Green Energy and Technology

Stefano Piraccini
Kristian Fabbri

Building a Passive House

The Architect's Logbook

Springer

Green Energy and Technology

More information about this series at http://www.springer.com/series/8059

Stefano Piraccini · Kristian Fabbri

Building a Passive House

The Architect's Logbook

Springer

Stefano Piraccini
Cesena
Italy

Kristian Fabbri
Cesena
Italy

ISSN 1865-3529 ISSN 1865-3537 (electronic)
Green Energy and Technology
ISBN 978-3-319-69937-0 ISBN 978-3-319-69938-7 (eBook)
https://doi.org/10.1007/978-3-319-69938-7

Library of Congress Control Number: 2017957204

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Fiorita Passive House
Via Ludovico Ariosto, no. 246–250, Cesena (FC) Italy

Work Commissioned by
Andrea Zoffoli, Davide Zoffoli, Loris Zoffoli, Marco Zoffoli

Design and Project Coordinator
Studio Piraccini/Architettura sostenibile a consumo zero: Arch. Stefano Piraccini (coordinator), Arch. Margherita Potente

Passive House Consultant
Studio Piraccini/Architettura sostenibile a consumo zero: Arch. Margherita Potente

Contractor
Zero Energy s.r.l.

Passive House Certification
ZEPHIR s.r.l.: Dr. Francesco Nesi

Monitoring
Arch. Kristian Fabbri

Awards and Recognitions
The *Fiorita Passive House* project has obtained the following recognitions: Pilot building for the European Projects: Passreg (*Intelligent Energy Europe Programme of the European Union*) and SEEDpass (*South East Europe strategic partnership vocational education and training in Passive House Design for nearly zero energy buildings development*); Sustainability special award, XI edition of the prize *IQU-Innovazione* e *Qualità Urbana* (2016).

Contributing to the Realisation of this Book were
Centro InfissiDue srl, CNA Forlì-Cesena, Mitsubishi Electric Europe B.V, Studio Piraccini/Architettura sostenibile a consumo zero, Zero Energy srl.

To Margherita,
without whom this would have been much
more difficult (or even impossible),
and to my daughter who she is carrying.

Stefano Piraccini

Citation

It is possible this Book may fall into the Hands of some Masters of Ships, and honest Mariners, who frequently, by contrary Winds or Tempest, or other Accidents incident to long Voyages, find themselves reduced to great Dissestress, either thro' Scarcity of Provision, or Want of Stores. I say, it may be a Direction to such as those, what Lengths they may venture to go, without violating the Law of Nations, in Case they should meet other Ships at Sea, or be cast on some inhospitable Shore, which should refuse to trade with them for such Things as are absolutely necessary for the Preservation of their Lives, or the Safety of the Ship and Cargo.

Daniel Defoe (1972) A general story of Pyrates, J.M. Dent & Sons, London, UK

Premise

This book is the first person account of the vicissitudes, as well as the design and technical solutions, involved in the construction of the *Fiorita Passive House*: the first Passive House certified multi-residence in wood in the Mediterranean area.

The style, simple and intuitive, describes the problems—*and the solutions*—which may be encountered in various moments of the construction process of Nearly Zero Energy Buildings (NZEB).

In the literature consulted during the planning stage, we found books that give step-by-step explanations of what architectural details to include and how to design them, what problems may arise in the construction site and how to resolve them, which products are more suitable or more economical, which expedients to adopt during construction to ensure the quality of laying, etc. The problems one could encounter are many and varied, but during the process, the authors of this book came to realise that what is lacking is a book that explains what the actual process is comprised of, … what actually can happen, …. in other words, to make a nautical analogy—which is present throughout the book—while you can find books that explain how to navigate, the characteristics that a boat must have or the characteristics of the various ports of call, it is more difficult to find books that explain how to tackle the journey, and so, this book is the tale of a journey, the journey that has led to the construction of a Passive House, and to the discovery—for all the actors involved, designers, construction company, tradesmen—of new territories, of a new way of dealing with the *architectural project*.

The objective is to reveal to the reader just how exciting this voyage is, and just how marvellous the new territories to explore can be.

In a more prosaic way, the project of the *Fiorita Passive House* has undergone a building process that is different from ordinary buildings: in the final construction design, in the role of the designers and collaborators, and other experts in the field, in the training of the tradesmen, in the organisation of the phases of the construction site and in the construction costs.

***

Designing a Passive House means establishing a new dialogue—*together with travel, "dialogue" is the other key word of the book*—between composition, technology of the architecture and building physics, different from traditional architecture: dialogue is necessary, putting yourself in a position of reciprocal listening in order to adopt the best solutions, even in the smallest construction detail, combining form and energy efficiency. We have gone from the "bioclimatic" approach—where the physical phenomena are represented with "*little arrows*", the sun that is sad or smiling or other schemes—to modelling with a calculation algorithm able to furnish us with the actual energy performance.

For this reason, this book is the work of two authors—the previously mentioned *dialogue*—from one side, the story of the project coordinator, which constitutes the narrative corpus of the book, the voyage from the inside, and on the other side, *or, more aptly, from alongside*, the support, the clarification of the "*instrumentation*", the thermophysical magnitudes and energy aspects that come into play in the design of a Passive House, as well as the monitoring—*as built*—of the comfort and of the actual thermophysical performance.

Stefano Piraccini and Kristian Fabbri, June 2017.

***

We would like to make some clarifications:

- The Passive House standard relates exclusively to energy efficiency and comfort. The Fiorita Passive House project introduces, with respect to the standard, further verifications that concern the summer season such as the shading and the calculation of the thermal lag. In addition, to aim for sustainability understood in the broadest sense, we have used dry technology, a wooden structure, insulation with mineral or biological origin, recovery of the rainwater and condensation.
- the *Fiorita Passive House* was designed and built using the PHPP Software, version 7 of 2014 (date in which the design began), which indicated a heating load equal to 7 W/m^2 and a cooling load equal to 6 W/m^2. Given this kind of performance, within the building we used for heating and air-conditioning system exclusively a controlled mechanical ventilation system with heat exchanger and post-treatment battery. For the *Passive House Certification*, which took place on 13 January 2017, the PHPP Software, version 9.6A of 2016, was used, which updates the calculation method, especially in the summer season, and indicates a heating load equal to 8 W/m^2 and a cooling load equal to 10 W/m^2.
- once the construction was completed, during the 8 months that passed between the end of the construction and the arrival of the occupants, the monitoring in the site (described in Chap. 10) shows that the building is able to guarantee a temperature of 25°C in the summer and 21°C in the winter, with minimum consumption, and relative humidity around 50%, with absence of the "dry air" phenomenon.

***

For academic purposes, Stefano Piraccini is the sole author of Chaps. 1, 2, 3, 4, 5, 7, 8, 9 and 11; Kristian Fabbri is the author of Chaps. 6 and 10.

Acknowledgements

The writing of this book cannot leave out our thanks to those who have been involved in the building's design, in the first place to Arch. Margherita Potente, Passive House Designer/consultant, for consulting and processing of the thermo-physical data. Without her help, both the realisation of this book and, especially, of the Fiorita Passive House would have been impossible.

Also, many thanks go to: The Zoffoli family (Andrea Zoffoli, Davide Zoffoli, Loris Zoffoli and Marco Zoffoli), who commissioned the work, for having always enthusiastically supported every design choice aimed at environmental sustainability; Dr. Phys. Francesco Nesi for having given us the possibility of a serene dialogue; Eng. Marco Boscolo (who prematurely died during the writing of this book) for the valuable information and suggestions on the subject of airtightness; Eng. Andrea Fagioli, Silvano Mazzoli and Geom. Abraham Ceredi for their technical competence, the passion for their work and respect for all the architectural choices of the designer; Andrea Salimbeni for technical information relating to door and window frames; Stefano Aloisi for technical information relating to the climate control system; Gabriele DiBonaventura for having coordinated several initiatives for the promotion of the project.

