demonstration projects are necessary vehicles for the adoption of innovations in the construction sector stems from construction innovation theory (Chapter 3), it was logical to examine this theoretical field as well. Within this framework, Chapter 2 confirms the emergence of innovations in demonstration projects and Chapter 3 also shows that demonstration projects in the construction sector can play a key role in facilitating innovation journeys and packing enterprises into innovation journeys. With regard to the development of construction innovation theory, Chapter 3 presents a new model for introducing radical innovation in the construction sector, which had previously not been described in the literature on construction innovation. The results of the study indicate that construction innovation theory should move away from an incremental vision of innovation in order to embrace a system-based vision, possibly by accepting modular innovation as a vehicle for incorporating architectural and system innovation. The study illustrates that an innovative idea can gradually change in the course of an innovation journey. The idea can grow from a notion of an incremental innovation into ideas for modular innovation, architectural innovation (in cases involving the integration of design and building) or system innovation (in cases involving the performance of entire buildings), and it can even contribute to the realisation of a market for radical innovation that supports system innovation. This in itself is an important new insight and model, as successfully illustrated in Chapter 3 for the context of supplier-led innovation.

In conclusion, the process of writing and digesting the comments of the peer-reviewers revealed that Rogers' framework is not always ideal for addressing all research questions involving the adoption and diffusion of innovation. In particular, questions related to developing systemic innovation (Chapter 3) and enterprise networks (Chapter 5) were found to need additional theoretical frameworks. Appendix B further suggests that the theoretical framework of 'strategic niche management' might relate better to specific success factors in innovation adoption, including vision formation and learning, as well as network composition and formation. In general, the theoretical frameworks of innovation adoption and diffusion (Rogers, 2003), systemic innovation (Chapter 3), construction innovation (Chapter 3), strategic niche management (Appendix B), environmental behaviour (Chapter 11), marketing research (e.g. Rødsjø *et al.*, 2010) and policy research (Chapters 9-11) are shown to be useful for addressing barriers and opportunities for innovation adoption. Although it might be useful to connect various theoretical fields in the future, an integrated theoretical approach is still lacking. A strong research effort is still needed in order to connect the various theoretical fields.

12.4.2 Limitations and future research

The research conducted within the scope of this study was limited, and future researchers are now challenged to enrich practical insights and comprehension of theory. The conclusions and recommendations reported here are obviously subject to the availability of information at the time of the research. In various studies, demonstration projects and innovation trajectories were used as sources of information, and the learning effects were limited to experiences derived from the chosen sources. Such experiences are bound to specific characteristics involving both space and time. In the identification of innovations of enterprises and in the examination of the experiences of enterprise networks and end-user experiences, the focus was on single-family and/or owner-occupied housing. The primary recommendations should therefore be understood as applying to this particular construction segment. For example, had the study addressed private or social tenants or groups of owners instead of individual owner-occupants, process innovation would probably have emerged as a much stronger recommendation. This was not explored in detail, largely because practical regional experiences in these segments were lacking at the time of the research. The exploration of these segments could now provide an opportunity for further research, however, as demonstration projects are becoming available.

This research focused on highly energy-efficient housing and related innovations in countries in which domestic energy use is dominated by space heating. The conclusions and recommendations should therefore be understood as most relevant for these countries. It was noted that national policy, building traditions and market development could differ across countries. In some instances, the 'case' research was limited to countries like Belgium and the Netherlands, and innovation research was limited to 'passive houses'. The conclusions and recommendations could be related to the more general notion of 'concept' innovation, however, and national experiences were used to discuss possible wider implications, particularly for defining general strategies that could contribute to the development of a market for highly energy-efficient single-family housing. They could also contribute to innovation-adoption strategies for construction sectors (or subsectors) that are dominated by SMEs. In particular, the observations regarding the need for quality assurance also target a more general problem of deficiencies in construction. Such deficiencies occur in various countries, and they are not necessarily related exclusively to highly energy-efficient housing.

In various countries, passive houses are still an emerging concept, and much remains to be learnt – particularly with regard to overheating in the summer, the perceived level of control and occupant apprehensions with regard to living in an 'air-tight', mechanically ventilated dwelling. Although the studies presented in Chapters 6 and 7 investigate end-user experiences in demonstration projects using questionnaire-based surveys, more attention is needed for the evaluation of the quality and user-friendliness of building services, as well as for their conformity to requirements, particularly with regard to space heating, cooling and ventilation. Because empirical studies regarding the quality of building services in recently built dwelling are still limited (Kroese *et al.*, 2009), it will be necessary to collect such data. Particularly in countries with an emerging market for highly energy-efficient housing, end-user experience surveys on demonstration projects can reveal ways of improving future projects and requirements. Given the rapid development of markets and policy towards nearly zero-energy housing, the adoption and acceptance of highly energy-efficient housing by end users is currently becoming a critical factor. Future research could extend the number of sampled houses surveyed and compare results when integrating results from other regions and countries. The Appendix in Chapter 7 highlights key issues that should be studied in such surveys.

This study provides an interesting framework for the further development of practical recommendations using innovation theory. For various kinds of building typologies, high energy efficiency can be achieved by clustering energy-efficient innovations into integrated concepts (Chapters 2 and 8). The study provides elaborate insight only for passive house concepts, and primarily for newly built single-family houses. Other innovation concepts (see e.g. Chapter 9: net-zero energy houses, energy-plus houses, CO_2-neutral houses) and market segments (e.g. multi-family houses, social housing, rental housing, neighbourhood developments) could be worth studying as well, and they could generate additional insight. The study does not prove nor claim that promoting the passive house concept is the sole way forward for enterprises and policy makers. It merely illustrates that in specific countries and regions the promotion of passive houses is currently considered best marketing practice by various enterprises and policy makers for achieving a transition towards highly energy-efficient homes. This study specifically questioned whether the strong focus on energy efficiency is also that important for end users. Besides energy efficiency, other emerging marketing approaches – for example concepts with a focus on living space, comfort, health, environment and the use of renewable energies – should be evaluated as they might respond better to real end user concerns. Such research can lead to optimization of existing concepts, like the passive house, or to the development of complementary (concept) approaches.

Given the limitations and focus of this work, the practical recommendations and models that are developed are not intended to provide a complete picture of all barriers and opportunities in the construction sector, involving various types of end-users and various specific regional or national situations. Other important barriers were not analysed in detail in this work. Examples include the lack of funding and the lack of specific enterprise competencies (e.g. project management competencies). With regard to the elimination of the barrier 'lack of funding', some solutions were treated only briefly: providing innovation grants for enterprises and innovation networks (Part A), covering extra investment cost with energy cost savings and other added values (Part B), and allocating resources for policy development while expecting return from market development (Part C). Further research is needed in order to address these barriers. In particular, within the market for single-family housing renovations, it appears that market-proof solutions are still needed in order to alleviate financial burdens and burdens related to project management (Chapter 4).

The importance of market phases is highlighted in this study. The findings offer confirmation for the hypothesis that immediately targeting the volume market makes no sense when developing policy or deploying innovation. Further research into the differences between the market-introduction, early-adoption and late-adoption market phases with regard to innovations is needed. As shown in Chapter 4, the renovation of single-family houses to achieve high levels of energy efficiency is still in the market-introduction phase. Further research is needed in order to explore barriers to and opportunities for adoption. As illustrated in Chapters 4 and 8, the barriers facing market actors and the process of innovation diffusion through opportunities for collaboration can differ between renovations and newly built houses. The models provided in Chapter 11 and Figure 12.3 offer an interesting starting point for future research in this area. Further research is also needed in order to understand challenges and opportunities in the early-adoption phase for newly built houses, and key barriers and opportunities related to the transition from early adoption to later adoption phases have yet to be identified. This is particularly important, given that marketing researchers have shown that delaying the transition to early majority can be detrimental to the entire process of market development (Moore, 2002). Within this framework, it is important to determine how the psychographic profiles of later adopters differ from those of other adopters (Moore, 2002; Rogers, 2003) and to define communication strategies for the new customer and business segments.

While the technological innovations and demonstration projects can be well documented, this study reveals that the social component of innovation, the concept approach and systemic innovation are in need of additional research attention. The theoretical framework presented in Chapter 3 reflects the need for strategies and theory on systemic innovation. Such theory development will require further research. In particular, system and architectural innovation using concepts as a reference is socio-technical in nature, and the social component deserves more research attention. More specifically, the role of networks in supporting communication, collaboration and transitions between phases could be investigated in more detail, also using networking and marketing theory.

Given the limited attention that Rogers' theory pays to social components, other theoretical frameworks could be considered as starting points when developing future research. For example, the literature on strategic niche management places stronger emphasis on the role of multi-player networks as a crucial element in the development of niche markets (Hegger *et al.*, 2007, Elzen *et al.*, 2004, Kemp *et al.*, 1998; Caniëls and Romijn, 2008; Raven, 2005; Weber *et al.*, 1999). It also emphasises sheltered spaces for learning and the incubation of ideas (Kemp *et al.*, 1998). Economic and environmental behaviour theory and marketing theory focus more sharply on the customer side. The utility of the framework of strategic niche management is briefly illustrated in Appendix B, in which key factors from the literature on strategic niche management are applied to the emergence of the passive house network used for the study in Chapter 5. Economic behaviour theory is touched upon briefly in the introduction to this dissertation, and the marketing literature proved useful in the development of business models for integrated housing renovation (Chapter 4). Environmental behaviour theory proved useful in Chapter 11. In addition, the theoretical framework for enterprise networks and regional innovation development could be used in order to gain additional insights. An important challenge for theory development remains with regard to connecting all of these theoretical frameworks.

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Appendix A Passive house projects in Belgium

Excerpt from: Mlecnik, E. & C. Marrecau, Passive house projects in Belgium,2008,
***International Journal of Environmental Technology and Management** 9 (4),*
pp. 390-401,
doi: 10.1504/IJETM.2008.019460,
http://www.inderscience.com/info/inarticle.php?artid=19460

Abstract
An enterprise nework was established in 2002 to introduce the passive house concept in the Flanders Region. Just four years later, demonstration projects and novel technologies were already available for the Benelux market, which swung the local market development by a factor four. Within the framework of the European project 'Promotion of European Passive Houses', these projects have been documented in English, Dutch and French and this part of the original paper discusses some design aspects, construction details, and technical information of example projects. The examples highlight the feasibility of the realisation of various types of passive houses in the Belgium.

A.1 Introduction

Previous papers have explained the creation of a passive house platform in 2002 and the development of its networking and initiatives for building passive houses during the first years (Mlecnik, 2003, 2004a). The platform proved itself to be a successful example of how to create the preconditions for a broad market introduction of cost-efficient passive buildings (Mlecnik, 2004b; PHP, 2003). The available knowledge was rigorously selected, analysed, structured and made accessible for future builders, architects and the general public.

A European project "PEP: Promotion of European Passive Houses", under the framework of Intelligent Energy Europe introduced a European passive house definition in Belgium and a regional certification methodology was established. In October 2005 the platform launched the Belgian 'certificates' for passive houses (habitats). Seven first projects were thus granted quality assurance by the State Secretary of Sustainable Development and Social Economy. Projects with quality assurance are promoted as good examples for reproduction in the general market.

A.2 Certified passive buildings in Belgium in 2005

The following tables show the buildings that have been realised in the Flanders Region since the creation of a passive house platform and that have re-

Figure A.1 Urban passive house in Heusden-Destelbergen

Photo: PHP

Table A.1 Urban passive house in Heusden-Destelbergen (architect: B. Cobbaert; calculation: denc!-studio; contractor: lab15; consultancy: Cenergie cvba; blower-door test: isoproC)

Construction				Technical information	
	Insulation	Thickness (mm)	U-value (W/m²K)	Earth-air heat exchanger	Length: 40 m, depth 1.5 m, Ø 110 mm
Floor	ESP	160	0.19	Heat recovery from exhaust air	Counter–flow heat exchanger
Wall-outdoors	Mineral wool + air gap	329 + 38	0.11	Supply water heating	Solar collectors + gas boiler
Wall-outdoors	Mineral wool + vermiculite	178 + 150	0.14	Solar collectors	Yes
Roof	Mineral wool	350 + 80	0.09	PV panels	Yes
Windows	Triple glazing with low-e coating	-	0.79	Air tightness	$n_{50} = 0.57\ h^{-1}$

ceived a passive house quality assurance document. The quality assurance guarantees that the energy use for space heating is limited to 15 kWh per m^2 net conditioned surface per annum and that an air tightness level is achieved of n_{50} equal to or below 0.6 h^{-1}. The specific performance criteria for passive houses, design guidelines and regional programmes of requirements are available from the website http://www.pep.ecn.nl. The passive house standard is purely an energy performance standard that allows architects to otherwise develop their projects in total freedom. A Dutch database of all passive house projects in Belgium is available on http://www.passiefhuisplatform.be. In some countries, like Belgium, certification as a passive house is coupled with regional grants. The owners are enthusiastic about the ventilation, light, thermal and acoustical comfort and the attention from outsiders.

A.2.1 Heusden-Destelbergen

Figure A.1 shows a view of this house from the garden side. This wooden row house with two exterior facades by architect Bart Cobbaert was the first exam-

Figure A.2 Passive house in Heusden-Zolder

Photo: G. de Bruyn

Table A.2 Passive house in Heusden-Zolder (architecture: E. Ubachs; contractor: Vanhout NV; materials: iso-proC, Hanssens Houtconstructies, ecom@Ecobouw; technical installation: IZEN, esco+; consultancy: Cenergie cvba)

Construction				Technical information	
	Insulation	**Thickness (mm)**	**U-value (W/m²K)**	Earth-air heat exchanger	Length: 40 m, depth 2 m, Ø 173–200 mm
Floor	ESP	250	0.13	Heat recovery from exhaust air	Counter–flow heat exchanger
Wall	2 × mineral wool + air gap	45 + 280 + 100	0.12	Supply water heating	Solar collectors + gas boiler
Roof	Mineral wool	350	0.10	Solar collectors	Yes
Windows	Triple glazing with low-e coating	-	0.79	PV panels	No
				Air tightness	n_{50} = 0.20 h^{-1}

ple of a cost-efficient passive house in Flanders. It is located in a dense urban area. Construction costs were limited to €800 per m² thanks to extensive collaboration in the building team. A double wood skeleton frame was used for the outside walls, and wooden trusses were used for floors and walls to integrate the ventilation conduits. Table A.1 shows some of the details of this project.

A.2.2 Heusden-zolder

This freestanding house by architect Eric Ubachs, shown in Figure A.2, was the first Benelux example of the implementation of a building system for the construction of a passive house. The project is constructed on a wood platform building method. OSB panels provide a good air tightness level. All details have further been documented and perfected within the framework of an innovation study of a merchant of FJI-studs. Table A.2 shows further construction details. Both previous examples are well documented in the Belgian national brochure of passive houses, available for download and for free on http://pep.ecn.nl.

Figuree A.3 Passive house in Ename

Photo: PHP

Table A.3 Passive house in Ename (architect: C. DeBrabander; materials: isoproC, ecom@, De Noordboom, Hanssens Houtconstructies; technical installation: Stroomop; blower-door test: @home)

Construction			
	Insulation	**Thickness (mm)**	**U-value (W/m^2K)**
Floor	ESP + cellulose	150 + 190	0.11
Wall	Cellulose + feather (air gap)	422 + 40	0.15
Roof	Cellulose + air gap	350	0.10
Windows	Wood/PUR joinery + triple PV panels No glazing with low-e coating	-	0.78

Technical information	
Earth-air heat exchanger	Length: 35 m, depth 1.8 m, Ø 200 mm
Heat recovery from exhaust air	Counter–flow heat exchanger
Supply water heating	Solar collectors + pellet boiler
Solar collectors	Yes
PV panels	No
Air tightness	$n_{50} = 0.47\ h^{-1}$

A.2.3 Ename

This house shown in Figure A.3, was constructed by a person working in the health sector as a (passive) house using ecological materials, with the main goal of living a healthy and economical lifestyle. Table A.3 shows construction details and technical information of this project. The house is now open for courses on "how to live and cook in a passive house".

More information on www.passiefhuisplatform.be.

Figure A.4 Passive house in Wijtschate

Photo: PHP

Table A.4 Passive house in Wijtschate (architect and calculation: denc!-studio; contractor: lab15; materials: MB Benelux, Artiklima, isoproC, Hanssens Houtconstructies; blower-door test: isoproC)

Construction				Technical information	
	Insulation	**Thickness (mm)**	**U-value (W/m²K)**	Earth-air heat exchanger	Length: 40 m, depth 2 m, Ø 200 mm
Floor	EPS + EPS	160 + 100	0.12	Heat recovery from exhaust air	Counter–flow heat exchanger
Wall	3 × mineral wool + mineral wool (air gap)	38 + 224 + 38 + 38	0.11	Supply water heating	Solar collectors + gas boiler
Roof	3 × mineral wool + air gap	38 + 324 + 38 + 22	0.09	Solar collectors	Yes
Windows	Wood/cork joinery + triple glazing with low-e coating	-	0.74	PV panels	No
				Air tightness	n_{50} = 0.35 h^{-1}

A.2.4 Wijtschate

This house – shown in Figure A.4 – is constructed with FJI studs as a carrier beam for the wall and the roof, a construction system developed mainly for passive houses. The habitat serves a family of five and a doctor's practice. There are three different temperature areas: the practice 24°C, the parent bedroom and the other rooms. Table A.4 summarises the most important construction details.