Stefano Piraccini and Kristian Fabbri, June 2017.

Personally, I would like to thank Kristian Fabbri for having convinced me to write this book, the tradesmen for their preparation, availability and assiduous collaboration: it is not a common thing to enter into a construction site and perceive the enthusiasm of the many who work there, aware of being an integral part in the realisation of a truly innovative project. To tell the truth, the highest levels of enthusiasm were clocked at 3 in the afternoon, when, from the building opposite the construction site, the owner's live-in nurse, an attractive Moldovan, just over thirty years old, started watering the rose garden. For 20 minutes, the noise of the construction site abated and all the workers, with a forearm resting on the parapet of the scaffolding, enjoyed the spectacle, smoking a cigarette. The ritual was repeated, like clockwork, every day, with even greater peaks of enthusiasm during the summer season: when the comely young woman adapted to the climatic context, with clothes that were rather skimpy.

Stefano Piraccini

Personally, … hey, why didn't you warn me? I would like to thank those who collaborated in the realisation of the monitoring system, Antea Franceschin and Christian Iasio, and I would like to thank Margherita and Stefano for letting me climb aboard.

Kristian Fabbri

The research that led to the writing of this book was financed with contributions from the following companies that participated in the construction of the Fiorita Passive House. Special thanks to:

- *Centro InfissiDue srl*, Via Cavecchia no. 1351, 47521 Cesena (FC), Italy;
- *CNA (Confederazione Nazionale dell'Artigianato e della Piccola e Media impresa) Forlì-Cesena*, Via Pelacano no. 29, 47122 Forlì (FC), Italy;
- *Mitsubishi Electric Europe B.V*, Centro Dir. Colleoni, Palazzo Sirio, Ingresso 1 —Viale Colleoni no. 7, 20864 Agrate Brianza (MB), Italy;
- *Studio Piraccini/Architettura a consumo zero,* Via Luigi Carlo Farini no. 90, 47522 Cesena (FC), Italy;
- *Zero Energy srl*, Via Raffaele Cadorna no. 25, 47522 Cesena (FC), Italy.

Contents

Nomenclature

ACPH	Certified Passive House Tradesperson
BEP	Building Energy Performance
BEPS	Building Energy Performance Simulations
BP	Building Physics
CLT	Cross-Laminated Timber
CMV	Controlled Mechanical Ventilation
CO_2	Carbon Dioxide (ppm)
DHW	Domestic Hot Water
EIFS	Exterior Insulation and Finishing System
EPDM	Ethylene-Propylene Diene Monomer
EPS	Expanded PolyStyrene
FSC	Forest Stewardship Council
HVAC	Heating Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
IPHA	International Passive House Association
MVHR	Mechanical Ventilation Heat Recovery
PD	Percent Dissatisfied (%)
PHPP	Passive House Planning Package
ppm	Parts per Million
RH	Relative Humidity
U	Thermal Transmittance (W/m^2K)
VOC	Volatile Organic Compounds (ppm)
WHO	World Health Organization
XPS	Extruded PolyStyrene
YIE	Periodic Thermal Transmittance (W/m^2K)

Chapter 1
An Uphill Trek

In June, every evening after 7:30 when it is cooler, I leave work, put on some comfortable clothes and take a walk. My favourite destination is the hillside that surrounds Cesena, the city in which I live, situated in north-central Italy. In that season, just before twilight: the sun's low rays, the scent of the countryside, the pleasant temperature, all combine to create a relaxing atmosphere, perfect for restoring myself after a day's work. Everything began on one of those evenings in June 2014: I'm walking along Via Garampa, a road that starts from the centre of the city and makes its way through the nearby hills, when I receive a call from Davide, an old friend of mine.

Davide told me about a property belonging to his family, built by his grandfather in the mid-1950s, composed of two shops and two large apartments, which has been on the rental market for several years. My friend was complaining about the low earnings through rent, barely enough to cover the maintenance costs of the entire building:

> I spend too much money in repairs, energy expenses have become unsustainable … the tenants complain because despite having the radiators running at maximum capacity they feel cold in some rooms and too hot in others, … and it's the same in the summer, despite having installed split system air conditioners,

and then he asked me:

> you're an architect, what type of intervention would you suggest?.

In the meantime, having finished the uphill climb of Via Garampa, my voice broken and rather breathless from that effort, I answer:

> "Davide," (deep breath) "you've got to make a Passive House! There's no other solution!".

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_1

1.1 The House of the Twentieth Century (1950s)

Let's take a step back.

The building that Davide is describing to me is located in a residential district of the city of Cesena, in an urbanised area dating from the years 1950–1970. It is a multi-storey brick building. The building has been subject to constant upkeep throughout the years with many small, specific interventions: a new coat of plaster here, a door frame replaced there, a gutter repaired above, an infiltration fixed below, wall painting to cover blackish stains that appeared on the inner side of the perimeter walls, the installation of air conditioners for cooling during the summer, the installation of a few frames with double glazing and a new boiler in the desperate attempt to reduce fuel consumption.

Despite these minor interventions, problems have continued to crop up in the building, such as the formation of moulds, water infiltration and, above all, astronomical bills for climate control.

However, Davide's building is neither better nor worse than other buildings built in those same years.

The 1950s and 1960s are characterised by a period of vigorous economic recovery and technological development. The boom would primarily involve the countries that participated in the conflict, such as the USA, Europe and Japan. The 1950s and 1960s are, for Italy, the period of the economic boom. It is in this decade that Italy makes the move from being a predominantly agricultural country to becoming an industrialised nation. They are years characterised by robust renewal followed by the increase of international trade, by the exchange of technology and the need to rebuild a modern country from the ashes of the war. The favourable moment carries with it an exponential growth in the construction industry, increasing the demand for accommodation in the city by the new masses of workers, merchants, labourers, new entrepreneurs, etc., accompanied by the progressive abandonment of the countryside, where farming represents a legacy of the past, far from the new lifestyle which demands a prevailing modernity.

Armando, Davide's grandfather, together with his family, had abandoned agricultural activity and the rural house in which he lived since his childhood for a move to the city in the search for better living conditions. Here, he used his savings in the construction of a new building for his family to settle in (the building that is the subject of this book), composed of two large apartments on the first and second floors and two shops on the ground floor. Armando and his wife sought to build a modern and functional building equipped with the best technologies of the era, such as heating, hot sanitary water and the bathroom in the house: a new frontier of progress now within the reach of many pockets.

Armando (finally) could forget about worrying himself with the supply of wood, and in spite of it, still waking up to the cold. He could now take as many hot baths as he wanted to, at long last getting rid, once and for all, of that annoying smell of soot that impregnates the clothes of the country dweller, differentiating him from the pleasant scent of the man of the city.

The building constructed in Via Ariosto 250 in Cesena has a structure in load-bearing masonry, a building envelope in brick, completely devoid of thermal insulation, wooden window frames with single glass panes, cornices and some terraces in reinforced concrete and, above all, a brand new boiler that pumps hot water in the showers and within the radiators. This is a building similar to many buildings built in that period throughout Italy, and it is not even very different from those built in other contexts. The economic boom, due also to the financing of the Marshall Plan and the policies for achieving, in a short time, a home for everyone, led to the diffusion of large residential districts composed of buildings made with standardised construction techniques that employed the materials of industrial production: these "new" buildings rely on the heating system for the fulfilment of any requirements related to comfort.

Before this new age, most rural dwellings were heated with wood-burning fireplaces, in other words, they guaranteed levels of comfort limited only to the hearth, through a progressive functional optimisation of their form and the use of local materials. Therefore, they had adapted to the climatic context by means of expedients for containing the heat internally and exploiting the heat produced by solar radiation and by the body heat of the persons and animals living within the walls. From the moment in which it became possible to install a heating system in each new home, relationships between construction and the climatic context were considered as nothing more than a tribal legacy.

In this regard Victor Olgyay, the father of bioclimatic design, has said (Fig. 1.1):

Fig. 1.1 Building owned by the Zoffoli family, subject of the intervention

> Despite the diversity of these contrasting community layouts, they have something in common: all of them have marked regional characteristics, strong statements that are a clear answer to their respective climatic demands. (Olgyay 1963, p. 9)

1.2 The House of the Nineteenth Century

Like many "modern" buildings built in the same period, the house in Via Ariosto has no relation to the climatic context in which it is located: its morphology is not a function of a correct orientation, it does not have systems to favour natural ventilation, the thin walls dissipate heat during the winter months and do not help to counteract overheating in the summer, there is no shielding for protection from the direct solar rays during the summer, nor to take advantage of their heat during the winter.

The lack of a relationship between the building and the climatic context has been replaced by the presence of a gas-fired boiler for heating and hot sanitary water. In this way, comfort levels were satisfied that for the time appeared to be high.

In some respects, the house that Armando built in Via Ariosto is the opposite of the rural house where he grew up, which he had abandoned in the move to the city. We are considering the rural house as a traditional typology developed through a slow, but progressive, adaptation to the climatic context. It was built by optimising the utilisation of the heat produced by the available energy resources (sun, people, animals, firewood) and keeping as much heat as possible within the walls. According to Jean Dollfus, author who has catalogued traditional houses in every corner of the world, the shapes of the dwellings are mainly defined by the environmental context in which they are located, and by elements which relate to taste and culture. Dollfus in this regard writes:

> the proportion of solid surfaces to openings in the exterior fa̧cades depends as much on popular psychology as on the climate and the material used. In the zones of extreme temperature, for inverse reasons to safeguard against the sun or the cold, the walls are pierced only in a small proportion of their surface. And in general, rural interiors are much more stingy of air and light than those of the towns. … In northwest Europe the shade of urban streets sets the demand for more illumination, and it is in those gabled houses that windows attain their greatest development. (Dollfus 1954, cited in Olgyay 1963, p. 7)

The rural house where Armando grew up is classified (since it still exists) as a "*Cesena-Rimini*" vernacular house, inhabited by an extended family of three generations, typical of the agricultural settlements of the plains and hills of the geographical region of Romagna, in north-central Italy, with the Adriatic Sea to the east and the Apennine mountains to the south-west. Armando's rural house is a masonry building, distributed on two floors, with a pitched roof and a large portico.

Luigi Gambi, in *La casa rurale in Romagna* (Gambi 1950), introduces the classification of the traditional types of this region and describes their development in the scattered settlements, starting from the isolated houses in the rural plain following the Roman centuriations (185–180 B.C.). The information, described by Gambi, is the result of extensive documentation obtained thanks to archaeological excavations. The centuriation is still visible today, since a large part of the territory is defined by a network of traces and orthogonal roads that comprise squares measuring 715 m per side. In the sources cited by Gambi, significant data emerges: the census of Anglic of 1371 testifies the presence in the plains of isolated houses built in masonry, while the characteristic of the portico has been documented since 1481, in a notarial deed of the nearby city of Rimini. To have some documentation of layouts or elevations, we must wait until the middle of the eighth century, where more precise evidence can be found in the land registers of the period of the Enlightenment. Lastly, to have an in-depth understanding of how the rural house has evolved; it is possible to study some ecclesiastical or nobiliary inventories of the second half of the fourth century, where there are perspective drawings and watercolours that give an accurate description of the construction materials.

The "*Cesena-Rimini*" vernacular house appears to be the result of a very lengthy process of technical and formal refining, with the purpose of optimising:

1. the use of local materials for its construction, for example, clay, lime, sand and wood;
2. the distribution of the spaces in relation to the agricultural culture and lifestyle of the time;
3. the adaptation to the regional climatic context in order to generate the best comfort level possible in all seasons.

The "*Cesena-Rimini*" vernacular house is oriented with the main elevation to the south to better take advantage of the sun as a source of heat. The walls, with a thickness greater than 50 cm, allow the staggering of the heat from solar radiation over time, so as to "release it" during the night hours. In the same way, the heat generated during the day, thanks to the fireplace or the hearth, is maintained within the building for the entire day. On the north face, which always remains cold because it is not heated by the sun, there are small openings (windows) that are rarely opened, so as to limit the dispersion of heat.

The ground floor is intended for housing animals: in this way, the heat produced by their bodies rises upwards, contributing to greater comfort in the rooms on the first floor that are used as living space. The large portico has the function of regulating solar radiation by creating a cool and shady place to work and restore one's strength.

The "*Cesena-Rimini*" vernacular house, in the same way as many examples of vernacular architecture, such as the *trulli* in Puglia, the *masi* of the Alps or the *Baraccas* of western Sardinia, are an intelligent example of bioclimatic architecture that combines compatibility with the environment, low management costs, comfort (in relation to the cultural context of the time) and sustainable use of energy and environmental resources (Fig. 1.2).

Fig. 1.2 *Cesena-Rimini* vernacular house

1.3 The Chickens Come Home to Roost

Victor Olgyay, in 1963, warned us with these words:

> The spread of populations and modern communications have accelerated the age-old interchange of ideas and technological effects. We must realize, however, that the wide dissemination of Western forms should proceed with caution. These forms evolved from the challenge of cool climates, and can pose grave problems when adopted as undigested and inappropriate symbols of cultural progress. (Olgyay 1963, p. 21)

So, was Davide's grandfather Armando wrong in abandoning his rural house: a building so skilfully built?

Absolutely not! Who would prefer living in a building where it is necessary to heat pots of water on the hearth every time one takes a bath, or waking up one morning in winter with the contents of the chamber pot literally frozen, if on the other hand, we have heating and water and showers that are always hot?

In fact, come to think of it, given that the mid-1950s was an historic moment where technology was able to provide most of the houses with a system for heating and the production of sanitary hot water, it would have seemed useless to worry about issues relating to energy savings, environmental impact or the search for even greater comfort.

For starters, it took another war, more precisely the Arab-Israeli war during Yom Kippur that led to the oil crisis of 1973 and the decision of the Arab members of OPEC (Organization of the Petroleum Exporting Countries), to interrupt the supply of oil to countries that supported Israel, such as the USA and all of its allies. The effects of the embargo had a devastating impact in all countries that were dependent on oil, primarily Europe and Japan, where emergency measures were launched that had strong repercussions on the economic and cultural levels. In Italy, for example, with the increase in the prices of oil products, the government introduced substantial austerity policies that brought about restrictions on the use of heating and electricity. Public lighting was halved, including Christmas decorations, while the shops had to shorten their opening hours. There was to be an early closing of cinemas, bars and nightclubs, and even the national television network was forced to end its programming schedule before the usual time.

Starting on 2 December 1973, a total blockade of private traffic during Sundays and holidays was imposed throughout Italy. It had been estimated, in fact, that only one day of suspension of the use of private cars entails a saving of 50 million litres of petrol.

Today we know that we have to pollute less, we know that we need to reduce the consumption of non-renewable energy sources, we also know that we must review our development model so as to preserve the environmental resources for future generations.