Figure A.5 Passive house in Torhout

Photo: PHP

Table A.5 Passive house in Torhout (Architect: G. Sabbe; contractor: De Noordboom; materials: isoproC, Deceuninck; blower-door test: isoproC)

Construction				Technical information	
	Insulation	**Thickness (mm)**	**U-value (W/m²K)**	Earth-air heat exchanger	Length: 40 m, depth 2 m, Ø 200 mm
Floor	ESP	300	0.11	Heat recovery from exhaust air	Counter–flow heat exchanger
Wall	3 × mineral wool + mineral wool (air gap)	320 + 90	0.12	Supply water heating	Solar collectors + pellet store
Roof	3 × mineral wool	168 + 210 + 90	0.09	Solar collectors	Yes
Windows	PVC/PUR joinery + triple glazing with low-e coating	-	0.76	PV panels	No
				Air tightness	$n_{50} = 0.40\ h^{-1}$

A.2.5 Torhout

This house – street side view shown in Figure A.5 – has a wooden skeleton structure filled with mineral wool and an outside brick facade. The construction costs are €1,250 per m². Construction details are given in Table A.5. The owner became so enthusiastic about his project that he convinced a major regional company in the neighbourhood to deliver suitable passive house technology. The project also uses a collector of rainwater of 15,000 l for the toilet, shower, laundry and garden.

Figure A.6 Passive house in Bocholt

Photo: PHP

Table A.6 Passive house in Bocholt (Architect: M. Cuyvers; calculation: denc!-studio; materials: MB Benelux, isoproC, Hanssens Houtconstructies)

Construction

	Insulation	**Thickness (mm)**	**U-value (W/m^2K)**
Floor	PUR	150	0.17
Wall	Cellulose + mineral wool (air gap)	350 + 53	0.10
Roof	Cellulose + air gap	36 + 400 + 22	0.09
Windows	Al/wood/cork joinery + triple glazing with low-e coating	-	0.75

Technical information

Earth-air heat exchanger	Length: 40 m, depth 2.3 m, Ø 200 mm
Heat recovery from exhaust air	Counter flow heat exchanger
Supply water heating	Solar collectors + gas boiler
Solar collectors	Yes
PV panels	No
Air tightness	$n_{50} = 0.34\ h^{-1}$

A.2.6 Bocholt

This wooden house is designed as a square oriented to the sun. An office has been included. Figure A.6 shows the project before the exterior cladding. Table A.6 illustrates the construction details.

Figure A.7 Passive house office building in Ghent

Photo: PHP

Table A.7 Passive house office building in Ghent (architect: evr-architecten; sustainable building concept: Cenergie cvba)

Construction			
	Insulation	**Thickness (mm)**	**U-value (W/m²K)**
Floor	Resol	140	0.14
Wall	Mineral wool + air gap	240 + 50	0.15
Roof	PIR	240	0.11
Windows	HDPU interrupted wood + triple glazing with low-e coating	-	0.80

Technical information	
Earth-air heat exchanger	2 x Length: 40 m, Ø 800 mm
Earth-air heat exchanger for the server room	Ø 300 mm
Heat recovery from exhaust air	Heat wheel with moisture recycling
Supply water heating	2 x gas-fired condensation boiler 64 kW
Overheating	Automatic sunshade blinds
Solar collectors	No
PV panels	No
Air tightness	$n_{50} = 0.55\ h^{-1}$

A.3 Introduction of the passive house standard in service buildings

In 2005 also a first service building in the passive house standard was realised in Belgium (see Figure A.7). This project is an office of the harbour company of Ghent, with improved specifications for ventilation, overheating and other requirements. Table A.7 gives more technical information about this project.

A.4 Conclusion

These examples show the variety of the first initiatives. About 40 new passive buildings were under construction at the end of 2005, and many more were planned. Amongst those were also large-scale new passive educational buildings in Beernem, Gent and Nivelles (PHP, 2004). The universities of Gent and Leuven have monitored the passive houses in Heusden-Destelbergen and Heusden-Zolder and the results are available from the proceedings of the Benelux symposia (PHP, 2003, 2004, 2005). The required air tightness levels were reached, concerns about the ventilation equipment led to improvements.

Acknowledgements

This text was a result of the participation of PHP in the project “PEP: Promotion of European Passive Houses”. The PEP-project was partially supported by the European Commission under the IEE Programme EIE/04/030/S07.39990.

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Appendix B Emergence of a passive house niche network

B.1 Introduction

Passive house oriented enterprise networks are already existing in most European countries. Some of these networks effectively contributed to creating a pioneering market niche for passive houses, and their efforts are interesting to examine in the framework of construction innovation development. This appendix describes the emergence of a successful network dedicated to passive house innovation development. The qualitative description below relates to general proposed Strategic Niche Management success factors such as vision formation, learning, and network composition and formation (Hegger *et al.*, 2007; Elzen *et al.*, 2004; Kemp *et al.*, 1998; Caniëls and Romijn, 2008; Raven, 2005; Weber *et al.*, 1999). The described network – Passiefhuis-Platform vzw (PHP) – focused on a niche market entry of innovation for the construction of single-family owner-occupied passive houses in the Flemish Region, northern Belgium (IWT, 2007; PHP, 2007).

B.2 Emergence of a Flemish passive house network

B.2.1 Development of expectations and visions

In 2000-2002, there was no perspective to expect a regional government policy to strengthen energy performance requirements so that these would stimulate higher energy efficiency in the short term: the Flemish Region was just confronted with the first implementation of the European Performance of Buildings Directive (EPBD, 2002) and just started approaching issues of energy calculation procedures in collaboration with industry. Flemish stakeholder consultations in the framework of the EPBD development indicated a wish from different companies to achieve better energy efficiency in buildings faster, so that companies could distinguish themselves in the market and gain a market advantage. However, the policy development did not yet include standard setting for high energy efficiency and merely tried to provide a framework for energy calculation.

Enterprises that had a common wish to achieve high energy efficiency were invited and brought together by a Flemish non-profit organization (Energie Duurzaam vzw) and a Flemish engineering office (Cenergie cvba). The non-profit organization was in search of setting up research and development regarding energy efficiency. The engineering office was keen on promoting a higher energy performance standard in order to promote energy-efficiency related services. During several subsequent presentations and brainstorms, invited participants – architects, suppliers, contractors, in general interested persons – acknowledged that more collaboration was needed in order to reach higher energy efficiency, especially with players from more advanced regions, since the fast development of this issue in other countries was observed to be exemplary. However, most companies in the construction chain operated within a maximum radius of 100 km. A pathway of know-how and technology retrieval from neighboring countries was expected by the consulted companies and several companies expressed interest in introducing technology innovations from other regions. A common wish appeared to reach potential clients with such innovations and try to create a market demand, notably by using demonstration projects. Expectations thus shifted to enhance people's knowledge about the existence of technology solutions and (national and international) demonstration projects.

Further, the non-profit organization developed to use a holistic perspective on needed energy performance and to provide integrated concepts as a vehicle for market transformation. The technology and service innovations proposed by different enterprises were very diverse. To motivate companies to collaborate and share knowledge about energy efficiency, an idea was launched to cluster different technologies in a neutral integrated conceptual approach with a focus on high energy efficiency. An important issue to solve was the exact level of 'energy efficiency' needed in order to attract the right competences. A mutual learning process (meetings in different company locations) was initiated and led to a better understanding of each other's perspective on possibilities in 'energy performance' of buildings. The stakeholders discussed ambition to aim for a higher standard compared to 'low energy'. First ideas were to find an acceptable standard in the range of a factor four to ten in energy reduction.

The engineering office proposed to examine the example of the passive house concept as a high energy-efficiency target, since they recently discovered[1] that in Germany hundreds of passive houses had already been built, with a measured energy use in the proposed range. In further meetings it became clear that of various low energy concepts, the passive house standard was best documented (be it in German) with directly available performance criteria, available technologies for import and diffusion, and available tools for energy calculation (which were still missing for normal EPBD calculation or evaluation of other concepts). In this situation the companies and the non-profit organization decided jointly to adopt the passive house standard as a focus concept for further learning processes.

1 In 2000 the engineering office visited the World Expo in Hannover and all employees spent a night in a nearby passive house. This stimulated some of them to visit Dr. Wolfgang Feist at the Passivhaus Institut in Darmstadt to gain more knowledge about how to implement passive houses. Passivhaus Institut Darmstadt provided multiple examples of available technological innovations related to the passive house concept.

B.2.2 First ideas about needed learning

At the time of the emergence of the network, studies (SENVIVV, 1998; CIR, 2000; Eurima, 2003) indicated that thermal insulation quality of buildings in the Flemish Region was amongst the worst in Europe, which created a sense of urgency for learning. Change was needed including positive community building and generation of hope that the Flemish construction sector could do better. The enterprises thus wanted to stimulate neutral communication with positive messages about higher energy efficiency to stimulate market demand, and at the same time pro-actively develop business cases of energy-efficient innovation. The many SME innovation developments in for example Germany and Austria were proposed by some enterprises as a positive reference framework for stimulating innovation learning.

Detailed information was needed to convince clients to adopt such innovations. It was detected that most companies could generate themselves information about their intended technological innovations, but that help was needed to provide learning at the concept level for example about the multiple benefits of the passive house concept, including energy saving and sustainability, but also focusing on why passive houses can have a higher comfort – thermal comfort in winter, thermal comfort in summer, air quality, acoustical comfort, lighting quality, healthy indoor environment –, better construction quality and better profitability and future value. In order to fill existing knowledge gaps about the integrated passive house concept, input would be needed from different types of players such as architects, engineers of consultancy firms, suppliers, materials producers, system providers, energy experts, installers, contractors, possible future owner-occupants, and so on.

Education was needed, not only regarding the energy performance wished for, but also on how to achieve it. This meant that current quality deficiency barriers such as insufficient thermal insulation, leaky construction details, improper use of solar gains and (health problems due to) lack of ventilation had to be addressed and solutions had to be provided. Furthermore, specific learning activities – such as courses, workshops, symposia, building fairs, study trips to Germany, client information exchange, and so on – were proposed in order to guide energy consciousness into supply side innovation and market demand. Several enterprises defended that to bridge the knowledge-action gap not only knowledge dissemination was needed, but also hands-on experience by means of the development of regional demonstration projects. They engaged in building the first regional demonstration projects.

B.2.3 Building of a formal enterprise network

One particular engineering office (Cenergie cvba) played a key role in providing competences and resources for the network building in a protected space. One of their R&D employees – the author – was externalized to the (allied) non-profit organization (Energie Duurzaam vzw) to pioneer the building of a formal network. The employee could rely on the connection network of the engineering office to find motivated individuals within companies and at the same time work in a protected environment away from daily routine of the engineering office. At the time of the creation of the formal network, there were some non-profit organizations in the Flemish Region that promoted for example renewable energy systems (ODE-Vlaanderen vzw), renewable construction materials (VIBE vzw) or low-energy housing (BBLV). However, according to the aspiring enterprises, these organizations insufficiently addressed the need for high energy-efficiency and/or innovation. At the organizational level, these organizations provided an example to enterprises for conceptualization of a new energy efficiency network as commercializing a non-profit organization. Enterprises thus suggested to investigate the formation of a new non-profit organization with a specific goal[2]. To fill knowledge gaps about passive houses, complementary regional players were actively searched for.

The R&D worker consulted companies individually and collectively and collected formal answers from individual enterprises interested in profiling themselves in best energy-efficiency. In-depth interviews with possible key stakeholders led to initial ideas about the formal set-up of the network, and to further persuasion and decision of some companies to join a passive house market development, using the promise to stimulate networking for the realization of regional demonstration projects and market infrastructure and the creation of synergies for innovation. To join the network, enterprises were asked to formalize their (innovation) intent and write a document signed by their director explaining how they would promote high energy efficiency and contribute to technology or eliminating know-how barriers regarding passive houses.

The R&D worker organized regular meetings between interested companies in order to gain confidence and to develop a common goal to be formalized in statutory documents. The goal of the network was finally formalized as "the diffusion of knowledge to stimulate high energy-efficiency in buildings". Once a proposal for a common goal was developed, draft statutes of a new non-profit organization, were presented to a larger group of possible stakeholders, including companies from the sustainable building sector, as well as traditional building companies and prominent building research institutes.

An important point of discussion that caused significant delay in the emergence of the formal network was the funding of the new non-profit organization. The benefits the network would create were supposed to be public,

2 Using Energie Duurzaam was considered, but the statutes of the organization did not directly comply to the wish of having a more transparent and independent organization, involving new types of members and goals.

but they could nonetheless incur private costs. Many enterprises were reluctant to join formally without a clear view how the organization would be able to support itself and with, for small enterprises, possibly large member contributions. Showing generation of dependable income to pay for network actions required developing a business plan. Several categories of membership fees[3] were proposed according to carrying capacity of a potential member, based on the size of the company and its number of employees, and in different funding scenarios. The collection of membership fees would only allow for a very limited amount of actions. Therefore, additional funding opportunities were searched and a resource channel of the Institute for the Promotion of Science through Technology (IWT, Flemish Community) was considered as a viable option. To obtain resources from this channel the companies had to engage in the generic scope of 'stimulating thematic innovation' and a needed substantial number of SMEs (more than ten according to the grant programme) had to co-contribute. Since this would allow 80% funding for more than two full-time employees during four years, the companies decided to cover the remaining 20%with membership fees.

After one year of preparatory work Passiefhuis-Platform vzw, alias PHP, was founded in October 2002 – just before the official IWT funding application was submitted – with eighteen members, of which fourteen were companies and four either individuals or non-profit organizations/ knowledge centers. After the foundation, a management board was selected – to represent and guard an integrated approach – from the participating members. This included a large contractor – as president/opinion leader –, a climate system supplier, an installer, an architect, the engineering office and the R&D worker. PHP was thus formalized to be the first multidisciplinary organization that assembles different types of players in the regional construction chain.

B.2.4 Successful development of a proto-market

It is not the intention of this appendix to discuss the evolution beyond the emergence of the network in detail, which has been dealt with in Chapter 5. While the word 'passive house' was regionally still unknown in 2002 to the general public, the number of founding members, the inclusion of a large enterprise as opinion leader, the transparency of the foundation process, and the originality of the organization, created a highly visible signal towards the media and the construction industry. Already two weeks after its founda-

3 In the introduction phase the enterprise membership fees were limited between €600 and €2.400, making distinction only between small, medium and large enterprises. However, from the beginning €600 was perceived as too high for micro-enterprises. This was adapted a few years after the creation of the network. Membership fees for companies now (2013) vary from €365 to €2,900 (excl. VAT).

tion PHP launched its first (yearly) passive house symposium and technology fair in order to increase visibility of the passive house concept, supported by several members. Soon afterwards, individuals with intention to build regional demonstration projects found complementary players willing to bear innovation risk. Consequently, after receiving its funding[4] and membership fees, in 2003-2004 PHP performed 155 actions for groups of companies and potential clients – including preparing publications, newsletters, company visits, project visits, web site actions, networking actions, cooperation in (preparing) innovation studies and activities in a wider perspective – and answered about 400 technology questions from clients. In 2005-2006 this augmented to 277 actions for companies/clients and 510 technology questions from clients.

The network has survived, the socio-technical experiment was successful. PHP maintained its multi-disciplinary setup and goal description. Continuous dynamic learning was provided by own technical consultants and network management. At the end of 2010, 265 enterprises were member of PHP, with a 92 percent share of SMEs. While in 2002 most members were still in an exploring phase, most of these members are now active in the realization of passive or low-energy houses.

B.3 Some detected success factors

The example confirms that the creation of niches is related to several essential success factors – the articulation of expectations and (sustainability) visions, learning processes at multiple dimensions, and the building of multiplayer networks as essential conditions for market niche creation. For market niche entry an ambitious vision is needed, acceptable for innovators, and a protected space for market niche creation needs to be created. Using a multi-player network appears to be very important, and a network manager is needed to guide the development of higher-order learning. The example that a bottom-up approach can be highly successful, if innovation policy allows to reward the creation of the niche, building on existing players and stimulating synergies and development of innovation knowledge and skills.