The energy requirements of our buildings, whether residential or commercial, for air conditioning in the summer and heating in the winter as well as for the production of sanitary hot water, account for approximately 40% of the energy produced in the entire European Union (Directive 2002/91/EC and Directive 2010/31/EU). The same is true for the building of Via Ariosto that today appears to us as energy intensive and obsolete.

Moreover, in 2016, alongside the problem of fuel consumption in Italy for heating is the progressive request for summer cooling in buildings, so as to obtain greater comfort. Following the summer of 2003, when high temperatures and excessive humidity caused numerous deaths, especially among older people, there has been an upsurge in the sales of split-systems for cooling.

Furthermore, the majority of buildings use non-renewable energy sources whose emissions increase the emission of greenhouse gases, carbon dioxide and particulate matter.

Apparently, a change of course is necessary, and this is what Directive 2010/31/EU calls for, wherein an ambitious objective is set: from 2020 new buildings should be Nearly Zero Energy Buildings (NZEB). What Europe asks of us (and, to some extent, of our conscience) must happen “tomorrow”; the year 2020 is upon us, but then: *from where we can begin to build a near zero energy consumption building?*

1.4 The House of the Nineteenth Century

In order to answer the question of the previous paragraph, in this chapter, we provide a brief overview of the buildings of the last century. We have seen how the "*Cesena-Rimini*" vernacular rural house of Davide's grandfather Armando has been refined over time by adapting its shape and use to the best local materials in relation to the climatic context, so as to obtain the maximum level of comfort possible at the time, a level which has progressively increased, making the dwelling obsolete.

We have seen how Armando, in the post-war period, in a particularly favourable moment of economic and technological growth, chose a house with a new heating system, which would have resolved any problem related to comfort. His new house in the city, built in Via Ariosto, equipped with a heating system, turns the factors of orientation, solar radiation, the characteristics of walls and windows into irrelevant ones.

The house in Via Ariosto, today owned by Davide and his brothers, despite being well-equipped with the systems of the time, is a perfect example of a building with low energy efficiency: it has relatively thin walls, there is no thermal insulation, its cornices, terraces and niches create thermal bridges, there are draughts everywhere, the heat of the sun is not taken advantage of in the winter and neither is the shade in the summer and so forth. In addition, the windows are placed on the faces of the building without taking into consideration exposition to solar radiation. Moreover, in 1989 a loggia placed on the south side of the building was closed with the intention of turning the space into a new bedroom. The closure was carried out using a system of sliding doors where the absence of an effective obscuration system caused serious problems of overheating in the summer. Added to this is the fact that the window frames, substituted in the last decade, with poor energy performance, have increased the dispersions of the building envelope and consequently the energetic costs for air conditioning.

In summary: the heat produced by the heating system escapes from the building as if the building were a sieve, the same is true for the cooling system. Unlike the buildings constructed in the post-war period, the normative evolution that began in the 1970s, continuing in the twenty-first century, has introduced on the market buildings with a greater attention to energy consumption.

So the building of Via Ariosto became obsolete even compared to buildings built at the end of the twentieth century that at least have a layer of thermal insulation and more efficient heating systems. Attention to energy efficiency demonstrates a clear change of tendency in the construction market.

Directive 2002/91/EC, transposed in Italy in 2005, introduced a requirement in the event of new construction, sale or rental of buildings: the drawing up of the Energy Performance Certificate (EPC). In this way, the real estate sector has a tool for evaluating the energy costs of a building.

Davide's tenants have often complained, saying:

> It's not worth paying low rent for an old building, because then I am going to have to pay high bills for heating and air conditioning: I'd be paying higher rent in a new building, but the energy costs would be lower and my comfort would be much greater.

And that is why I told Davide that:

> there is only one solution: you have to intervene on the property to make it more energy efficient and improve the comfort level, so as to obtain a greater appeal on the market.

At this point, given the only direction possible: "*Why not reach the maximum possible objective: a building with near zero energy consumption*?"

In order to obtain the objective, it is necessary to focus on six elements:

1. relying on a serious and sufficiently tested design protocol, capable of guaranteeing the result in energetic terms and able to meet the needs of the project owner;
2. recovery of the bioclimatic attention of the "*Cesena-Rimini*" vernacular house with its exploitation of passive energy resources (remember how it made use of the heat of the animals and the sun?);
3. using everything that technological innovation has produced in terms of building materials to produce an efficient building envelope;
4. relying on technical physics during the design phase to obtain control of the actual energetic behaviour of the building;
5. protecting the thermal bridges and reducing draughts to avoid energy losses;
6. using as few systems as possible and among them, only the most efficient ones.

This is what (**That's all folks!**), more or less, went through my head in that uphill trek along Via Garampa when, with a broken and breathless voice I said (Fig. 1.3):

> Dear David, you've got to make a Passive House! There's no other solution!.

Fig. 1.3 Old and new building in comparison

References

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

Directive 2010/31/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

Gambi L (1950) La casa rurale in Romagna. Centro di Studio per la Geografia Etnologica, Olschki Editore, Firenze, Italy

Jean D (1954) Les aspects de l'architecture populaire dans le mond. Albert Morancè, Parigi, France

Olgyay V (1963) Design with climate: bioclimatic approach to architectural regionalism. Princeton University, Princeton, USA

Chapter 2
Is the Passive House Right for Us? (Follow the Money)

Davide seemed excited by my proposal, so we agreed to meet the following week to discuss it. Once back at the desk in my studio, I organised my thoughts about my skills:

- I have already constructed buildings with good energy efficiency;
- I have adopted construction solutions for protecting the thermal bridges;
- I have used the design solutions of bioclimatic architecture;
- I have studied the general criteria of passive buildings in the preparation of my lessons at the University (where I teach Architectural Final Construction Design for energy efficiency);
- I have read quite a few books on the topic, finding mostly theoretical concepts and practical applications that are partial and not all-encompassing.

Even if I did not feel as if the task was totally beyond my capacity, I've never actually built a Passive House, though it's always been my wish to do so. An excellent opportunity fell into my lap, but I was lacking what anthropologists call "*field experience*".

The anthropologist Bronislaw Malinowski writes about field experience:

> It would be easy to quote works of high repute, and with a scientific hall-mark on them, in which wholesale generalisations are laid down before us, and we are not informed at all by what actual experiences the writers have reached their conclusion. No special chapter or paragraph is devoted to describing to us the conditions under which observations were made and information collected. I consider that only such ethnographic sources are of unquestionable scientific value, in which we can clearly draw the line between, on the one hand, the results of direct observation and of native statements and interpretations, and on the other, the inferences of the author, based on his common sense and psychological insight. (Malinowski 1922, p. 11)

There were many things that I still did not know and many questions still ran through my mind without finding an answer. I took a deep breath and thought "this will be my field experience". I know I can do it: all I need to do is avoid the traps hidden in the thick of the jungle and dodge any poisoned arrows.

I stopped daydreaming and began to concentrate on the main objective of every architect: satisfying the client.

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_2

How much time is saved and therefore how much money, if a building is built in brick? *Is there any way of knowing*? One can only make rough estimates. Should the work be done with a truck-mounted crane or with a tower crane? Should all the curing times be calculated? How long does it take for the client to make his or her choices, because the mason has to fit the wiring and tubes in the wall while that isn't necessary with wood? And if it rains? And even more difficult: how much have you saved in terms of bank interest through reducing the time by one month and how much more have you spent building a wooden slab rather than a concrete and masonry flooring system? How much more is spent building a Passive House compared to a building with energy performance standards regulated by law? One would have to make an economic analysis of the specifications, minus all the costs of the extra thickness of insulating, obtain estimates from several companies in order to arrive at the correct price, divide some all-encompassing items to subtract the elements relevant to the protection of the thermal bridges, etc.

Transforming the specifications in a detailed economic analysis of the intervention is equivalent to writing an encyclopedia: the focus of this book is the Passive House, the technology, the construction site and so forth.

This is a "logbook" of the professional activity, the approach is operational and aimed at optimising the times and choices for the construction of a Passive House. In regards to the economic aspects, I reasoned that the construction times of technologies in wood are usually lower than those in concrete and masonry, so I enquired with the undertakings which gave me estimates and construction schedules, confirming my hypothesis.

In this chapter, I discuss all the preliminary evaluations that I have made before beginning the planning for the construction of a Passive House capable of achieving Davide's objective: increasing the number of real estate units, framing the building intervention in renovation in order to obtain tax incentives, finding the right technology to build a passive building that would keep the thickness of the walls to a minimum in order to gain useable and commercial surface area.

Davide's objective was primarily increasing the income received from the old building in Via Ariosto. In the current state, the building is composed of two apartments and two shops, all of them on the rental market.

The new project must therefore meet such a requirement by creating apartments with nearly zero energy consumption and high standards in terms of comfort, all of it ensuring the economic sustainability of intervention so that, figures in hand, would make it worth the effort. *But what is the relationship between zero energy consumption and the increase in income from rent?* The tenants of the old building in Via Ariosto complained about energy costs that were simply too high. Davide was forced to reduce the rent to avoid a mass migration of his tenants towards newer and more energy-efficient apartments. Apartments with near zero energy consumption and high comfort levels would have justified higher rents for Davide and meant high appeal on the market, given that, at least as far as Italy is concerned, it would be the first building of its kind.

To increase the income, the new project must be based on the following strategies:

1. increasing the number of real estate units compared to the existing property: with more apartments, there is an increase in the income from rents;
2. obtaining the tax incentive provided by Italian law for the interventions of building renovation and retrofitting;
3. individuating a construction technology capable of reducing the thickness of the external walls, so as to increase the usable area;
4. reducing construction time, thus limiting the interest on loans requested from banks and accelerating the generation of income from the property;
5. building a Passive House standard building so as to place on the market buildings with near zero energy costs and high levels of indoor comfort;
6. seeking to combine sustainable economics and environmental sustainability.

2.1 Increasing the Number of Real Estate Units

The building in Via Ariosto has to be demolished to allow for the reconstruction of a new building composed of 8 apartments, the maximum permitted by the regulations of the Municipality of Cesena (FC—Italy).

The new building should produce greater income, and the increase of the real estate units plays in our favour: at the same location and with the same construction quality, the sum of the rents of two small apartments measuring 50 m^2 is greater than the rent of one apartment with an area of 100 m^2. To determine the most convenient size for new apartments and to make an estimate of adequate rents, we have availed of consultants in the real estate market, data banks made available by the Revenue Agency and real estate agents located in the territory. This method allowed us to verify the rental cost of newly built apartments of the same type that are located in the vicinity.

The rental market was showing a robust demand for real estate of small/medium dimensions (studio apartments, two-room and three-room apartments) compatible with the maximum number of eight apartments that local laws allowed us to build.

The preliminary project thus provides apartments that are different from one other, with medium/small dimensions that respond to market demands. The types, studio apartments and two-room and three-room apartments, on the one hand, guarantee diversification of the commercial offer, and on the other hand, they aim at social sustainability by ensuring access to many categories: singles, students, couples without children, families with children and so forth.

In order to evaluate whether this would be the right strategy, we need to make a rough economic evaluation, comparing the assumed rents of the new project with those received from the old building.

The overall income received by the monthly rents of the old building amounted to € 2560, divided as shown in Table 2.1.

The rents were rather low, the reason being that the property had not aged well and, especially, it was due to the high energy costs that on many occasions the tenants were deprived of the money needed to pay the rent.

Table 2.1 Monthly rents prior to the intervention

Description	Surface area (m2)	Rental income (€)
Apartment 1 (four rooms, one bathroom)	100	600
Apartment 2 (four rooms, one bathroom)	112	700
Shop 1	110	760
Shop 2	110	500

Table 2.2 Monthly rents after the intervention

Description	Surface area (m^2)	Rental income (€)
Apartment 1 (onr room, one bathroom)	33.60	520
Apartment 2 (one room, one bathroom)	35.10	520
Apartment 3 (one room, one bathroom)	33.10	530
Apartment 4 (three rooms, one bathroom)	68.70	730
Apartment 5 (one room, one bathroom)	35.00	500
Apartment 6 (three rooms, two bathrooms)	66.80	770
Apartment 7 (three rooms, two bathrooms)	77.60	740
Apartment 8 (two rooms, one bathroom)	53.60	680

The expected income from monthly rents of the new building, considering eight apartments designed through a preliminary project, can amount to € 4990, divided as shown in Table 2.2.

The new building can put in the pockets of the Zoffoli family (Davide and his brothers) an additional € 2430 each month. The new building, just with the increase of the real estate units, brings about an increase of about 95% compared to the income received from the old building.

2.2 Tax Incentives

To reduce construction costs, we decided to take advantage of the tax incentives for the renovation of buildings and energy retrofitting. Starting in 2007 with Law 296/2006 and DM 19/02/2007, Italy has introduced the deduction of 55% (since 2015, it has been increased to 65%) of the amounts for expenditure on "Energy Retrofitting" which are added to the incentives introduced for the first time in 2006 for the "Building Retrofitting" interventions (deduction of 50% of the expenses per real estate unit).

The law has been amended several times over the years and probably will be once again at the time of this book's publication. It is a law with broad margins of interpretation and its application is susceptible to many variables. In this paragraph, we illustrate its application limited to the case in question.

Currently, tax incentives are translated into a deduction, distributed over the course of 10 years, from the taxes on the IRPEF (tax on the income of individuals) or IRES (tax on the income of companies) tax base of a quota of the building cost, i.e. the cost necessary for the construction work and design.

Incentives for "Building Retrofitting" involve a deduction amounting to 50% of the cost of construction up to a maximum of € 96,000 of the amount of the works, deduction which can reach 65% in case the intervention concerning the primary residence provides for a structural improvement. The ceiling can be incremented by multiplying it by the number of real estate units present at the time of the construction intervention.

Additionally, the law allows an extra bonus in the deduction of a maximum of € 10,000 for furnishing, a bonus that once again can be multiplied by the number of real estate units.

It is possible to access the incentive when the building work is defined as building retrofitting or extraordinary maintenance.

The incentives for "Energy Retrofitting", when the entire building is involved, are able to bring about a deduction amounting to 65% of the construction cost with a ceiling of € 153,846. It is possible to obtain the incentive when the construction intervention ensures a reduction of the energy performance index lower than the minimum limit of law (*about 20% lower*). Those able to take advantage of the tax incentives are the owners of the property, the cohabiting family members, tenants including commodatary ones. In this case, the beneficiaries of the tax deductions are Davide, his two brothers and their father. At the time of the building intervention, Davide was resident in the building in Via Ariosto therefore, being his main residence, he was entitled to a quota of the incentives for retrofitting amounting to 65%, while for his father and two brothers, residents in other buildings, the quota was reduced to 50%.

Using this information, it is possible to calculate the total value of the incentives on the tax deduction that one is entitled to receive with the construction of the new building (Table 2.3).