The focus on knowledge transfer between regional enterprises leads to regional innovation development, and such geographical focus is essential in order to stimulate collaboration between SMEs from the construction chain. Formal relationships reinforce vision of future collaboration and risk sharing for innovation, thus stimulating continuation of networks. Establishing a

4 It is noted that at this stage the network members would have continued with setting up their network without government funding – albeit with limited means from membership – but the innovation adoption process would be much slower because of limited resources and capacities.

formal network or center for know-how retrieval requires financial support, skills and knowledge of multiple players and formal collaboration. Particularly knowledge from demonstration projects and on the concept level is highly valued by innovators.

The example additionally shows that a concept approach is important to stimulate adoption of innovation by multiple players. A concept approach, not focused on single technologies or players, has the advantage that it facilitates involving stakeholders from different disciplines, clustering innovation opportunities, and defining common know-how needs. Concepts identified should be sufficiently specific to inspire innovation, and the ‘passive house’ apparently provides such concept. Collaboration for know-how development is needed between multiple players in order to realize innovation, such as passive houses. The passive house concept apparently fulfils a concept innovation need in the construction sector, that, once detected by regional enterprises, can stimulate the much needed socio-technical and organizational innovation, in order to speed up necessary sector progress towards high energy efficiency.

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Appendix C Glossary

This glossary provides an overview of terms that have been used throughout the study. These terms have been referenced or introduced in the various chapters. The terms related to innovation are mainly based on the references introduced in the first chapter – theoretical framework. The terms related to energy and buildings are sourced from the International Energy Agency, the European Economic and Social Committee and the Architects' Council of Europe. Some of these terms were interpreted to fit the purpose of the present study.

Terms related to innovation

Adoption
The acceptance and continued use of a product, service or idea.

Change agent
An individual who influences the innovation decisions of clients in a direction deemed desirable.

Communication channels
The means by which messages are transmitted from one individual to another.

Compatibility
The extent to which an innovation fits into the existing norms and values of the adopter.

Complexity
The extent to which an innovation is experienced as being relatively difficult, whether in usage or the understanding thereof.

Confirmation (stage of the adoption process)
Stage during which an individual finalises a decision to continue using the innovation and is able to use the innovation to its fullest potential.

Consequences of an innovation
Changes that occur to an individual, organisation or a social system due to the adoption or rejection of an innovation.

Decision (stage of the adoption process)
Stage during which an individual considers the concept of an innovation, weighing the advantages/disadvantages of using the innovation and deciding whether to adopt or reject it.

Diffusion
The process by which an innovation is communicated amongst the members of a social system through certain channels over time.

Early adopters
The second fastest group of adopters of an innovation, after innovators: Early adopters are often characterised by a high degree of opinion leadership, and they are typically younger in age, of higher social status, have more financial lucidity and advanced education, and are more socially forward than late adopters are.

Early majority
Adopters who take up innovations after a significantly longer time than the innovators and early adopters: Early majority adopters tend to be slower in the adoption process and have above average social status; they are in contact with early adopters, and they seldom hold positions of opinion leadership in a system.

Entrepreneur
Individual or unit who undertakes innovations, finance and business in an effort to transform innovations into economic goods.

Entrepreneurship
The act of being an entrepreneur.

Enterprise network
Network that focuses on social relations amongst people who share business interests and/or activities.

Growth market
Market phase in which a rapid increase in the demand for a particular innovation over time is observed.

Heterophily
The degree to which pairs of individuals who interact differ according to certain attributes (e.g. beliefs, education, social status).

Holistic approach
Method that takes account of all relevant factors in order to produce the best possible result.

Homophily
The degree to which pairs of individuals who interact are similar in certain attributes (e.g. beliefs, education, social status).

Implementation (stage of the adoption process)
Stage during which an individual employs an innovation to a varying degree depending on the situation: During this stage, the individual determines the usefulness of the innovation and may search for further information about it.

Incremental innovation
Innovations aimed at improving existing ideas, practices or artefacts, usually involving small changes based on current knowledge.

Innovation
Any idea, practice or material artefact perceived to be new to the relevant adopting unit: This includes not only products, but also services, techniques, methodologies and more or less abstract ideas of concepts. Innovation differs from invention in that innovation refers to the use of a new idea or method, whereas invention refers more directly to the creation of the idea or method itself.

Innovation-decision process
The period required to pass from initial knowledge about an innovation to persuasion, decision (adoption or rejection), implementation and confirmation of the innovation.

Innovation journey
Process in which new ideas are developed and implemented in order to achieve desired outcomes by people who engage in transactions (relationships) with others within changing institutional and organisational contexts.

Innovation market
Market phase in which an initial demand for a particular innovation is observed.

Innovation system
Term used to emphasise the fact that the flow of technology and information amongst people, enterprises and institutions is crucial to an innovative process.

Innovators
The first adopters of an innovation: Innovators are characterised by a willingness to take risks. Of all adopters, they are often youngest in age and have the highest social class; they have great financial fluidity, are very social and maintain close contact with scientific sources and interaction with other innovators.

Knowledge (stage of the adoption process)
Stage during which an individual is first exposed to an innovation but lacks information about the innovation: During this stage of the process, the individual has not been inspired to find more information about the innovation.

Laggards
The last group to adopt an innovation: Laggards typically exhibit little to no opinion leadership, are averse to change agents and tend to be advanced in age. They tend to be focused on 'traditions'. Of all adopters, they are likely to have the lowest social status, the lowest financial fluidity and the highest age. Their contact networks consist solely of family and close friends.

Late majority
Those adopting an innovation after the average member of the society: Late-majority adopters tend to approach innovations with a high degree of scepticism, even after the majority of society has adopted them. They are typically in contact with other late-majority and early-majority adopters. They tend to be sceptical about innovations, have below average social status, very little financial fluidity and very little opinion leadership.

Market development
The expansion of the total market for an innovation by entering new segments of the market, converting non-users into users and/or increasing usage per user.

Network
A structure composed of individuals (or organisations) that are tied (connected) by one or more specific types of interdependency (e.g. friendship, kinship, common interest, financial exchange, dislike, sexual relationships or relationships of beliefs, knowledge or prestige).

Niche (market)
A focused targetable portion or subset of a (market) sector.

Observability (or visibility)
The extent to which the results of an innovation or the innovation itself can be seen by others.

Opinion leadership
The extent to which an individual is able to influence the attitudes or overt behaviour of others informally, in a desired way and with relative frequency.

Persuasion (stage of the adoption process)
Stage during which an individual is interested in an innovation and actively seeks information/detail about it.

Radical innovation
Innovation aimed at breaking away from existing ideas, practices or artefacts.

Rate of adoption
The relative speed with which members of a social system adopt an innovation.

Re-invention
The extent to which an innovation is changed or modified by a user in the process of adoption and implementation.

Relative advantage
The extent to which an innovation is experienced by the adopter as being better than existing alternatives.

Segmentation (customer/market)
The narrow definition of a group of potential customers or portion of a larger market.

Small and Medium-sized Enterprises (SMEs)
Enterprises employing fewer than 250 people and having an annual turnover not exceeding €50 million, and/or an annual balance sheet total not exceeding €43 million.

Social innovation
New strategies, concepts, ideas and organisations that meet a wide range of social needs.

Sociotechnical landscape
Exogenous environment beyond the direct influence of niche and regime actors, referring to macroeconomics, deep cultural patterns and macro-political developments.

Sociotechnical regime
A broader community of social groups and their alignment of activities, emphasising that scientists, policymakers, users and special-interest groups also contribute to the patterning of technological development.

Socio-technical transition
Term used to emphasise the co-evolutionary dynamics of system innovations: The socio-technical transition approach has focused on the way in which some societal functions (e.g. transport, communication and energy supply) are structured around systems of complementary elements, including technology, infrastructure, retail and distribution networks, regulation, user practices, markets and culture.

Strategic niche management
The creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of learning about the desirability of the new technology and enhancing its further development and rate of application.

System innovation
Innovation characterised by the integration of multiple independent innovations that must work together in order to perform new functions or improve performance as a whole.

Systemic innovation
Term introduced to emphasise the need for coordination and cooperation in innovation processes, as opposed to 'autonomous' (independent) innovation.

Trialability (or: demonstrability)
The extent to which it is possible to experiment with an innovation (on a limited basis).

Volume market
Market phase in which a substantial demand for a particular innovation is observed, following the launch of the innovation and the market-growth phase: The volume market is characterised by large-quantity sales.

Terms related to energy and buildings

Acoustic performance
A building's ability to enhance or minimise airborne noise from outside to inside and vice versa, and/or to affect the transmission of noise between floors, walls and ceilings.

Air changes per hour [ach^{-1} or h^{-1}]
Number of times each hour that the total volume of air within an enclosure is replaced with fresh (or conditioned) air.

Air conditioning
Mechanically aided heating, cooling and conditioning of indoor air in order to optimise thermal and humidity conditions.

Air infiltration
Air that leaks into a building through small cracks in the building envelope, e.g. door and window frames.

Air leakage
Uncontrolled movement of air out of a building or ventilation system that is not for the specific and planned purpose of exhausting stale air or bringing in fresh air.

Air-ground heat exchanger
Tubular device that transmits heat passively from the ground to the fresh air used for ventilating a building, through direct contact between the tubular device and the ground: Alternatively, the device can be used for cooling incoming fresh air.

Air source heat pump
Pump that extracts heat from the outside air (in the same way that a refrigerator extracts heat from its inside) in order to heat a building.

Airtightness
Measure of an envelope's resistance to inward or outward air leakage.

Auxiliary energy [kWh]
The quantity of energy used by pumps, ventilators, controls and other devices to transform and transport the delivered energy into effective energy for lighting, heating, domestic hot water and other purposes.

Blower door
A testing device used to measure the airtightness of buildings: The device consists of a calibrated variable-speed fan, a pressure measurement instrument and a mounting system for mounting the fan in a building opening (e.g. a door or a window) in an airtight manner.

Building envelope
The separation between the interior and the exterior environments of a building: The physical components of the envelope include the foundation, roof, walls, doors and windows. The dimensions, performance and compatibility of materials, fabrication process and details, their connections and interactions are the primary factors determining the energy efficiency and durability of the building-enclosure system.

Building envelope area A [m²]
Total external area of the building envelope enclosing the heated volume – facade (including doors and windows), roof and ground – and measured at the outer boundaries of the building.

Certificate
A professional systematic evaluation, based on standardised methods, of the conformity of a product, system, process or person. A confirmatory information tool may be used by independent agents working according to requirements and research methods established with input from several representatives of stakeholders.

Certification
The confirmation of certain characteristics of a product, system, process, person or organisation: This confirmation is often, but not always, provided by some form of external review, education, assessment, or audit.

Commissioning
The use of the owner's project requirements (particularly with regard to the usage of energy and facilities) to audit and verify different judgments, actions and documentations in order to realise a requested performance.

Compact unit
Device that integrates various building services in the ventilation system.

Construction
Process by which paper-based or computer-based designs for construction works are translated into reality on a particular site.

Delivered energy/site energy [kWh]
Measure of the amount of energy arriving at a site or building; energy supplied to the building through the system boundary from the last market agent, particularly to satisfy the energy requirements for heating, cooling, ventilation, domestic hot water and lighting: No adjustment is made with regard to energy losses occurring in the generation, transmission and distribution of energy.

Design criteria
Set of conditions and requirements that must be met by architects when designing any building or urban space.

Embodied energy [kWh]
Total of all the energy used in the processes associated with the production of the materials and products that go into a building or structure: Embodied energy describes the energy required to manufacture a product. Products that require large amounts of energy to obtain and process the necessary raw materials or those that are transported long distances during processing or to market have high levels of embodied energy.

End-user
For the purposes of this study, to be interpreted as people who use buildings.

Energy use [kWh]
The actual measured quantity of energy needed for heating, cooling, ventilation, hot water heating, lighting, appliances and other purposes (metering).

Energy demand [kWh]
Amount of energy used by a building to fulfil all of its energy needs in order to provide its occupants with a comfortable indoor living or working environment; calculated quantity of energy for all applications and given end use.

Energy efficiency
A ratio between an output of performance, service, goods or energy, and an input of energy; the process of using less energy, while allowing the same or improved function or task performance: As applied to buildings, energy efficiency generally indicates the existence of extra insulation, weatherproofing, and/or special features and equipment designed to reduce the use of energy for space heating and cooling, hot water production, household activities and electrical equipment.

Energy-efficiency improvement
Improvement made to the structure, fabric or environmental control systems of a building that results in a reduction of the building's energy use, as compared with the situation before the work began.

Energy-efficient behaviour
Behaviour adopted by users resulting in a reduction of the usage of or the demand for energy.

Energy Performance Certificate (EPC)
Certificate, required by EU law, which informs a potential owner or user of a building of its designed energy performance and which contains recommendations for improving the energy efficiency of the building.

Energy performance of a building
Amount of energy required to render the building fit for its intended purpose.

Energy Performance of Buildings Directive (EPBD)
European Directive that came into effect in 2002 (revised in 2010) in order to promote the improvement of energy performance of new and existing buildings (subject to major renovation), taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

Environmental performance
The quantification of the performance of a product, service or organisation in terms of its environmental consequences of material production, construction, land or site development, and end-of-life processing.

Factor 4
Hypothetical fourfold increase in 'resource productivity' brought about by simultaneously doubling wealth and halving resource use.

Factor 10
90% global reduction in resource turnover, within the next 50 years, in order to achieve dematerialisation.

Global warming
Result of the greenhouse effect, in which the average global temperatures are increasing at such a rate that they provoke significant climate change, resulting in risks to future generations.

Gross volume V [m^3]
The heated building volume calculated according to the outdoor dimensions.

Ground source heat pump
Electrically driven device that extracts heat from the ground in order to provide space and water heating for a building through a simple heat-exchange mechanism.

Heat use [kWh]
The measured quantity of energy for heating and domestic hot water.

Heat demand [kWh]
The calculated quantity of energy for heating and domestic hot water.

Heat exchanger
Device built for the efficient transfer of heat from one medium to another.

Heat recovery
Any conservation in which some air heating, space heating or water heating is accomplished by actively capturing by-product heat that would otherwise be ejected into the environment.

Highly energy-efficient building
Buildings with the explicit intent of using less energy than low energy buildings: No specific requirements have been defined.

HVAC
Heating, ventilation and air conditioning: This term refers to technology for indoor and automotive environmental comfort.

Indoor air quality
Quality of the air within and around a building or a structure, related to the health and comfort of building occupants.

Infrared thermography
Thermal imaging using cameras to detect radiation within the infrared range of the electromagnetic spectrum and to produce images of that radiation: When viewed by thermography camera, warm parts of a building stand out well against cooler backgrounds.

kWh/m²a
Kilowatt hours per square metre per annum.

Kyoto Protocol
International agreement linked to the United Nations Framework Convention on Climate Change, the major feature of which is the specification of binding targets for 37 industrialised countries and the European Community for reducing greenhouse gas (GHG) emissions.

Label
For the purposes of this study, to be interpreted as a policy tool that is used to induce socio-technical transition within the construction sector and to change the behaviour of end-users (particularly in terms of the energy use).

Life cycle
Consecutive and interlinked stages of a product system, from the acquisition of raw materials or generation from natural resources to final disposal.

Low-energy building
Buildings with the explicit intent of using less energy than standard buildings: No specific requirements have been defined.

Mechanical ventilation
Forced replacement of air in any building space in order to provide high indoor air quality.

Mtoe
Million tonnes of oil equivalent: The tonne of oil equivalent (toe) is a unit of energy: the amount of energy released by burning one tonne of crude oil, approximately 42 GJ (depending upon the calorific values of crude oil).

n_{50} [ach^{-1} or h^{-1}]
Value determining building airtightness/air leakage levels (in volume air changes per hour): This value is obtained by using a blower-door test at various pressure-difference levels, both pressured and depressurised. An average value of air leakage per hour (ach^{-1}) for a pressure difference of 50 Pascal is calculated from these measurements. In passive houses, the requirement is n_{50} not greater than 0.6 ach^{-1}.

Net heated volume [m^3]
The heated volume, calculated according to the indoor dimensions.

Net heated floor area [m^2]
The sum of the floor areas of all heated rooms, including heated corridors and heated internal stairways, but not unheated rooms.

Net-zero energy building
Building in which, due to its very high level of energy efficiency, the net energy used over a year is matched by an equal amount of energy produced on site (usually produced from renewable energy sources). See also Chapter 9 for a discussion on various existing definitions.

Net-zero carbon building
Building that, due to the materials from which it is constructed and to the fact that it produces surplus energy from renewable sources, ensures that it will compensate for all carbon emissions associated with the construction and use of the building throughout its design life. See also Chapter 9.

Maintenance
Combination of all technical and associated administrative actions during an item's service life, with the aim of retaining it in a state in which it can perform its required function.

Natural ventilation
Use of outdoor airflow into buildings in order to provide ventilation and space cooling.

Passive design approach
Building-design approach that seeks to fulfil all of the energy needs for comfortable use without resorting to active systems for the maintenance of the indoor environment.

Passive house
Building designed in such a way that the following requirements must be fulfilled:
- maximum end-energy space heating demand of 15 kWh/m²a;
- primary energy demand for all end-uses, including electricity for appliances, does not exceed 120 kWh/m²a (m² refers to the net heated floor area).

See also Chapter 9 for a discussion on various existing definitions.

Passive house label
Voluntary labelling system devised, managed and promoted by private parties in order to assure the obtained energy performance for passive houses.

Passive house standard
Rigorous voluntary standard for energy efficiency in buildings: In some European regions and municipalities, the standard is obligatory.

Passive solar design
Building design that uses the sun's energy for the heating and cooling of occupied spaces in the building.

Photovoltaic panel (PV)
Panel that transforms the photon energy in solar radiation directly into electrical energy without an intermediate mechanical or thermal process.

PHPP
Passive House Planning Package (PHPP): A design and certification tool, originally developed by the Passive House Institute (PHI) in Darmstadt: The tool consists of an Excel-based calculation workbook and a handbook.

Positive-energy building/plus-energy building
Building in which due to its very high level of energy efficiency, more primary energy is produced annually than used: In most cases, this is achieved through the use of renewable energy sources, generating on-site electricity.

Post-occupancy evaluation (POE)
Diagnostic system and tool that allows the systematic identification and evaluation of critical aspects of building performance: For the purposes of this study, this term should be interpreted as the systematic evaluation of end-user opinion about buildings in use. In addition, POE can refer to the comparison of actual building performance with stated performance criteria (e.g. using measurements).

Primary energy PE [kWh]
Energy that has not been subjected to any conversion or transformation process: Primary energy may consist of resource energy, renewable energy or a combination of both. For a building, it is the energy used to produce the energy delivered to the building. It is calculated from the delivered amounts of energy carriers, using conversion factors.

Quality assurance
The planned and systematic activities implemented in a quality system in order to ensure that the quality requirements for a product or service are fulfilled.

Renewable energy
Energy generated from renewable (i.e. naturally replenished) natural resources (e.g. sunlight, wind, rain, tides, biomass and geothermal heat).

Solar shading
Solar system that controls the amount of heat and light admitted to a building, thereby permitting users to control heat gains from the sun.

Solar panel (solar collector)
Device specifically intended to absorb sunlight to provide heat.

Technical performance
Ability of a building or structure to fulfil required functions under intended use conditions or behaviour when in use.

Thermal bridge
Thermal 'short circuit' through a construction element due to a locally much higher conductivity than is found in the surrounding material: Typical effects of thermal bridges include decreased interior surface temperatures at the place of the thermal bridge and increased heat losses.

Thermal comfort
State of mind expressing satisfaction with the thermal environment.

Thermal insulation
Material, method or design used to reduce the rate of heat transfer from one space to another.

Thermal mass
Capacity of a material to store heat.

Trias energ(et)ica
Energy policy approach consisting of three consecutive steps:
1. permanent increase in energy efficiency;
2. augmented use of renewables;
3. cleaner use of remaining fossil fuels.

U-value [W/m²K]
Thermal heat-loss coefficient of a building part; used to characterise heat loss through a construction part (an external wall, a floor to the basement or a slab on ground, a ceiling or a roof). This value shows how much heat (in Watts, W) is lost per m^2 at a standard temperature difference of 1 degree Kelvin (K) between inside and outside.

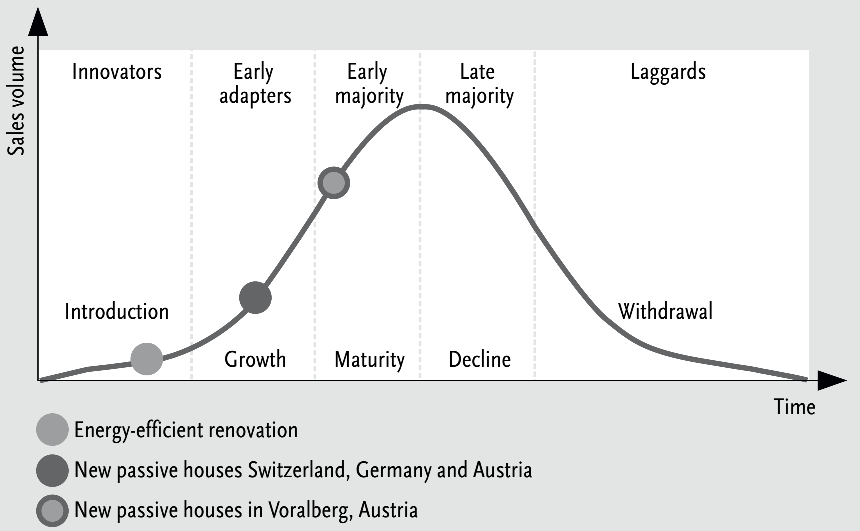
Summary

Introduction

The debates about climate change and security of energy supply, perceived opportunities for a ‘greener’ economy and policy developments like the Energy Performance of Buildings Directive have all revived interest in energy efficiency and related innovations. Significant potential has been recognised for reducing energy use through innovation, especially in such energy-intensive sectors as the construction sector, where a large part of the energy use goes to residential buildings. Achieving policy objectives related to climate change and energy will require significant carbon reduction in residential buildings, particularly with regard to energy demand for space heating. For this reason, this study investigates innovation opportunities and challenges related to the adoption of highly energy-efficient housing concepts, particularly passive houses, which largely reduce the demand for space heating.

In addition to differences between newly built construction and renovation, some countries (e.g. Austria, Germany, Switzerland) and regions (e.g. Flanders, Vorarlberg Region) were found to be quicker than others (e.g. the Netherlands) are to adopt highly energy-efficient housing concepts (e.g. passive houses), as illustrated in Figure 1. Like the Netherlands, Belgium began relatively late with the adoption of the passive house concept, although it managed to develop its market more rapidly than was the case in the Netherlands. Given the author’s considerable experience with the introduction of passive houses

Figure 1 Product Life Cycle curve illustrated for passive house development



Source: Haavik *et al.* (2012)

into the market in Flanders, northern Belgium, it was possible to use these experiences to explore various questions related to adoption and diffusion.

The practical goal of this study is to develop a more general definition of barriers to and opportunities for the introduction and continued market development of highly energy-efficient housing concepts (in particular passive houses), in order to define recommendations for accelerating their adoption and diffusion. The empirical part of the study focuses primarily on finding recommendations for the market for single-family housing in countries and regions in which the development of energy-efficient concepts is lagging behind. Innovation opportunities and barriers related to the promotion of highly energy-efficient housing concepts are investigated, in order to define pathways towards the elimination of barriers to their adoption and diffusion. This was accomplished through the empirical investigation of the viewpoints and experiences of enterprises (Part A), end-users (Part B) and government policymakers (Part C), in order to identify various factors that could lead to a rapid increase in the adoption and diffusion of innovative concepts (e.g. passive houses).

From the theoretical side, the study focuses primarily on exemplifying, interpreting and developing the innovation adoption theory developed by Rogers (E.M. Rogers, Diffusion of Innovations, Free Press, NY, 5th edition, 2003). As such, the study also provides a deeper understanding and conceptualisation of various issues that could lead to improvement of innovation theory, by using practical goals and real market, end-user and policy experiences as a laboratory. The traditional theoretical perspective of the enterprise or the customer as an adopter of innovation is expanded to include groups of enterprises and policymakers. Another theoretical challenge involves considering innovation theory beyond the level of individual technologies towards the concept level. The study challenged Rogers' innovation diffusion theory to take more explicitly into account the experiences developed in other theoretical fields (e.g. construction innovation theory, enterprise network theory and environmental behaviour research).

Research approach

To structure the research in relation to the applied theories and key concerns regarding market development, the main research question was subdivided into three primary questions as follows: *Which challenges and opportunities are related to the innovation adoption of highly energy-efficient housing concepts, particularly passive houses (main question), as observed from the supply side (Part A), the demand side (Part B) and the policy side (Part C)?*

Various issues related to technology innovation, business innovation and government policy were studied within the context of specific sub-questions, and pathways were suggested for the integration of highly energy-efficient housing concepts as innovations by analysing technological, societal and policy factors that can stimulate or hinder the diffusion of innovation.

Analysing demonstration projects involving single-family housing, the first part of the study identifies innovations that enterprises associate with passive houses and highly energy-efficient renovations. Innovation theory is then developed further within the context of the examination of a supplier's innovation-adoption process, in order to explore systemic innovation opportunities. The path of collaboration between enterprises is then further explored for an emerging market (highly energy-efficient housing renovation). In addition, opportunities and barriers related to the transition from an innovator market to early adoption are examined, using the experiences of a passive house enterprise network.

The second part of the study addresses the viewpoint of the demand side. The first study in this part examines the innovation adoption experiences of end-users, based on post-occupancy evaluation research for various categories of newly built nearly zero-energy homes in the Netherlands. To ascertain the need for quality assurance and for improving passive house certification, the subsequent study then draws upon the experiences of end users with certified passive houses. To support the emerging market for highly energy-efficient renovation, the decision processes of owner-occupants regarding innovation adoption involving highly energy-efficient renovation are further examined.

The third part of the study aims specifically to derive lessons from European policies and policy initiatives that could stimulate the adoption of highly energy-efficient housing concepts. To this end, the first study in this part is based on the examination of the definitions of nearly zero-energy houses that are contained in the market and policies of European member states. A consequent study puts particular emphasis on the adoption of labels in governmental policy. In addition, opportunities for increasing innovation adoption through communication channels are explored, as exemplified by the activities of the previously discussed passive house enterprise network.

Several research methods are used to explore the issues mentioned above, depending upon the specific research issue being addressed. In addition to literature study, data are collected from existing Belgian and Dutch residential demonstration projects in order to identify innovations and end-user experiences in newly built passive houses, nearly zero-energy houses and highly energy-efficient renovations. Additional empirical data are obtained through questionnaires directed towards companies, end-users and policymakers, along with database and web searches, and interviews with demonstration project stakeholders (e.g. end users, architects and enterprises). Lessons are also derived from the author's action-based experiences with innovation guidance for enterprises, the establishment of a passive house

Figure 2 The three main parts in the book, the main themes covered in the ten studies, the research input used in each chapter, and the research output expected from each part

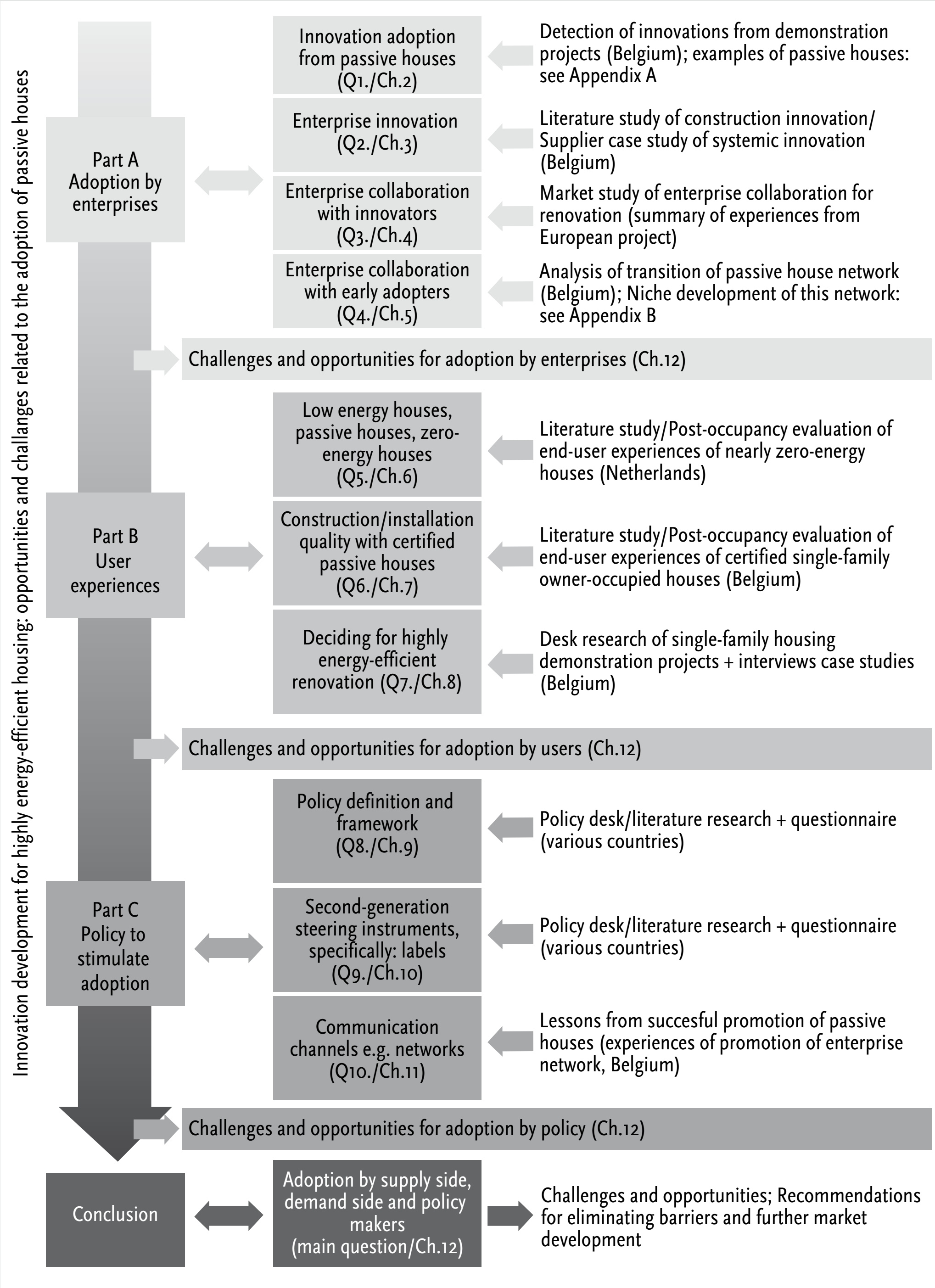
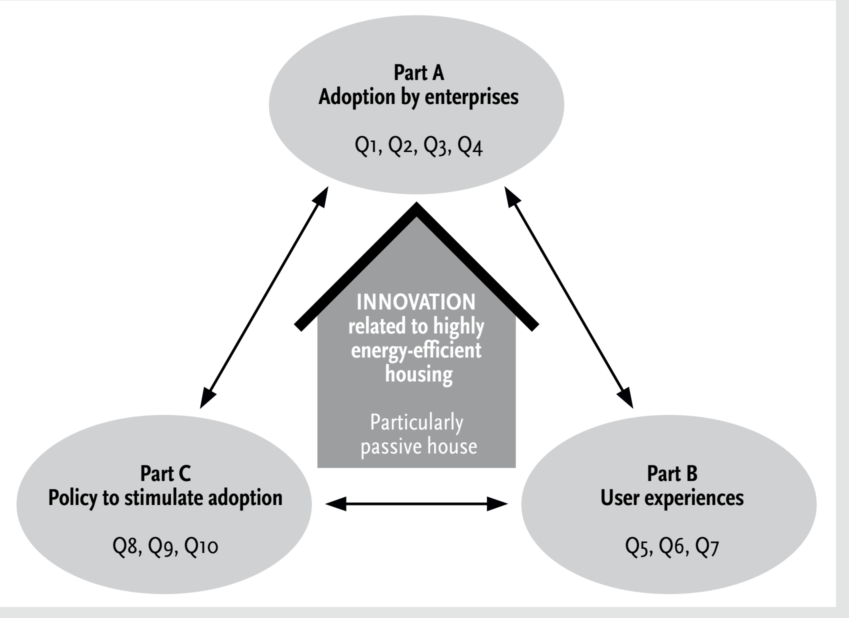


Figure 3 The research defined the 'innovation' and studied its adoption by enterprises (Part A, four studies/sub-questions), end users (Part B, three studies/sub-questions) and policy (part C, three studies/sub-questions)



network and the development of a market for passive houses in Flanders, northern Belgium.

The general research approach is illustrated in Figure 2.

Challenges and opportunities for the adoption of highly energy-efficient housing concepts

This research has identified very important challenges to and opportunities for the innovation adoption of highly energy-efficient housing concepts, particularly passive houses, as observed from the supply side (Part A), the demand side (Part B) and the policy side (Part C), see Figure 3.

The study developed many answers to the main question by studying the issue from various perspectives. When addressing the main research question from the perspective of the supply side, the main conclusion is that multi-player enterprise collaboration plays a key role in the adoption of 'concept' innovation (e.g. passive houses). From the perspective of the end user, it can be concluded that the problems and positive experiences of end users should be used to guide further innovation. From the policy perspective, it can be concluded that increasing the diffusion of highly energy-efficient housing (particularly passive houses) requires an active role on the part of government policymakers with regard to the adoption of the innovation.