In total, the intervention is able to benefit from a quota of tax deductions amounting to € 306,440, corresponding to € 537,846 of the construction costs,

Table 2.3 Tax deductions on the "Building Retrofitting" calculated on the four real estate units

Deduction	Description		Deduction amount (€)
Building Retrofitting	Main home (no. 1)	€ 96,000 × 65% × 1	=€ 62,400
	Real estate units for rent (no. 3)	€ 96,000 × 50% × 3	=€ 144,000
	Furnishing bonus for all real estate units (no. 4)	€ 10,000 × 4	=€ 40,000
Energy Retrofitting	Entire building	€ 153,836 × 65%	=€ 100,000 (maximum amount)

more than half of what has been estimated for the intervention. The tax deduction, divided into ten years, amounts to an annual allowance of € 30,644 to split in relation to payments made by the various beneficiaries of the Zoffoli family.

The Zoffoli family (Davide, his brothers and their father), every year, for 10 years, would have obtained a refund from the State amounting to about € 7661 each.

To ensure the economic sustainability of the intervention, tax incentives play an important role, therefore in order to qualify for them, it is necessary to frame the intervention in terms of retrofitting, even if the only way to obtain the desired number of real estate units is to completely demolish the old building and build a new one from scratch.

We are accustomed to thinking that the retrofitting measures relate to a set of works that maintain the original structure of the building and not its complete demolition. Demolishing a building and rebuilding it are an operation that comes closer to the definition of new construction.

For this purpose, recent updates of urban planning regulations come to our aid. They introduce demolition into the definition of building retrofitting as long as there is faithful reconstruction with an equal volume of the building that was demolished.

In order to fall within this definition, the project must maintain the same volume of the demolished building without the possibility of any volumetric increase: *this is a difficult condition to meet when one intends upon doubling the number of real estate units.* To reach the goal, the maximum optimisation of the usable surface area is required, to the detriment of the thickness of the external walls.

2.3 Individuating the Construction Technology

In parallel with the economic evaluations of this phase, I had to individuate the most effective technological solutions for the construction of this building. The goal was to build, in a reasonably short time, an energy-efficient building; therefore, the characteristics of the walls, of the insulation and the construction technology itself, had to closely follow the economic evaluations, also because these choices are, in fact, economic choices in the construction and management phases.

To ensure an energy-efficient envelope, it is necessary to use copious layers of thermal insulation, which normally increases the thickness of the external walls. Satisfying this requirement, which takes on greater significance in the construction of a Passive House, is not at all easy when you have little usable surface area at your disposal.

In our case, the reduction in the useable surface area could compromise the number or the size of the apartments, with the consequent decrease of the income from rents.

Therefore, it is necessary to use construction technologies that, at equal thickness, ensure excellent energy efficiency in terms of *transmittance,* the ability to reduce heat transfer through the wall and *thermal lag*, the ability to delay the heat wave that flows from the outside towards the inside of the wall (see Chap. 6).

In a climatic context such as that of the Mediterranean, determined by cold winters and warm summers, both conditions are important: transmittance in winter conditions and thermal lag in summer conditions. Basing myself on the examination of some case studies recorded in the Passive House database (http://www.passivhausprojekte.de/) and on research in the literature of the sector, I deemed it appropriate to orient myself towards construction technologies capable of guaranteeing a thickness of the external walls of approximately 40 cm with transmittance values of U $\pm$ 0.13 W/m^{2}K and a thermal lag of $\varphi \pm 16$ h.

The dry layered systems can achieve high performance in terms of transmittance, due to a large number of gaps where insulating panels can be placed, but normally it does not excel in terms of thermal lag, since it is constituted of "*light*" materials that have a reduced mass.

Construction technologies in concrete and masonry are defined as "*heavy*" in relation to the substantial thickness and high mass that is characteristic of the materials employed (bricks, hollow blocks, reinforced concrete, etc.). These systems are deficient in terms of transmittance, a problem that is solved with the subsequent application of ample layers of insulation, which considerably increases the overall thickness of the walls.

The construction system in concrete and masonry is widely used in Italy: known by the local craftsmen, it is normally the most economical construction system, given the strong competition among construction companies. However, to ensure suitable thermal transmittance for a Passive House built in concrete and masonry, the perimeter walls would have to be approximately 50 cm thick.

In this case, the use of such a system would have resulted in greater thickness of the external walls, and therefore a sharp decrease in the usable surface area, parameter used for the calculation of the rents. Furthermore, the project must maintain the same volume of the old building: an envelope of elevated thickness reduces the habitable volume and can affect the number of real estate units planned for the new building.

Reinforced concrete is an excellent thermal conductor (thermal conductivity λ = 2.3 W/mK), and steel is even more effective (λ = 60 W/mK), therefore, the use of both materials requires particular care and attention in the design of thermal bridges through the use of considerable layers of insulation. The protection of a thermal bridge generated by a structure in reinforced concrete, especially in correspondence to the projecting elements (cornices, balconies, etc.), may entail high costs in the use of high-performance insulation and surface coatings so that the insulating material is hidden from view, and in some cases also in the use of structural joints with thermal break that can significantly increase costs.

Unlike the previous materials, wood has low thermal conductivity if one considers that fir, the main wooden species used in construction, *and therefore, the least expensive* amounts on average to 0.126 W/mK.

In reference to wood, the book "Il progetto dell'involucro in legno" states that:

> (…) it is the most widely used wood in the construction sector. Its good mechanical characteristics in terms of resistance make it particularly versatile, especially as regards the production of structural elements and recomposed wood products such as plywood and structural panels. (Boeri et al. 2012, p. 31)

The thermal conductivity characteristics in terms of the material favours the choice of wood as the primary building material, especially for facilitating the design of the thermal bridges, reducing both the design time and the insulation necessary for their protection.

The dry layered systems in wood can be divided into two families:

- frame systems;
- load-bearing walls systems.

Which one is the best for our case?

The frame systems are innovations of traditional technologies that were developed in climatic contexts characterised by an abundance of the material and a consequent establishment of this building culture. They are composed of a more or less dense structural framework with vertical and horizontal frames, generally with a rectangular, square or double T section, anchored with metal connections.

Although they are systems that are fairly widespread on the construction market, I encountered difficulties in obtaining solutions capable of satisfying the prerequisite requirements in terms of the necessary thickness and thermal lag.

2.4 The Choice of the CLT System

After having discarded the technologies in cement and masonry and the frame system, we have no other choice but to orient ourselves towards the load-bearing walls system. However, once again, they too are divided into two further types: a system of overlapping logs and a system of cross-layered solid wood panels.

The first, characteristic of the traditional architecture of the mountainous regions of Northern Europe, consists of a succession of stacked logs that constitute the load-bearing walls of the building. Today, the main construction systems of stacked logs use standardised elements with a rectangular section, with rough logs no longer being used. Despite this innovation, the technology presents major structural limits in the construction of multi-storey buildings, characteristic that, to a certain extent, also is true of the frame systems.

All that remains is the system in cross-laminated solid wood panels or cross-laminated timber (CLT), better known in Italy as X-LAM. These panels are composed of crossed layers of wooden slats in fir. It is a technology that has been developed mainly in Austria and Germany in the mid-1990s, spreading to Italy over the last ten years.

Compared to the previously examined construction systems in wood, CLT is particularly suitable for the construction of multi-storey buildings: through the use of metal anchors, the panels can be used both in the production of floor slabs and for load-bearing walls. Moreover, the panels are provided with a considerable mass that, unlike the frame systems, favours the performance in terms of thermal lag, while the mechanical characteristics of the material allow high structural performance and at the same time maintain reduced thickness.

Given its technical characteristics and the starting requirements, CLT is the most suitable construction technology in our case.

2.5 Reducing Construction Time

The main advantage of the dry layered systems is the execution time of the works.

But why is it so important for my client to reduce construction times as much as possible?