Multi-player enterprise collaboration plays a key role in the adoption of 'concept' innovation

Examination of the experiences of enterprises with innovations in demonstration projects reveals that an integrated architectural 'concept' innovation diffusion approach – like experienced during the promotion of passive houses – can stimulate enterprises to adopt a multitude of innovative technologies (possibly in clusters), services and systems as well as architectural innovations. One advantage of the passive house concept is that it can be easily translated into generally recognised principles, which enterprises can relate to specific requirements.

Findings from the study indicate that, for the construction sector, suppliers can be important players for innovation adoption. The empirical research includes an investigation of a reference innovation journey for the adoption of the passive house by a supplier, thereby shedding light on the potential for systemic innovation involving various stakeholders, who supply the necessary competencies, expertise and resources. Led by the passive house 'concept' approach, and with the help of an innovation agent, the supplier was found to start a formal structured risk-sharing innovation journey towards modular innovation as a vehicle for incorporating architectural and system innovation. This is in sharp contrast to the usual ad hoc generation of knowledge and loose actor collaboration found in demonstration projects, which usually rather results in incremental innovation taking place during specific project phases.

Project-related fragmentation, characterised by separate small and medium-sized enterprises (SMEs), each performing a fraction of a supposedly integrated project, was found to pose an important barrier to the development of passive houses, particularly for the renovation market. To counteract this barrier, it is essential to develop and cultivate a network around the proposed and actual 'concept' innovations. Given the specificity of the construction sector and the 'concept' innovations for achieving a high level of energy performance, it would be worthwhile to cultivate and develop specific innovation agents as intermediaries between suppliers and other players in the construction chain.

One particular challenge involves increasing the flow of necessary technical information, knowledge and project management skills from the frontrunners to the many less experienced implementing actors, most of which are SMEs, which form an important target group for the market introduction of 'concept' innovation in the construction sector. For example, in the case of the development of the Flemish market for single-family passive houses, small enterprises played the most important role in sparking radical innovation at the regional level, while large companies were slower to adopt innovation through incremental innovation, particularly given the financial and networking incentives that were in place and that targeted a larger market. The results identify the need to characterise, cultivate and develop enterprise collaboration in various subsequent innovation phases and transitions between phases. Business-to-business collaboration was found crucial to the development of 'concept' innovation in both the market-introduction phase and the early-adoption phase. Such collaboration can be facilitated by multi-player enterprise networks, in which various types of actors (e.g. architects, installers, contractors and consultants, as well as clients and knowledge institutes) can network and collaborate.

In sharp contrast to the market for newly built passive houses, the renovation market still has far to go with regard to the development of improved collaboration structures. A pool of experienced actors for implementation of highly energy-efficient housing renovation has yet to be defined, and adapted quality-assurance instruments and support schemes are needed as well. A major opportunity lies in finding market-proof structures for collaboration and communication, in order to reduce the burden on homeowners, particularly with regard to alleviating financial burdens and burdens related to project management.

The needs and experiences of end users should be used to guide further innovation

On the one hand, enterprises need to innovative. On the other hand, they are more likely to find a market by responding to customer needs and expectations with their technologies, systems, services and architecture. Findings from the post-occupancy evaluation studies in this research show that potential residents have various reasons for choosing nearly zero-energy dwellings, with the energy costs associated with a dwelling being an important argument. The passive house requirements allowed clients to negotiate a well-defined target with executing parties. Nevertheless, a survey of end-user experiences in the Netherlands revealed that the choice for low-energy, passive houses or zero-energy houses was not very obvious from the perspective of the client. On the other hand, end users living in highly energy-efficient houses were quite satisfied with their dwellings, indicating a high level of comfort. These findings could be used as additional arguments in the promotion of such dwellings. One potential area for improvement involves the promotion of innovative renovation concepts towards owner-occupants. Factors that motivate owner-occupants to adopt highly energy-efficient renovation concepts include – in addition to structural improvement and increased surface area – the promise of improved comfort, a more general concern for the environment and improved health conditions.

The results of this research indicate that the demand side suffers largely from a lack of knowledge regarding available innovative concepts. With regard to the lack of knowledge, social strategies can be recommended (e.g. establishing peer-to-peer knowledge-exchange networks for owner-occupants, nurturing those networks with experiences from experienced owner-occupants, architects and contractors). In order to improve diffusion, the relative advantages and visibility of the actors involved should be addressed. The attractiveness of highly energy-efficient concepts, particularly for renovations, could still be increased by providing reference networks, suitable tools and significant economic incentives for both customers and executing parties.

One barrier to the adoption of nearly zero-energy houses involves the perception that such houses offer insufficient air quality and/or comfort in the summer, independent of energy category. Design deficiency (e.g. lack of shading or ventilation bypass) or technical deficiencies in the heating and ventilation systems could be linked to negative experiences. In addition, the simplicity and the user-friendliness of control systems were identified as being of the utmost importance. These experiences suggest opportunities for architectural and technological innovation.

Process innovation is also needed, primarily with regard to quality assurance during design and execution, combined with requiring the high level of energy performance of nearly zero-energy houses. A post-occupancy evaluation study of certified passive houses in Flanders shows that current obligatory requirements for passive house certification (like those used in Flanders) do not always lead to positive appreciation of indoor temperatures, indoor air-humidity levels and/or noise levels. There is room for improving the requirements regarding cooling demand, the design and the installation of indoor climate systems, as well as for those regarding user-friendliness and information on building services (particularly mechanical ventilation systems). These recommendations can be discussed in the development of widely supported plans that aim to improve the general quality of building services in housing, indicating adaptations to regulations and building codes. Careful design and execution, including noise protection, sufficient air humidity control and odour removal strategies, are critical points for attention in relation to possible improvements in all housing categories.

In order to avoid negative end-user experiences, it is strongly recommended that inhabitants be provided with information in addition to that provided in the standard short introduction to the house. At the very least, this information should include operation manuals, although it should ideally include detailed instructions concerning the advanced systems they will encounter in the dwelling as well. Particularly for end users who are not involved in the building process (e.g. end users in rental housing), it is advisable to provide user-oriented technical information and/or training by qualified and/or experienced sources.

Increasing the diffusion of highly energy-efficient housing, particularly passive houses, requires an active role on the part of government policymakers with regard to the adoption of the innovation

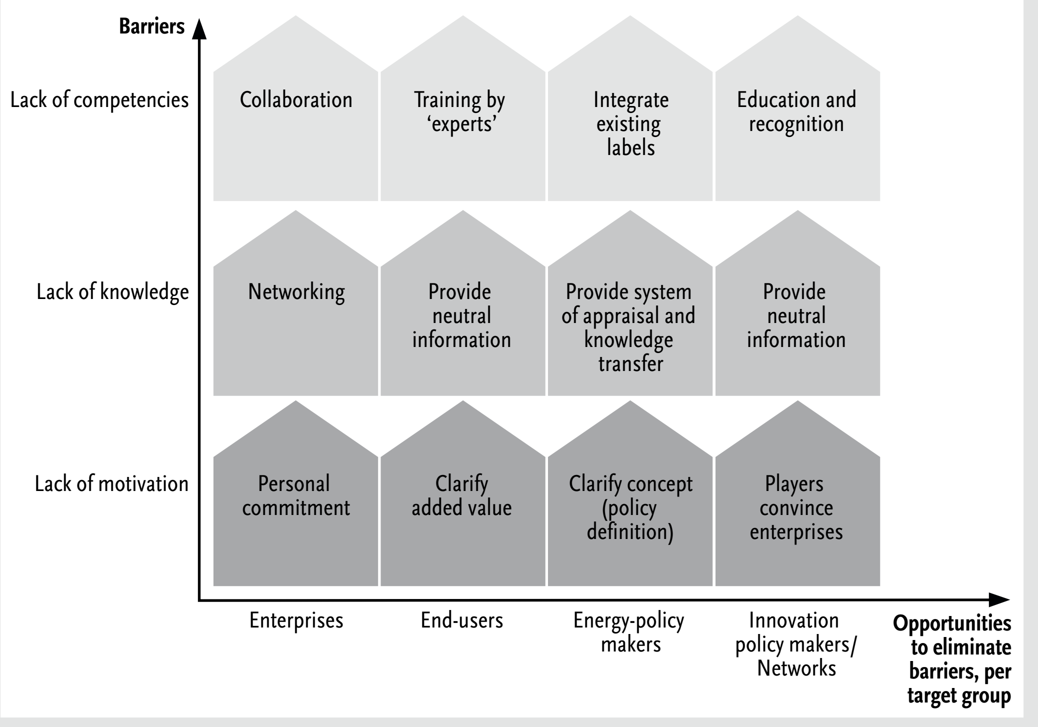
For the future implementation of national energy policies in Belgium and the Netherlands, the findings indicate that ‘passive house’ is an important and useful term, which offers market visibility and some level of policy acceptance. One important challenge with regard to avoiding market confusion is to ensure that definitions are clearly formulated and used consistently at all political levels (i.e. national and regional) and that they are compatible with the recast European Energy Performance of Buildings Directive (EPBD). Within this framework, government policymakers who are responsible for the development of energy policy should define and reward better energy performance for highly energy-efficient housing concepts (e.g. by using fiscal tools and an associated control system).

European states could benefit from integrating available labels in their implementation of the Energy Performance of Buildings Directive. Labels for passive houses have already been introduced as an option in many European countries, in order to introduce more user influence and to encourage market differentiation amongst enterprises. The diffusion of labels has benefited from the support of governments, banks, companies or combinations of these entities. Combining existing advanced labels (e.g. passive house) with the energy certificate scheme of the EPBD is recommended, although the way in which this should be done can be highly country-specific. National, regional and municipal authorities could further facilitate the adoption of labels through such actions as increasing their visibility in knowledge-transfer activities and by recognising the expertise of label providers. In addition, educational programmes for specific target groups are needed in order to support the acceptance of related quality-assurance procedures.

In general, it is essential to nurture a high level of corporate involvement and collaboration, as well as quality assurance with regard to nearly zero-energy concepts. To achieve this goal, a broad range of potentially interlinked communication activities is needed, with high intensity of communication. This communication should be neutral, positive and peer-to-peer, addressing various customer and business segments. The availability and attractiveness of conceptual approaches to highly energy-efficient housing should be increased, particularly during the market-introduction phase. Neutral actors (e.g. passive house networks) can contribute to develop communication strategies and market infrastructure.

Very important is that customers and businesses are guided with appropriate information at each step of their innovation decision-making processes. Customer confidence should be enhanced, and perceived compromises should be eased by cultivating motivation, increasing availability, highlighting attractiveness and guaranteeing quality. To induce environmentally conscious behaviour, communication policies should focus more on exemplification (i.e. the effective use of experiences from demonstration projects), as well as on engaging, enabling and encouraging clients and businesses. In addition to targeting the development of customer demand, communication should be specifically directed towards the uptake of innovation by businesses. A set of coherent communication activities could be defined in order to realise the diffusion of innovation by focusing on behavioural change and by creating synergies to produce identifiable innovation outcomes.

Figure 4 Integrated approach to eliminating adoption barriers for highly energy-efficient housing



Specific competencies and resources are needed in order to guide companies in their innovation journeys.

Recommendations for further market development

To accelerate the transformation of the energy and housing market significantly, we should address all barriers to innovation diffusion and early market development simultaneously. Collaboration amongst all adopter categories in the elimination of barriers could be expected to result in successful market development for highly energy-efficient housing and renovation.

Various categories of important adopters were defined in Figure 3: enterprises (particularly groups of SMEs and suppliers), end users (noting the importance of owners and occupants) and policymakers (particularly for the development of energy policy and innovation policy). Throughout the various studies, three reoccurring important barriers for market development of highly energy-efficient housing emerged. These three barriers can be roughly summarised as 'lack of motivation', 'lack of knowledge' and 'lack of competencies'. Figure 4 integrates the findings of the various studies regarding the elimination of these barriers and presents the key objectives recommended for actors as a general pathway for the transition beyond the demonstration project towards a larger market for highly energy-efficient housing.

The various studies illustrate that innovation adoption by enterprises for highly energy-efficient housing is not a stand-alone process in which enterprises promote and end-users adopt single technologies. Instead, this research reveals strong support for a 'concept' approach to innovation diffusion, in addition to drawing various connections between recommendations from the supply side, the demand side and for policy development. In general, the continued use of collaborative strategies can be highly recommended. As indicated by the findings of this study, peer-to-peer knowledge exchange networks for owner-occupiers, architects and contractors or multi-player enterprise networks can be trustworthy players who can provide neutral information, networking opportunities and a system of appraisal. Networks and policymakers should now work together to develop an integrated master plan, focusing on the further development of quality-assurance systems and enterprise collaboration towards systemic innovation. Both networks and policymakers should seriously reflect on their communication strategies and respond adequately to enterprise demand for various innovation phases, as well as to end-user demand emerging from various market segments.

This cross-reflection generates two main recommendations for increasing the adoption and diffusion of highly energy-efficient housing concepts. These recommendations are directly based on various recommendations emerging from the studies.

Makers of innovation and energy policy should support specific change agents

- Energy policy and innovation policy should be integrated for the construction sector.
- Enterprise collaboration and multi-player networking should be stimulated.
- Funded innovation agents should guide committed SMEs and suppliers.
- Funded change agents should guide potential adopters in each step of their innovation-decision processes.
- In some cases, these change agents could also combine their communication activities with positions as enterprise-innovation agents.

Quality-assurance schemes for highly energy-efficient housing should be introduced or revised

- Benefits that are not related to energy should be used to persuade potential adopters.
- The quality of demonstration projects should be assured.
- A pool of experienced actors should be developed.
- End users should be provided with detailed information.
- Indoor comfort and the adequate performance of building services should be guaranteed.
- A system of appraisal for nearly zero-energy housing should be defined, using available passive house labels or related experiences.
- An educational programme should be developed, particularly for highly energy-efficient housing renovation.

These recommendations should be implemented in order to eliminate barriers to innovation and to stimulate opportunities for innovation. In turn, this could accelerate the adoption of highly energy-efficient housing and the achievement of energy-policy objectives.

Theoretical development and limitations of the research

Scientific literature concerning the barriers to effective adoption and the opportunities that can lead to the effective adoption of highly energy-efficient innovation in construction companies is relatively scarce, as are studies on the reasons that enterprises and users have for deciding to adopt and experience concept solutions (e.g. passive houses). These barriers and opportunities are explored in the various studies included in this research. In relation to a concept approach, the studies have identified the emergence of multiple innovations, novel opportunities for eliminating barriers that impede supplier-led innovation, and opportunities and barriers related to enterprise collaboration in the innovation-development phase, as well as in the early market-development phase.

One major theoretical insight developed in this study is that many innovation researchers often tend to address the adoption of individual technologies, paying little attention to concept approaches or systemic innovation. As indicated by the findings of this study, the adoption of innovative concepts in order to achieve energy-saving objectives is more likely to lead to the adoption of a multitude of innovations (including radical innovations) involving technology, systems, service and architecture, in addition to generating the systemic collaboration needed for the adoption and diffusion of innovation. Moreover, transition processes from one market-development phase to the next (e.g. from innovation to early adoption) are not well understood in the literature on innovation diffusion. This study contributes to the exploration of this knowledge gap.

While Rogers' innovation diffusion theory proved useful for studying highly energy-efficient housing (particularly with regard to structuring innovation-decision processes), this research has identified the need to develop a communication model that looks beyond the supply side and that integrates the views of demand-side actors and those of policymakers. Rogers' framework was not ideal for addressing all research questions relating to innovation diffusion. In particular, the study identifies a need for additional theoretical frameworks for addressing questions related to the development of systemic innovation and enterprise networks. The theoretical framework of 'strategic niche management' relates better to specific success factors in innovation adoption (e.g. vision formation and learning, as well as the composition and formation of networks), but only in a market introduction phase. The study demonstrates the relevance of integrating environmental behaviour change models. The studies investigating demand-side perspective further indicate that post-occupancy evaluation research using questionnaires can provide important insights for discussing the elimination of barriers to adoption and communication. In addition, marketing literature references to 'business model generation' proved more effective for developing collaborative approaches for connecting market segments, customer values and innovation supply.

In general, this study shows the theoretical frameworks of systemic innovation, construction innovation, strategic niche management, environmental behaviour, marketing research and policy research to be useful, in addition to Rogers' innovation diffusion theory, for exploring barriers and opportunities related to innovation adoption. On the other hand, the studies also reveal several limitations to the theoretical framework applied. Given the limited attention that Rogers' theory devotes to social components, it could be useful to consider using other theoretical frameworks as a starting point when developing future research. In the future, it might be useful to connect what are now often separate theoretical fields. An integrated theoretical approach is still lacking, however, and a strong research effort is still needed in order to connect various individual theoretical fields.

While the technological innovations and demonstration projects can be well documented, the social component in innovation, the concept approach and systemic innovation are still in need of additional research attention. Further research into the differences between the market introduction of innovation, the early-adoption market and the late-adoption market is also needed. The renovation of single-family houses towards a high level of energy efficiency is still in the market-introduction phase. In this field, further research is needed in order to recommend adoption strategies.