The Zoffoli family, in order to proceed with the realisation of the new building, has taken out a loan from a credit institution that covers 80% of the amount of the construction costs. Once construction has ended, the income generated by rent of the eight apartments will be such as to almost entirely cover the monthly loan payment. However, *during the entire period of construction, the building will not generate any income at all, only costs.* The monthly instalment of the loan payment will have to come from the pockets of Zoffoli family.

In this context, reducing construction time is an important requirement for hastening the income generation of the property, therefore limiting my client's exposure to debt.

Specifically, the loan requested by the Zoffoli family from the credit institutions involved an average monthly instalment before repayment (interest) amounting to € 900 that, starting from the 18th month, amounted to € 5600 (interest + capital).

For the entire duration of the construction, Davide and his brothers would have to provide for the payment of the monthly instalment of the loan exclusively from their salaries. Once the construction was terminated, they could receive an extra monthly income of about € 4990 from the collection of the rents of the eight apartments.

The construction system in CLT, like all dry layered construction systems, ensures shorter construction times compared to conventional technologies.

In my experience as a designer, timber construction, at least as regards the area of Italy where I live, is still an exception. Suffice it to say that at the time of the drafting of the project (2013) in the province of Forlì-Cesena (North-central Italy) only one construction company had built buildings with this technology. The same applies to the building material: the CLT was not produced in Italy but processed and imported from Austria. This situation reflects the national panorama to some extent, even if, currently (2016), it is showing some sign of improvement.

The presence of a limited number of manufacturers and construction companies with experience in buildings in CLT reduces the competition. This phenomenon produces an escalation in the cost of the technologies that are not very widespread, especially in relation to the competitive costs of technologies in concrete and masonry that are widely used in Italy.

In the province of Forlì-Cesena, the construction costs for a multi-storey building in concrete and masonry, of good quality, contracted to a single, well-structured building company are approximately € 1300–1400/m^2, value that rises to € 1450–1550/m^2 for a building in wood. Construction in wood costs on average 11.5% more than that in concrete and mansonry.

Taking the example of a commercial area (defined by the Standard UNI 10750) of about 490 m^2, close to what is hypothesised for the new building, construction in concrete and masonry costs about € 1400 × 500 m^2 = € 700,000, while the construction of a building in CLT costs about € 1550 × 490 m^2 = € 759,500.

From this rough evaluation, we can see that construction in CLT has an extra cost amounting to € 59,500.

Is the speed of construction enough to justify the extra cost?

Wooden construction is faster: it is not necessary to respect the curing times of the concrete, it does not use water, it increases the level of prefabrication and many operations are performed in the production plant.

Ok, but how "fast" is it? By way of example, the construction of the new building in wood in via Ariosto, composed of four levels of floors and walls in CLT was assembled *in just 10 days with the use of a truck crane*.

The same structure built in concrete and masonry requires approximately two months for the construction of just one floor: 28 days of curing of the concrete for the casting of the pillars, 28 days for the casting of the beams of the slab, plus the time required for infilling the entire framed structure with bricks and hollow clay blocks, time that varies in relation to the number of workers employed in the operations.

In the structures in concrete and masonry the plumbing and wiring installations are normally inserted in the masonry curtain walls. This operation involves the running of the installation in the masonry, the placement of the wiring and pipes and the subsequent smoothing in plaster: all operations that are not necessary in the stratified structures.

Wooden structures are usually completed with metal frames infilled by panels of fibre-plaster or fibre-cement, systems that have spaces where it is possible to place the systems, creating the outlet holes in correspondence with all the system devices (switches, light fixtures, sanitary fixtures, etc.).

The constructions in wood, compared to those in cement and masonry, have a greater level of prefabrication. By way of example, the walls in CLT are brought into the construction site complete with holes for windows and doors. This involves longer planning times and accurate, detailed final construction designs, a process that simplifies the execution phase and reduces time, because the decision-making process is shifted to the planning phase.

The constructions in concrete and masonry have a more hand-crafted process, many decisions or changes may be made in the course of the work using a hammer and chisel, without significantly affecting costs. On the other hand, to intervene in the course of the work on the cut of the structures in CLT is not at all easy and it entails high costs, therefore it is necessary to begin the final construction phase with very clear ideas and a complete awareness of the final construction project.

Design times extend even more in the planning of a Passive House because it is necessary to have an accurate design of all thermal bridges, of the airtightness and the correct exposure to the sun. This additional level of detail, although once again lengthening the design time, elevates the degree of awareness of the project, further speeding up the decision-making processes during the final construction design phase.

Extending the design times—*in my case, they have doubled*—did not cause particular problems for the Zoffoli family, because it can continue to collect the rents of the old building in Via Ariosto while waiting for the commencement of the construction.

The process of construction of a building is subject to many variables that depend on the organisation of the construction company, the number of workforce available, the effectiveness of suppliers, any indecision regarding the design choices, regulatory interpretations, bad weather and so forth.

It is therefore difficult to make a precise estimate of the difference in the time schedule of the construction site when comparing a building in wood to one in concrete and masonry. In the evaluation of the times, the parameter of experience once again comes into play. Comparing the times required for the construction of other buildings that I have designed and built I have analysed the processes capable of *reducing working time*.

In summary,

- the assembly of a multi-storey structure in CLT is measured in days while a multi-storey structure in concrete and masonry is measured in months;
- the structure in CLT is constituted of load-bearing wall sections and does not require infill walls, differently from the framed structures in concrete and masonry;
- the integration of the installations system in the vertical walls of the buildings in wood occurs in the gaps present in its functional layers (mainly in coverings or walls in fibre- or drywall), while for buildings in concrete and masonry, it is normally necessary to create the conduit and tubing route in the masonry with a hammer and chisel, lay the installations and then plaster with cement;
- the constructions in wood require a more detailed design that involves longer planning time, but in compensation, simplify the decision-making process in the course of the work;
- the multiplication of all previous points in a multi-storey structure.

Taking into account these evaluations and after discussion with the operators of the sector, the estimated time for construction of the entire building using a CLT structure was 12–13 months, an amount of time that, in the final balance, is half of what would be necessary for the construction of the building in concrete and masonry.

Halving the time translates into approximately 12 months of rent, amounting to € 59,880 (€ 4990 × 12), a *figure just slightly greater than € 59,500, which is the extra cost of construction of the structure in CLT!*

This economic evaluation, with all the approximations necessary, shows that on the one hand it is possible to cover the extra cost of construction (€ 59,500), on the other, it is possible to finish the construction within the time frame for the amortisation of the loan (18 months) to then take advantage of the income of rents (€ 4,990) as partial coverage of entire loan instalment (€ 5,600).

Moreover, let us not forget that, according to the Passive House database, we were about to realise the *first* certified Passive House multi-residence in wood in the entire Mediterranean area, we had already begun a commercial promotion in this sense, it was necessary to make haste: *how embarrassing it would be if we were to arrive second.*

2.6 The Advantages of a Certified Passive House Building

Having identified the energy-efficient construction technology capable of reducing the construction times, it is necessary to evaluate if reaching the highest levels of efficiency by constructing a building with near zero energy consumption according to the international Passive House protocol is economically advantageous for my client. The advantages of a Passive House can be summarised in the following points:

- energy costs close to zero, especially in relation to air conditioning in summer and heating in winter;
- raising the levels of indoor comfort, which translates into better quality of the air and relative humidity, and constant internal surface temperatures;
- increasing the life cycle of the building, due to the higher quality of construction that provides the air seal and the protection of the thermal bridges;
- it is a sustainable building in environmental terms: the building does not use renewable fuels, does not release pollutants into the atmosphere, takes advantage of the passive energy resources (sun, the heat of the human body and of household appliances), uses renewable energy sources.

These characteristics can only obtain a greater appeal on the market.