The research conducted within the scope of this study was limited, and future researchers are now challenged to enrich practical insights and comprehension of theory. The focus of this research was on highly energy-efficient housing and related innovations in countries where domestic energy use is dominated by space heating. The identification of innovations from enterprises and the examination of the experiences of enterprise networks and end users focus on single-family or owner-occupied housing in Belgium and the Netherlands. It is important to note that building traditions and market development can differ across countries; conclusions should therefore be interpreted with caution for other regions and market segments. For example, different conclusions could emerge when addressing private or social tenants or groups of owners instead of individual owner-occupants. In various studies, demonstration projects and innovation trajectories were used as sources of information. The learning effects could obviously be limited to the experiences derived from the chosen sources, which could also be bounded in terms of both space and time. Conclusions and recommendations are subject to availability of information at the time of the research.

The conclusions and recommendations could be related to the more general notion of ‘concept’ innovation, however, and national experiences were used to discuss possible wider implications, particularly for defining general strategies that could contribute to the development of a market for highly energy-efficient single-family housing. They could also contribute to defining innovation-adoption strategies for construction sectors (or subsectors) that are dominated by SMEs. In particular, the observations regarding the need for quality assurance also target a more general problem of deficiencies in the planning and construction of buildings.

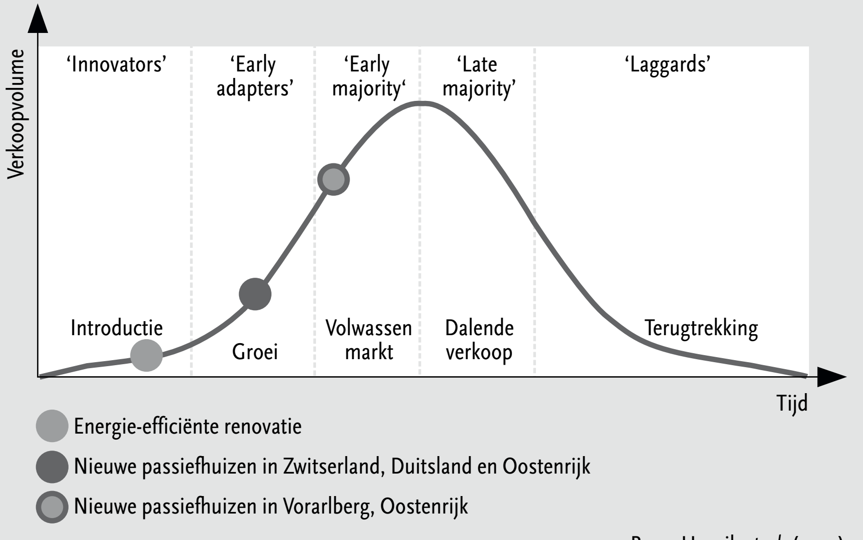
Samenvatting

Innovatieontwikkeling voor zeer energie-efficiënte huisvesting. Kansen en uitdagingen met betrekking tot de adoptie van passieve woningen

Inleiding
De interesse in energie-efficiëntie en hieraan gerelateerde innovaties is hernieuwd door de debatten over klimaatverandering en veiligheid van energielevering, de gestegen kansen op een 'groenere' economie en de invoering van de Europese richtlijn betreffende energieprestatie van gebouwen. Innovatie wordt gezien als een belangrijk instrument om energie te besparen, in het bijzonder in energie-intensieve sectoren zoals de bouwsector, waar een groot deel van het energiegebruik gaat naar woningen. Het bereiken van energie- en klimaatbeleidsdoelstellingen vergt een aanzienlijke CO_2-besparing in woningen. In het bijzonder het reduceren van de energievraag voor ruimteverwarming speelt hierin een belangrijke rol. Daarom zijn in deze studie innovatie-mogelijkheden en -belemmeringen van de toepassing van zeer energie-efficiënte woningconcepten onderzocht, in het bijzonder passiefhuizen, die de vraag voor ruimteverwarming sterk reduceren.

Naast verschillen tussen nieuwbouw en renovatie, blijkt dat bijvoorbeeld Oostenrijk, Duitsland en Zwitserland, – en ook regio's zoals Vlaanderen en Vorarlberg – sneller waren dan bijvoorbeeld Nederland met de 'adoptie' van zeer energie-efficiënte woningconcepten, zoals geïllustreerd in Figuur 1. België is, net als Nederland, relatief laat gestart met de adoptie van het passiefhuis-concept, hoewel de markt er sneller werd ontwikkeld dan in Nederland. De ruime ervaringen van de auteur met de introductie van passiefhuizen op

Figuur 1 Productlevenscyclus-curve, illustratie voor de ontwikkeling van passiefhuizen



Bron: Haavik *et al.* (2012)

de markt in Vlaanderen (België) vormden een fundament om diverse vraagstukken te verkennen met betrekking tot adoptie en diffusie.

Het praktische doel van deze studie was om belemmeringen en mogelijkheden te definiëren voor de introductie en marktgroei van zeer energie-efficiënte woningconcepten (in het bijzonder passiefhuizen), om vervolgens aanbevelingen te definiëren voor het versnellen van hun toepassing en verspreiding. Het empirisch kader van deze studie richt zich in het bijzonder op het vinden van aanbevelingen voor de markt van eengezinswoningen in landen en regio's waar de marktontwikkeling van energie-efficiënte concepten achterblijft. Kansen voor innovatie en hindernissen met betrekking tot de promotie van zeer energie-efficiënte woningconcepten worden onderzocht, met het doel om trajecten te definiëren die leiden tot het verwijderen van adoptie- en diffusiehindernissen. Dit wordt bereikt door de standpunten en ervaringen van bedrijven (Deel A), eindgebruikers (Deel B) en beleidsmakers (Deel C) empirisch te onderzoeken, om diverse factoren te identificeren die kunnen leiden tot een snelle toename van de toepassing en verspreiding van innovatieve concepten (in het bijzonder passiefhuizen).

Voor wat betreft het theoretisch kader richt de studie zich in de eerste plaats op het met voorbeelden toelichten, interpreteren en ontwikkelen van de innovatietheorie van Rogers (E.M. Rogers, Diffusion of Innovations, Free Press, N.Y., 5th edition, 2003). Op deze wijze levert de studie ook een beter begrip en betere conceptualisering van diverse punten die kunnen leiden tot vooruitgang van de innovatie-theorie. Hierbij worden praktische doelen en ervaringen uit de markt, en van zowel de eindgebruiker als van beleidsmakers gebruikt. Het traditioneel theoretisch perspectief van bedrijf of klant als innovatie-aannemer wordt uitgebreid om ook groepen van bedrijven en beleidsmakers mee te nemen. Een andere theoretische uitdaging is het in acht nemen van de innovatie-theorie op een niveau verder dan individuele technologieën, in het bijzonder het concept-niveau. De studie daagt Rogers' innovatie-theorie uit om meer expliciet rekening te houden met de ervaringen ontwikkeld in andere theoretische velden, zoals bouwinnovatie-theorie, de theorie met betrekking tot bedrijvennetwerken en onderzoek naar milieugedrag.

Benadering van het onderzoek

Om het onderzoek te structureren wat betreft de toegepaste theorieën en de problematiek betreffende de marktontwikkeling, werd de hoofdonderzoeksvraag als volgt opgesplitst in drie primaire vragen: *Welke uitdagingen en opportuniteiten zijn gerelateerd aan de innovatie-adoptie van zeer energie-efficiënte huisvestingsconcepten, in het bijzonder passiefhuizen (hoofdvraag), zoals waargenomen in de aanbodzijde (Deel A), de vraagzijde (Deel B) en de zijde van het beleid (Deel C)?*

Diverse opgaven met betrekking tot technologische innovatie, bedrijfsinnovatie en overheidsbeleid zijn bestudeerd in samenhang met specifieke deelvragen. Het analyseren van technologische, maatschappelijke en beleidsfactoren die de verspreiding van innovatie kunnen stimuleren of verhinderen leidde tot het voorstellen van innovatietrajecten voor de integratie van zeer energie-efficiënte huisvestingsconcepten.

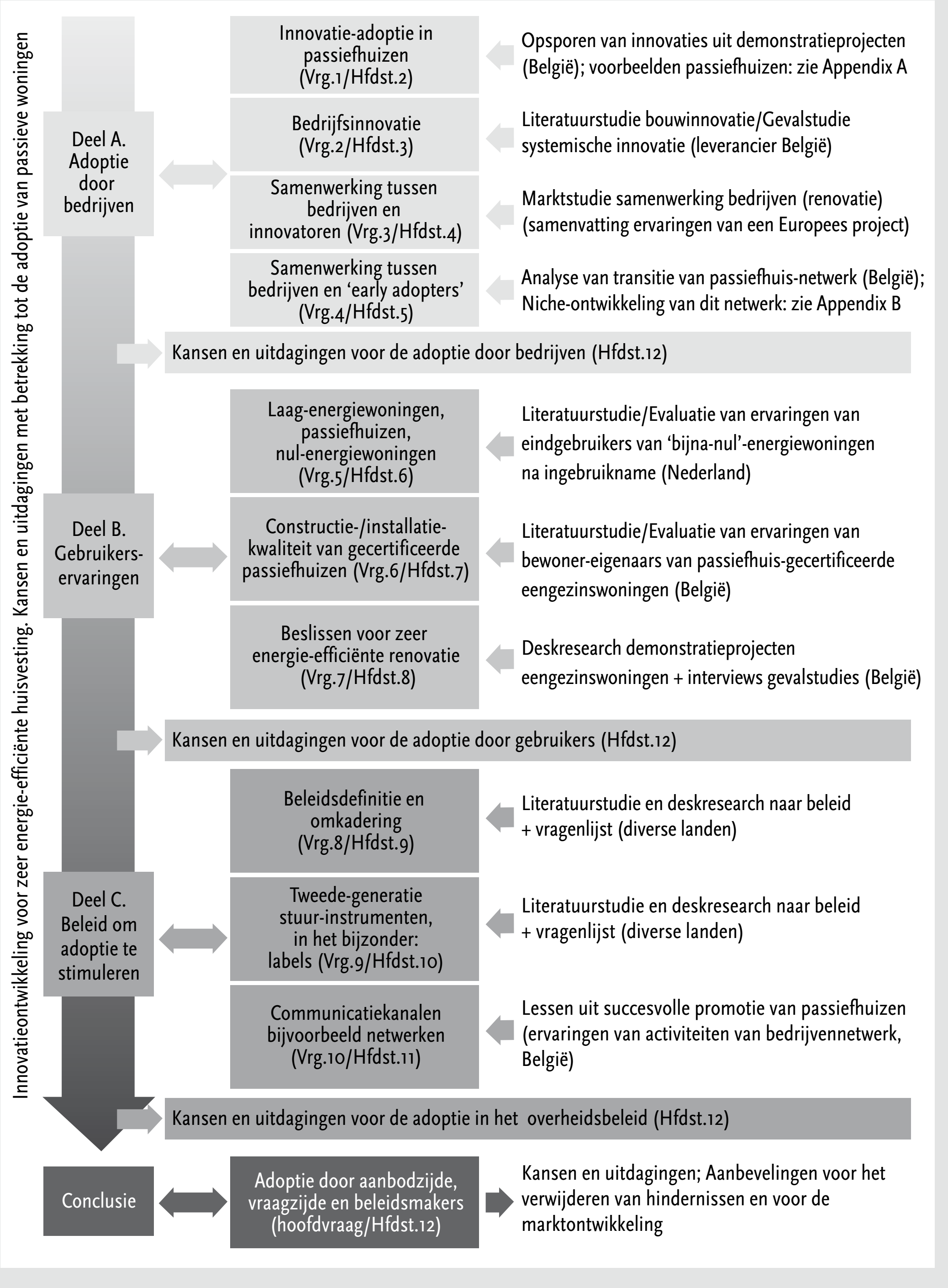
In het eerste deel van de studie zijn demonstratieprojecten op het gebied van eengezinswoningen geanalyseerd om de innovaties te identificeren die bedrijven associëren met passiefhuizen en met zeer energie-efficiënte renovaties. Vervolgens werden nieuwe inzichten verschaft in de innovatietheorie door het bestuderen van het innovatie-adoptieproces van een leverancier. Hierbij werd de nadruk gelegd op het verkennen van systemische innovatiemogelijkheden. Het pad van samenwerking tussen bedrijven wordt vervolgens verder verkend voor een opkomende markt (zeer energiezuinige woningrenovatie). Bovendien worden mogelijkheden en hindernissen met betrekking tot de transitie van marktintroductie naar marktgroei onderzocht, gebruik makend van de ervaringen van een passiefhuis-bedrijvennetwerk.

Het tweede deel van de studie neemt het perspectief van de vraagzijde door het bestuderen van ervaringen van eindgebruikers met het oppakken van innovatie. De eerste studie in dit deel is gebaseerd op evaluatieonderzoek na ingebruikname van nieuwbouw van diverse categorieën bijna-nul-energiewoningen in Nederland. Om de noodzaak van het bewaken van kwaliteit en het verbeteren van passiefhuiscertificatie vast te stellen, werd een volgende studie gebaseerd op ervaringen van eindgebruikers in gecertificeerde passiefhuizen. Met het doel de ontluikende markt van zeer energie-efficiënte renovaties te ondersteunen, zijn in een daaropvolgende studie de besluitvormingsprocessen van eigenaar-bewoners rond innovaties zoals zeer energie-efficiënte renovatieconcepten bestudeerd.

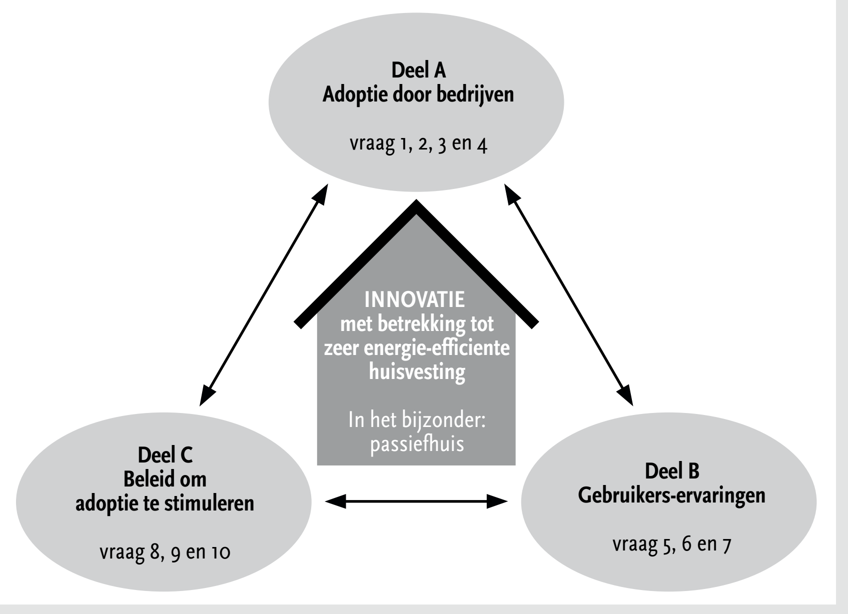
Het derde deel van de studie beoogt in het bijzonder om lessen te trekken uit beleidsvormen en beleidsinitiatieven van diverse Europese landen. Dit verschaft inzichten hoe beleidsmakers de adoptie van zeer energie-efficiënte huisvestingsconcepten zouden kunnen stimuleren. Om dit doel te bereiken, bestudeert een eerste deelstudie de definities van 'bijna-nul'-energiewoningen die gelden in de markt en in het beleid van de Europese lidstaten. Een volgende studie legt in het bijzonder de nadruk op het toepassen van labels in het overheidsbeleid. Vervolgens worden in een derde deelstudie mogelijkheden verkend voor het gebruik van communicatiekanalen om acceptatie van innovatie te versterken; deze worden toegelicht met de activiteiten van het voorheen besproken passiefhuis-bedrijvennetwerk.

In de studies zijn diverse onderzoeksmethoden gebruikt om bovenstaande punten te verkennen, afhankelijk van het specifieke vraagstuk dat wordt behandeld. Naast literatuurstudie werden gegevens verzameld van bestaande Belgische en Nederlandse demonstratiewoningen (nieuwbouw passiefhuizen en 'bijna-nul'-energiewoningen en zeer energie-efficiënte renovaties) om innovaties en ervaringen van eindgebruikers te identificeren. Bijkomende empirische gegevens werden verkregen door middel van vragenlijsten die

Figuur 2 De drie hoofdcomponenten in de algemene benadering van het onderzoek, de hoofdonderwerpen die worden behandeld in elk van de tien studies, de input (onderzoek) die werd gebruikt in ieder hoofdstuk en de output (conclusie) die werd getrokken in elk deel.



Figuur 3 Het onderzoek definieerde de 'innovatie' en bestudeerde de adoptie hiervan door bedrijven (Deel A, vier studies/deelvragen), eindgebruikers (Deel B, drie studies/deelvragen) en in het overheidsbeleid (Deel C, drie studies/deelvragen)



verstuurd zijn aan bedrijven, eindgebruikers en beleidsmakers, samen met het doorzoeken van gegevensbestanden en het internet, evenals interviews met belanghebbenden in demonstratieprojecten (bijvoorbeeld eindgebruikers, architecten en bedrijven). De auteur heeft ook geput uit eigen ervaring, opgedaan met innovatiebegeleiding van bedrijven, de oprichting van een passiefhuis-netwerk en de marktontwikkeling voor passiefhuizen in Vlaanderen.

De algemene benadering van het onderzoek wordt geïllustreerd in Figuur 2.

Uitdagingen en mogelijkheden voor de adoptie van zeer energie-efficiënte huisvestingsconcepten

Dit onderzoek heeft zeer belangrijke mogelijkheden voor en hindernissen bij de innovatie-adoptie van zeer energie-efficiënte huisvestingsconcepten, in het bijzonder passiefhuizen, geïdentificeerd vanuit de aanbodzijde (Deel A), de vraagzijde (Deel B) en de zijde van het overheidsbeleid (Deel C). Zie Figuur 3 voor een schematische weergave.

Antwoorden op de hoofdvraag zijn gevonden door het bestuderen van het onderwerp vanuit verschillende invalshoeken. Vanuit het perspectief van de aanbodzijde is de belangrijkste conclusie dat samenwerking tussen vele bedrijven een sleutelrol speelt in de adoptie van 'concept'-innovaties, zoals bijvoorbeeld passiefhuizen. Vanuit het oogpunt van de eindgebruiker moeten de problemen en positieve ervaringen van eindgebruikers worden gebruikt bij verdere ontwikkeling van innovatie. Vanuit het perspectief van de overheid kan worden geconcludeerd dat toenemende verspreiding van zeer energie-efficiënte huisvesting (in het bijzonder passiefhuizen) een actieve rol vraagt van de makers van het overheidsbeleid bij de adoptie van innovatie.

Samenwerking tussen vele bedrijven speelt een sleutelrol in de adoptie van 'concept'-innovatie

De ervaringen van bedrijven met innovaties in demonstratieprojecten tonen aan dat een integrale architectuurgerichte 'concept'-aanpak – zoals ervaren bij de promotie van passiefhuizen – bedrijven kan stimuleren om innovaties te verspreiden en om een veelheid aan innovatieve technologieën te adopteren. Deze adoptie kan mogelijk in clusters gebeuren. Ook innovatieve diensten en systemen en architecturale innovaties werden geadopteerd. Een voordeel van het passiefhuis is dat dit concept eenvoudig kan worden vertaald in algemeen herkenbare principes, zodat bedrijven zich daarop kunnen richten.

De bevindingen van de studie tonen voor de bouwsector aan dat leveranciers een belangrijke rol kunnen spelen bij de adoptie van innovatie. De gedetailleerde beschrijving van een innovatietraject van een leverancier wordt gebruikt om het potentieel en het theoretisch belang van systemische innovatie toe te lichten. In dergelijke innovatietrajecten wordt samengewerkt met diverse belanghebbenden die de noodzakelijke bevoegdheden, expertise en kennis leveren. Gedreven door de passiefhuis-conceptaanpak, en met behulp van een innovatiebemiddelaar, is in het nader onderzoek vastgesteld dat de leverancier een formeel gestructureerd en risicodelend innovatietraject startte richting modulaire innovatie. Hierbij werden architectuur- en systeeminnovatie met elkaar verbonden. Dit staat in scherp contrast tot de gebruikelijke ad hoc toepassing van kennis en gebruikelijke losse samenwerking tussen actoren in demonstratieprojecten, welke doorgaans veeleer uitmondt in incrementele innovatie die plaatsvindt tijdens specifieke projectfasen.

Een belangrijke hindernis voor de ontwikkeling van passiefhuizen, en dan vooral in de renovatiemarkt, is de projectgerelateerde fragmentatie van het Midden- en Kleinbedrijf (MKB). Dit wordt gekarakteriseerd door afzonderlijke kleine en middelgrote ondernemingen die elk een fractie uitvoeren van een verondersteld integraal project. Om deze hindernis te neutraliseren is het essentieel om een netwerk te ontwikkelen en te cultiveren rond nieuwe en bestaande conceptinnovaties. Vanwege de karakteristieken van de bouwsector is het de moeite waard om specifieke innovatiebemiddelaars op te leiden. Die kunnen als intermediair dienen tussen leveranciers en andere spelers in de bouwketen om conceptinnovaties voor het bereiken van een zeer goede energieprestatie te stimuleren.

Een bijzondere hindernis wordt gevormd door de verschuiving van de benodigde technische informatie, kennis en vaardigheden met betrekking tot projectmanagement van de voorlopers naar de vele minder ervaren uitvoerende actoren, waarvan vele uit het MKB. Deze laatste vormen een belangrijke doelgroep voor de marktintroductie van conceptinnovatie in de bouwsector. In de ontwikkeling van de Vlaamse markt voor eengezins-passiefhuizen speelden kleine bedrijven bijvoorbeeld de belangrijkste rol bij de eerste introductie van radicale innovatie op regionaal niveau, terwijl grote ondernemingen trager waren in de adoptie van innovatie als gevolg van hun incrementele innovatiebenadering. Deze grote ondernemingen innoveerden pas op het moment dat financiële prikkels en netwerkprikkels waren geïnstalleerd die gericht waren op een grotere markt.

De resultaten tonen de noodzaak om samenwerking tussen bedrijven te karakteriseren, te cultiveren en te ontwikkelen in diverse opeenvolgende innovatiefasen en transities tussen fasen. Uit het onderzoek blijkt dat business-to-business samenwerking onontbeerlijk is voor de ontwikkeling van conceptinnovatie, zowel tijdens de marktintroductie als in de groeifase. Dergelijke samenwerking kan worden gefaciliteerd door multi-speler bedrijvennetwerken, waarin verschillende soorten actoren (bijvoorbeeld architecten, installateurs, aannemers en adviseurs, evenals klanten en kennisinstellingen) kunnen netwerken en samenwerken.

In sterke tegenstelling tot de markt voor nieuwbouw-passiefhuizen, dient de renovatiemarkt nog een hele weg af te leggen op het gebied van de ontwikkeling van betere samenwerkingsverbanden. Een pool van ervaren actoren voor de uitvoering van zeer energie-efficiënte woningrenovaties moet nog worden gedefinieerd, en aangepaste kwaliteitsbewakingsinstrumenten en steunregelingen zijn nodig. Een belangrijke mogelijkheid ligt in het vinden van 'market-proof' samenwerkings- en communicatiestructuren om woningeigenaars te ontlasten, in het bijzonder met het opvangen van financiële lasten en lasten inzake projectmanagement.

De noden en ervaringen van eindgebruikers moeten worden gebruikt om verdere innovatie te begeleiden

Enerzijds dienen bedrijven te innoveren. Anderzijds zullen bedrijven gemakkelijker een markt vinden door met hun technologieën, systemen, diensten en architectuur te antwoorden op noden en verwachtingen van de klant. De onderzoeksbevindingen van evaluatiestudies na ingebruikname tonen aan dat potentiële bewoners diverse redenen hebben om te kiezen voor 'bijna-nul'-energiewoningen. Zij vinden het beperkt kunnen houden van de energiekosten van een woning belangrijk. De keuze voor een passiefhuis blijkt het voordeel te bezitten dat tijdens onderhandelingen met uitvoerende partijen duidelijke prestatie-eisen kunnen worden bepaald. Een onderzoek naar ervaringen van eindgebruikers in Nederland toont aan dat hun keuze voor een laag-energiewoning, passiefhuis of nul-energiewoning niet vanzelfsprekend is. Aan de andere kant waren bewoners van zeer energie-efficiënte woningen behoorlijk tevreden met hun woning, in het bijzonder ook vanwege een hoog niveau van comfort. Deze bevindingen kunnen worden gebruikt als bijkomende argumenten voor de promotie van dergelijke woningen. Een potentieel domein voor verbetering behelst de promotie van innovatieve renovatieconcepten gericht op eigenaar-bewoners. Factoren die eigenaar-bewoners motiveren om zeer energie-efficiënte renovatieconcepten toe te passen zijn, naast structurele verbetering en meer gebruiksoppervlakte, onder meer de beloftes van verbeterd comfort, een meer algemene zorg voor het milieu en verbeterde gezondheidscondities.

De resultaten van dit onderzoek wijzen erop dat de vraagzijde doorgaans lijdt aan een gebrek aan kennis van beschikbare innovatieve concepten. Daarom zijn sociale strategieën aan te bevelen, bijvoorbeeld het oprichten of van 'peer-to-peer' netwerken voor de kennisuitwisseling tussen eigenaar-bewoners. Dergelijke netwerken kunnen worden gevoed door ervaren eigenaar-bewoners en betrokken ontwerpers en uitvoerders. Om de verspreiding te verbeteren dienen het relatief voordeel en de zichtbaarheid van marktpartijen te worden verbeterd. De attractiviteit van zeer energie-efficiënte concepten kan nog worden verhoogd, in het bijzonder voor renovaties, door het leveren van referentienetwerken, passende tools en beduidende financiële prikkels voor zowel afnemers als uitvoerende partijen.

Een belemmering voor de adoptie van 'bijna-nul'-energiewoningen, behelst de perceptie van eindgebruikers dat dergelijke woningen onvoldoende luchtkwaliteit en/of zomercomfort bieden. Deze belemmering geldt voor zowel laag-energiewoningen, passiefhuizen en nul-energiewoningen. Onvolkomenheden in het ontwerp (bijvoorbeeld het gebrek aan beschaduwende bouwdelen of het ontbreken van een ventilatie-bypass) of technische onvolkomenheden in verwarmings- en ventilatiesystemen kunnen de oorzaak zijn van negatieve ervaringen. Bovendien worden eenvoud en gebruiksvriendelijkheid van binnenklimaatregelsystemen als zeer belangrijke voorwaarden aangemerkt. Deze ervaringen suggereren mogelijkheden voor architecturale en technologische innovaties.

Procesinnovatie is ook nodig, hoofdzakelijk kwaliteitsbewaking tijdens het ontwerp en de uitvoering, gecombineerd met hoge niveaus van energieprestatie verbonden aan 'bijna-nul'-energiewoningen. Een evaluatiestudie na ingebruikname van gecertificeerde passiefhuizen in Vlaanderen toonde aan dat het huidige verplichte passiefhuiscertificaat (zoals gebruikt in Vlaanderen) niet altijd leidt tot een positieve beoordeling van de binnentemperatuur, de luchtvochtigheid binnenshuis en de geluidniveaus. Er is ruimte voor verbetering van de specificaties voor ruimtekoeling, het ontwerp en de installatie van binnenklimaatsystemen, evenals de gebruiksvriendelijkheid van en de informatie over binnenklimaatsystemen (in het bijzonder mechanische ventilatiesystemen).

Er kan een breed draagvlak worden gecreëerd voor het verbeteren van de algemene kwaliteit van binnenklimaatsystemen in huisvesting. In dergelijke plannen kan ook worden gewezen op aanpassingen van regelgeving en bouwnormen. Er moet aandacht worden besteed aan een zorgzamer ontwerp en een waakzamere uitvoering. Geluidhinder moet worden vermeden en er moet voldoende controle over de luchtvochtigheid komen. Geuren moeten verwijderd kunnen worden. Deze factoren zijn kritische punten in alle categorieën woningen.

Om negatieve ervaringen van eindgebruikers te vermijden, wordt sterk aanbevolen om bewoners te voorzien van extra informatie, naast de informatie die standaard wordt geleverd bij de oplevering van de woning. Op zijn minst moet deze informatie de bedieningshandleidingen bevatten. Idealiter worden daarnaast gedetailleerde instructies gegeven voor de vooruitstrevende systemen waarmee de bewoner zal worden geconfronteerd. Met name wordt geadviseerd dat eindgebruikers die niet betrokken waren bij het bouwproces (bijvoorbeeld eindgebruikers in huurwoningen), gebruikers-georiënteerde technische informatie, training, of beide, door gekwalificeerde of ervaren personen ontvangen.

Toenemende diffusie van zeer energie-efficiënte huisvesting (in het bijzonder passiefhuizen) vraagt een actieve rol van de makers van het overheidsbeleid met betrekking tot de adoptie van innovatie

Met betrekking tot de toekomstige uitvoering van nationaal energiebeleid in België en Nederland tonen de onderzoeksbevindingen aan dat 'passiefhuis' een belangrijke en bruikbare term is, die markzichtbaarheid biedt en een zekere mate van acceptatie van het beleid. Een belangrijke uitdaging bij het voorkomen van verwarring in de markt, is het ervoor zorgen dat de definities duidelijk worden geformuleerd en consistent worden gebruikt op alle politieke niveaus (lees: nationaal en regionaal) en dat deze overeenkomen met de herziening van de Europese energieprestatieregelgeving voor gebouwen. In dit kader zouden de beleidsmakers die verantwoordelijk zijn voor de ontwikkeling van het energiebeleid, betere energieprestaties van 'bijna-nul'-energieconcepten moeten belonen, bijvoorbeeld door gebruik te maken van fiscale instrumenten en hieraan gerelateerde controlesystemen.

Nationale overheden zouden voordeel kunnen halen uit de integratie van beschikbare labels in de herziening van de energieprestatieregelgeving voor gebouwen. Labels voor passiefhuizen zijn al in vele Europese landen geïntroduceerd om de klant meer invloed te geven en om marktdifferentiatie tussen bedrijven te bevorderen. De ondersteuning door overheden, banken en bedrijven heeft voordelen opgeleverd bij de verspreiding van labels. Het is aan te bevelen om bestaande geavanceerde labels (bijvoorbeeld 'passiefhuis') te combineren met het energiecertificaat zoals bedoeld in de energieprestatieregelgeving voor gebouwen. De manier waarop dit dient te gebeuren kan per land sterk verschillen. Nationale, regionale en gemeentelijke autoriteiten kunnen de adoptie van labels verder faciliteren door hun zichtbaarheid in activiteiten van kennisoverdracht te verhogen en door het erkennen van expertise van leveranciers van labels. Scholingsprogramma's zijn nodig voor specifieke doelgroepen ter ondersteuning van de acceptatie van gerelateerde procedures van kwaliteitsverzekering.

Over het algemeen is het belangrijk om een hoge graad van betrokkenheid van bedrijven te stimuleren, evenals kwaliteitsverzekering van 'bijna-nul'-energieconcepten. Om dit doel te bereiken is een breed spectrum nodig van potentieel samenhangende communicatie-activiteiten, met hoge intensiteit van communicatie. Deze communicatie dient neutraal te zijn, positief en 'peer-to-peer', en gericht op diverse segmenten van klanten en bedrijven. De beschikbaarheid en de attractiviteit van de conceptmatige aanpak van zeer energie-efficiënte huisvesting dient te worden verhoogd, in het bijzonder tijdens de marktintroductie. Neutrale actoren (bijvoorbeeld passiefhuisnetwerken) kunnen bijdragen aan de ontwikkeling van communicatiestrategieën en marktinfrastructuur.

Het is zeer belangrijk dat klanten en bedrijven worden begeleid met aangepaste informatie tijdens iedere stap van hun acceptatie-besluitvormingsproces. Het vertrouwen van de klant dient te worden gewonnen en het maken van compromissen dient te worden vergemakkelijkt door het stimuleren van motivatie, het verhogen van beschikbaarheid, het benadrukken van de aantrekkelijke punten en het garanderen van de kwaliteit. Om milieubewust gedrag uit te lokken moeten beleidsmakers hun communicatie ook richten op de adoptie van innovatie door bedrijven. Een verzameling van coherente communicatie-activiteiten rond de verspreiding van innovatie kan worden gedefinieerd door zich te richten op gedragswijziging en door het creëren van samenwerkingsverbanden voor het produceren van identificeerbare innovatieresultaten. Specifieke competenties en middelen zijn nodig om bedrijven te begeleiden in hun innovatietrajecten.

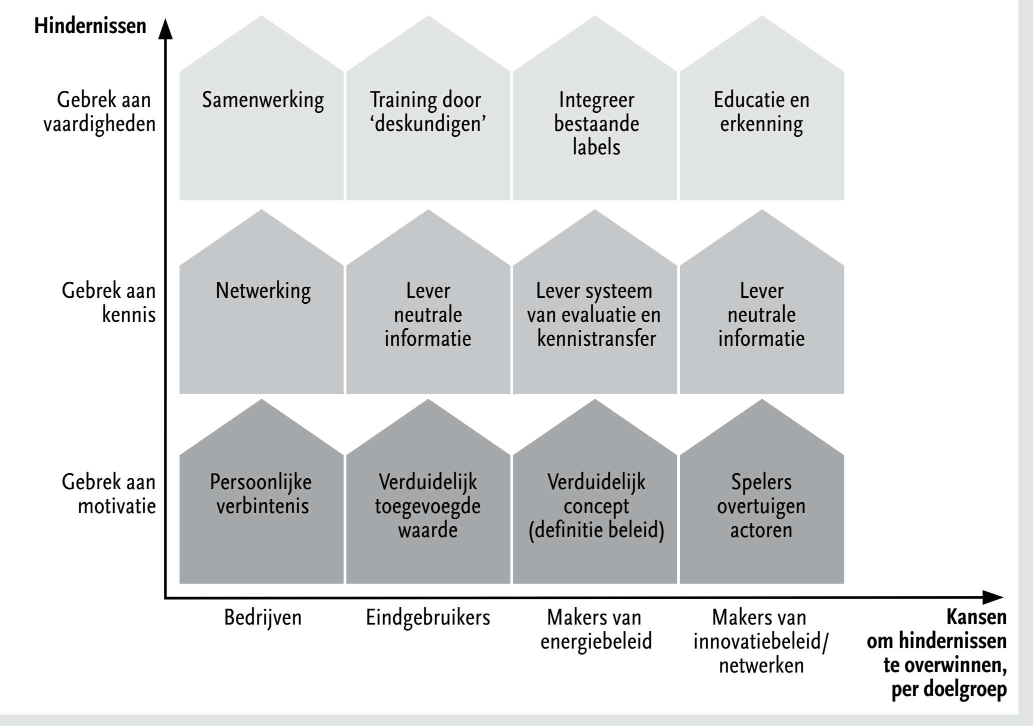
Aanbevelingen voor de verdere marktontwikkeling

Om de transformatie van de woningvoorraad tot een zeer energiezuinige voorraad te versnellen, moeten alle hindernissen met betrekking tot de verspreiding van innovatie en de marktgroei simultaan aangepakt worden. Het ligt in de lijn der verwachting dat de samenwerking tussen alle adoptercategorieën bij het overwinnen van hindernissen resulteert in succesvolle marktontwikkeling van zeer energie-efficiënte huisvesting en renovatie.

Diverse categorieën van belangrijke adopters worden weergegeven in Figuur 3: bedrijven (in het bijzonder groepen bedrijven uit het MKB en leveranciers), eindgebruikers (in het bijzonder eigenaars en bewoners) en beleidsmakers (in het bijzonder voor de ontwikkeling van energie- en innovatiebeleid). Vanuit verschillende studies kwamen drie belangrijke hindernissen voor de marktontwikkeling van zeer energie-efficiënte huisvesting naar voren. Deze drie hindernissen kunnen ruwweg samengevat worden als 'gebrek aan motivatie', 'gebrek aan kennis' en 'gebrek aan vaardigheden'. Figuur 4 integreert de bevindingen van deze studies met betrekking tot het verwijderen van de hindernissen en laat de kernaanbevelingen zien in de vorm van een transitietraject (van demonstratieprojecten) naar een meer energie-efficiënte huisvesting.

De studies illustreren dat innovatie-adoptie van zeer energie-efficiënte huisvesting door bedrijven geen op zichzelf staand proces is waarbij bedrijven

Figuur 4 Integrale aanpak om hindernissen te verwijderen die in de weg staan van de adoptie van zeer energiezuinige huisvesting



afzonderlijke technologieën promoten en eindgebruikers deze toepassen. In de plaats daarvan levert dit onderzoek steun voor een conceptaanpak om diffusie van innovatie te beteugelen, en toont het diverse dwarsverbanden aan tussen aanbevelingen vanuit de vraagzijde, de aanbodzijde en de ontwikkeling van beleid. Over het algemeen kan het herhaaldelijk gebruik van samenwerkingsstrategieën sterk worden aanbevolen. Zoals geconstateerd in enkele van deze studies, kunnen 'peer-to-peer' netwerken voor kennisuitwisseling tussen eigenaar-bewoners, ontwerpers en uitvoerders, samen met multispeler bedrijvennetwerken, betrouwbare spelers zijn. Deze spelers kunnen neutrale informatie verschaffen, evenals mogelijkheden voor netwerking en een systeem van evaluatie. De volgende stap is dat netwerken en beleidsmakers samenwerken om een integraal masterplan te ontwikkelen, dat zich concentreert op de verdere ontwikkeling van kwaliteitsverzekeringssystemen en op de samenwerking tussen bedrijven ten behoeve van systemische innovatie. Zowel netwerken als beleidsmakers moeten zich ernstig bezinnen op hun communicatiestrategieën en adequaat antwoorden op de vragen van bedrijven in diverse innovatiefasen, net als op de vragen van eindgebruikers in verschillende marktsegmenten.

Deze kruisanalyse genereert twee hoofdaanbevelingen voor het bespoedigen van het toepassen en de verspreiding van zeer energie-efficiënte huisvestingsconcepten. Deze aanbevelingen zijn rechtstreeks gebaseerd op diverse aanbevelingen voortvloeiend uit de studies.

Hoofdaanbeveling 1: Makers van innovatie- en energiebeleid moeten specifieke veranderingsbemiddelaars ondersteunen

- Energiebeleid en innovatiebeleid dienen te worden geïntegreerd voor de bouwsector.
- Samenwerking tussen bedrijven en multi-speler netwerken moet worden gestimuleerd.
- Gefinancierde innovatiebemiddelaars moeten geëngageerde actoren uit het MKB en leveranciers begeleiden.
- Gefinancierde veranderingsbemiddelaars moeten potentiële adopters begeleiden in iedere stap van hun innovatie-besluitvormingsproces, en
- In sommige gevallen kunnen deze veranderingsbemiddelaars hun communicatie-activiteiten ook combineren met een positie als innovatiebemiddelaar.

Hoofdaanbeveling 2: Kwaliteitsverzekeringssystemen voor zeer energie-efficiënte huisvesting moeten worden geïntroduceerd of herzien

- Voordelen die niet gerelateerd zijn aan energie zouden moeten worden gebruikt om potentiële adopters te overtuigen.
- De kwaliteit van demonstratieprojecten dient te worden verzekerd.
- Een pool van ervaren actoren moet worden ontwikkeld.
- Eindgebruikers moeten worden voorzien van gedetailleerde informatie.
- Klimaatcomfort en de afdoende prestatie van klimaatsystemen dienen te worden gegarandeerd.
- Een evaluatiesysteem voor 'bijna-nul'-energiewoningen moet worden gedefinieerd, gebruik makend van beschikbare (ervaringen van) passiefhuislabels, en
- Een scholingsprogramma dient te worden ontwikkeld, in het bijzonder voor zeer energie-efficiënte woningrenovaties.

Deze aanbevelingen dienen te worden uitgevoerd om innovatiehindernissen te verwijderen en om mogelijkheden voor innovatie te stimuleren. Per direct kan deze uitvoering de adoptie van zeer energie-efficiënte huisvesting en het verwezenlijken van energiebeleidsdoelstellingen versnellen.

Ontwikkeling van theorie en limieten van het onderzoek

Wetenschappelijke literatuur over de hindernissen voor de effectieve adoptie en de opportuniteiten die kunnen leiden tot effectieve adoptie van zeer energie-efficiënte innovaties in bouwbedrijven is relatief schaars. Ook studies naar redenen waarom bedrijven en gebruikers besluiten om concept-oplossingen (bijvoorbeeld passiefhuizen) te adopteren en te gebruiken zijn relatief schaars. Deze hindernissen en kansen worden verkend in de diverse studies van dit onderzoek. In de vorm van een conceptaanpak, identificeren deze studies het ontstaan van een veelvoud aan innovaties, nieuwe mogelijkheden voor het overwinnen van hindernissen die in de weg staan van leverancier-gedreven innovatie, en kansen en hindernissen bij de samenwerking van bedrijven tijdens de marktintroductie en groeifase.

Een belangrijk theoretisch inzicht dat werd ontwikkeld in deze studie is dat vele innovatieonderzoekers vaak de neiging hebben om de adoptie van individuele technologieën te behandelen, met weinig aandacht voor conceptaanpakken of systemische innovatie. Zoals aangegeven in de bevindingen van deze studie, leidt de adoptie van innovatieve concepten voor het bereiken van energiebesparingsdoelstellingen allicht tot de adoptie van een hoeveelheid aan innovaties, met inbegrip van radicale innovaties. Deze innovaties behelzen zowel technologie, als systemen, diensten en architectuur. Daarnaast wordt systemische samenwerking gegenereerd die nodig is voor de adoptie en diffusie van innovatie. Ook de transitieprocessen van één marktfase naar een volgende marktfase (bijvoorbeeld van innovatie naar groei) worden niet goed verstaan in de literatuur over de diffusie van innovatie. Deze studie draagt bij aan het verkennen van deze leemte in onderzoek.

Terwijl Rogers' theorie over diffusie van innovatie nuttig bleek voor de studie van zeer energie-efficiënte huisvesting – in het bijzonder voor het structureren van innovatie-besluitvormingsprocessen –, identificeerde dit onderzoek de noodzaak om een communicatiemodel te ontwikkelen dat verder gaat dan het beïnvloeden van de aanbodzijde. Ook de beschouwingen van de actoren van de vraagzijde en van beleidsmakers moeten erin worden geïntegreerd. Rogers' omkadering was niet voldoende om alle onderzoeksvragen met betrekking tot de diffusie van innovatie te behandelen. In het bijzonder identificeerde dit onderzoek een noodzaak voor bijkomende theoretische omkaderingen voor het behandelen van vragen over de ontwikkeling van systemische innovatie en bedrijvennetwerken. De theoretische omkadering van 'strategisch niche management' gaat beter samen met specifieke succesfactoren in de adoptie van innovatie (bijvoorbeeld het vormen van een visie en leerprocessen, evenals de compositie en formatie van netwerken), doch enkel in een fase van marktintroductie. Dit onderzoek demonstreert de relevantie van het integreren van modellen voor het beschrijven van veranderend milieugedrag. De studies die het perspectief van de vraagzijde onderzochten tonen aan dat evaluatieonderzoek na ingebruikname met behulp van vragenlijsten belangrijke inzichten kan verschaffen in het beredeneren van het verwijderen van adoptie- en communicatiehindernissen. Bijkomend bleken referenties uit de marketingliteratuur, zoals voor het ontwikkelen van bedrijfsmodellen, effectiever voor het ontwikkelen van manieren van samenwerking, in het bijzonder om marktsegmenten, waarden van klanten en innovatie-aanbod te verbinden.

Over het algemeen toont deze studie aan dat de theoretische omkaderingen van systemische innovatie, bouwinnovatie, strategisch niche management, milieugedrag, marketingonderzoek en beleidsonderzoek nuttig kunnen zijn voor het verkennen van hindernissen bij en kansen voor de adoptie van innovatie, naast Rogers' theorie over de diffusie van innovatie. Daarnaast maken deze studies diverse limieten van de toegepaste theorie-omkadering duidelijk. Gelet op het feit dat Rogers' theorie weinig aandacht besteedt aan de sociale componenten, kan het nuttig zijn om andere theorie-omkaderingen te gebruiken bij de ontwikkeling van toekomstig onderzoek. In de toekomst kan het nuttig zijn om de diverse theoriedomeinen met elkaar te verbinden, welke nu nog vaak als afzonderlijke theorieën worden beschouwd. Een geïntegreerde theorie-aanpak ontbreekt echter. Een stevige onderzoeksinspanning is nog nodig om de diverse individuele theoriedomeinen met elkaar te verbinden. Terwijl technologische innovaties en demonstratieprojecten goed gedocumenteerd kunnen zijn, is bijkomende aandacht nodig voor onderzoek betreffende de sociale component van innovatie, van de conceptaanpak en van systemische innovatie. Verder onderzoek is ook nodig naar de verschillen tussen de marktintroductie van een innovatie, de groeimarkt en de volwassen markt. De renovatie van eengezinswoningen naar een hoog niveau van energieprestatie is nog steeds in een fase van marktintroductie. Op dit vlak is verder onderzoek nodig om adoptiestrategieën aan te bevelen.

Het onderzoek dat werd verricht in het kader van deze studie was beperkt, en toekomstige onderzoekers worden nu uitgedaagd om praktische inzichten en het begrip van theorie te verrijken. De focus in dit onderzoek lag op zeer energie-efficiënte huisvesting en gerelateerde innovaties in landen waar het huishoudelijk energiegebruik gedomineerd wordt door ruimteverwarming. De identificatie van innovaties van bedrijven en het bestuderen van de ervaringen van bedrijvennetwerken en eindgebruikers legde de nadruk op eengezinswoningen of woningen van eigenaar-bewoners in België en in Nederland. Het is belangrijk om te benadrukken dat bouwtradities en marktontwikkeling kunnen verschillen tussen landen; de conclusies moeten daarom voor andere regio's en voor andere marktsegmenten voorzichtig worden geïnterpreteerd. Andere conclusies kunnen bijvoorbeeld naar voren komen wanneer men de sector van de private of de sociale huur behandelt, of wanneer groepen van eigenaars in plaats van individuele eigenaar-bewoners onderzocht worden. In diverse studies werden demonstratieprojecten en innovatietrajecten gebruikt als kennisbronnen. De leereffecten kunnen gelimiteerd zijn tot de ervaringen komend uit de gekozen bronnen, welke mogelijk beperkt zijn in termen van ruimte en tijd. Conclusies en aanbevelingen zijn onderhevig aan de beschikbaarheid van informatie gedurende de tijdsspanne van het onderzoek.

Ondanks deze beperkingen konden de conclusies en aanbevelingen worden gerelateerd aan het meer algemeen begrip van conceptinnovatie. Ervaringen werden gebruikt om mogelijk bredere gevolgen te bespreken, in het bijzonder voor het definiëren van algemene strategieën die kunnen bijdragen aan de marktontwikkeling van zeer energie-efficiënte eengezinswoningen. De conclusies resulteerden ook in het definiëren van strategieën voor de adoptie van innovatie in de bouwsectoren (of sub-sectoren) die worden gedomineerd door het MKB. De observaties met betrekking tot kwaliteitsverzekering richten zich in het bijzonder op het meer algemene probleem van gebreken in de planning en uitvoering van gebouwen.

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Curriculum vitae

Erwin Mlecnik was born on May 3rd, 1969 in Genk, Belgium. He completed his secondary education at the Koninkijk Atheneum in Genk. In 1987 he started his studies in Civil Engineering at Vrije Universiteit Brussel. He received his Master's Degree in Civil Engineering – Architecture in 1992. After graduation he worked for four years as a researcher at the Department of Architecture of the Vrije Universiteit Brussel. During this period he contributed to a task force of the multi-player research network Worldviews (established by philosopher Leo Apostel) and paid research visits to the Laboratoire de Mécanique et Génie Civil of the University of Montpellier in France and to the Dipartimento di Ingegneria Chimica dei Processi – dei Materiali of the University of Palermo in Italy. In 1996 he received a Prize for the Environment from H.R.H. Prince Laurent of Belgium. After 1996 he worked on a research contract at the University of Palermo. From 1998 he has worked for four years as an R&D consultant for Cenergie cvba in Berchem, Belgium. From December 2000 he has coordinated the non-profit organisation Energie Duurzaam vzw, formerly known as STEM vzw (Studiecentrum Technologie Energie en Milieu, a spin-off from the University of Antwerp, Belgium). During this time he facilitated the establishment of the non-profit organisation Passiefhuis-Platform vzw, which he coordinated for four years, from 2002 to 2006. From 2006 he became senior expert R&D at Passiefhuis-Platform vzw. In addition to his work at Passiefhuis-Platform vzw, in 2008 he started his PhD research at OTB Research Institute for the Built Environment of TU Delft in the Netherlands. During his research career of more than 20 years he focused on sustainable living and construction and produced numerous publications. In addition to his contributions to knowledge development for universities, institutes and policymakers, innovation development in businesses and enterprise networks, and participation in research networks, he coordinated various Belgian research projects, e.g. 'E-GiDS – Energiezuinige Gebouwen in de DienstenSector' (Vliet-bis), 'Duurzaamheidscriteria voor welzijns- en verzorgingsinstellingen' (VIPA), 'Passiefhuis-Platform' (IWT thematic innovation stimulation) and 'Low Energy Housing Retrofit – LEHR' (Belgian Federal Science Policy). He was a key research partner in various Belgian and international projects, e.g. 'Kantoor 2000' (Vliet-bis), 'PEP – Promotion of European Passive Houses' (Intelligent Energy Europe), 'Task 37: Advanced Housing Renovation with Solar and Conservation' (International Energy Agency: Solar Heating & Cooling) and 'One Stop Shop – From demonstration projects towards volume market: innovations for sustainable renovation' (ERANET-Eracobuild). He is currently also chairman of the scientific committee of the regular 'Passive House' symposia in Brussels and involved in 'Task 40 – Towards Net Zero Energy Solar Buildings' (International Energy Agency: Solar Heating & Cooling, and Energy Conservation in Buildings and Community Systems).

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