The Passive House database records, at the time of writing of this book, in the main countries of the Mediterranean area: 171 certified buildings in France, 24 in Italy, 19 in Spain, 2 in Greece. Their numbers increase in areas of a temperate climate such as Germany, with 441 certified buildings.

There are many more Passive Houses without certification, i.e. designed according to the same protocol but without having requested verification of the work performed by the Passive House Institute or other IPHA (International Passive House Association) affiliated institutes. The certification is voluntary, and it configures as a review by a third entity of the design and construction process by the designer, to guarantee that all aspects of the Passive House standard have been complied with. It is therefore a quality seal that does not have any effect whatsoever on the efficiency of the building. This procedure has a cost that, in many cases, the client prefers to economise on, especially when he or she has no need to approach the real estate market to rent or sell the property.

They are buildings that are not yet widespread and are inserted as a novelty with respect to the real estate market of reference.

In a commercial transaction such as that of the Zoffoli family, obtaining the certification means demonstrating that it tells the truth, that the work of the designer has been reviewed and it is free of errors and that the building functions as a Passive House. A plaque issued by the Passive House Institute is affixed on the building, certifying that it is indeed a Passive House, irrefutable data available to any potential tenant.

In a context such as the current one, where issues such as renovation and retrofitting of the existing property, energy efficiency, environmental sustainability and indoor comfort, begin to take hold with the mass culture, from cultural debates to conversation in the neighbourhood, a certified Passive House building can be identified as a virtuous example of this cultural movement, that sees its own objectives concretely made manifest.

Building a certified Passive House building in North-central Italy, in Emilia-Romagna, in Cesena, in Via Ariosto, as in many other places on the planet, cannot fail to promote the market response since it would be, with high probability, the only building with this level of characteristics in terms of energy efficiency, environmental sustainability and indoor comfort.

In my experience, this evaluation has obtained positive feedback; all eight apartments were rented out with long-term contracts before the construction was concluded.

The building began to produce income as soon as the work was finished, allowing the Zoffoli family to obtain a speedy return on their investment and the sustainability of their loan instalment. We have no way of knowing for certain, but if we had built a building with characteristics in the norm, it is doubtful that the results would have been the same.

However, the technological features relating to the use of additional layers of insulation, the protection of thermal bridges, the use of high-performance window and door frames, etc. entails, *in the construction of a Passive House, an extra cost amounting to approximately 3%: given that it has been hypothesised in the stage of preliminary design and was verified in the final balance at the end of the construction.*

2.7 Economic Sustainability and Environmental Sustainability

Could the advantages in terms of efficiency and comfort justify such an extra cost, considering that our apartments are intended for the rental market? We have seen that the cost of construction of the new building with structure in CLT amounts to approximately € 1,550/m^2, while the extra costs for building a Passive House entail an increase of the cost of construction amounting to about 5%, that is, € 1,628/m^2. The extra cost quota therefore amounts to € 78/m^2 (1,628 − 1,550 = € 78/m^2) that, multiplied by the 490 m^2 of useable commercial surface of the new building amounts to an overall figure of € 38,220.

The energy-saving advantages of a Passive House can rapidly cover this extra cost, also acting on the rent.

To continue the reasoning, it is important to bear in mind that normally a tenant must pay monthly, beyond the cost of rent, also the cost of the bills for climate control in the winter and in the summer, for domestic hot water, for the annual maintenance of the boiler that in Italy is required by law, in addition to other expenditure of lesser entity such as television fees, taxes on waste, ADSL, household appliances.

We have evaluated an average of the rents of the new building net of energy costs through a market survey that has analysed the rents of new buildings of the same dimensions present in our area of reference, a value which we shall call (*A*).

This value is added to the average value, obtained with the same principle, of the energy costs for heating and air conditioning, the maintenance of the boiler and the production of domestic hot water of buildings built with traditional technologies and present on the market, the value which we shall call (*B*). The sum of the two values (*A*) + (*B*) has produced an all-encompassing rent which we shall call "all inclusive" of the energy costs (*A*) + (*B*) = (*C*).

For greater clarity, we will take a two-room apartment as an example: it is composed of two bedrooms and a bathroom, the average monthly rent (*A*) amounts to approximately € 573, the monthly energy expenses (*B*) are approximately € 135, and therefore, the "all-inclusive" monthly rental (*C*) will amount to € 708.

This evaluation was carried out considering a building built with traditional technologies and an energy consumption that is within the norm. Monetising the energy consumption is a very complicated procedure because it varies, in addition to the parameters relating to the structure of the building, also in relation to the energy cost, therefore the values used are precautionary.

In a two-room apartment of this type, the lessee will be able to keep the amount of the quota (*A*) of € 573, since the quota (*B*) € 135, will be used in its entirety to pay energy costs.

But what happens if we use the value (C), as previously calculated, to define the rent inclusive of expenses for a two-room Passive House?

A Passive House has energy costs close to zero and, if well designed, does not need a boiler but only a mechanically controlled ventilation system, where maintenance translates into the washing of the filters, an operation that can be executed directly by the tenant.

In this case, the entire quota (*C*) of € 708 will remain in the pockets of the lessee, except for that minimum quota of energy costs slightly above zero. Defining such a low quota with precision is not easy, since it depends on many small variables; therefore, a wide margin of caution was used in the planning phase.

As of today (February 2017), the building was built, thus the share of expenditure can be easily determined: the monthly consumption of approximately € 60 for the domestic hot water and € 90 for climate control of the rooms. An overall total of € 150 that, divided for each apartment, omitting the differences of size, amounts to € 18.75 monthly.

In the case of a two-room Passive House apartment, the lessee will obtain about € 689.25 (€ 708.00 − € 18.75 = € 689.25), earnings that are approximately 20% higher (associated with an extra cost of only +5%) compared to € 573 of a traditional solution.

This strategy involves extra earnings from the rent that, having the data of the built building, we can now estimate with greater precision as being € 116.25 (=€ 135.00 − € 18.75), value which, multiplied by eight apartments, produces extra earnings of € 930 monthly and € 11,160 annually.

By using only the extra earnings derived from the "all-inclusive" formula, the extra cost for the construction of a Passive House, approximately € 38.220, can be amortised in just over 3 years' time.

Lastly, what are the advantages in the building of a Passive House?

For tenants: overall expenditure congruous with that of the market, comparable to the sum of the rent with the energy expenditure, and furthermore:

- the guarantee of the highest levels of indoor comfort:
  - comfortable indoor temperatures in every season;
  - air at the right level of relative humidity;
  - almost constant internal surface temperatures;
  - healthier air and reduction of CO_2;
  - a healthier environment without the formation of moulds or condensates and with reduced formation of dust.
- and for my client:
  - greater income from rent through the "all-inclusive" formula;
  - longer lease contracts because the tenants are satisfied, reducing the costs of administration and registration of the contracts;
  - increase of the life cycle of the property and reduction of regular maintenance interventions. The airtightness and protection of thermal bridges inhibits the formation of moulds and condensation: agents of deterioration of the structures.

- and for the environment:
  - an energy demand by the building that is nearly zero, reducing the pollution derived from the extraction of methane gas or by the production of electricity;
  - the building does not use renewable fuels; therefore, it does not produce and does not emit CO_2, particulate matter and other polluting substances into the atmosphere;
  - the spreading of a culture of sustainable building that combines profit with respect for the environment and of the people who live there, preserving the quality of the air and energy resources for future generations.

Acknowledgements Many thanks to the Zoffoli family, in particular to Davide Zoffoli, for his availability and the data provided.

References

Boeri A, Longo D, Piraccini S (2012) Il progetto dell'involucro in legno. Dario Flaccovio, Palermo, Italy

IPHA (International Passive House Association)

Malinowski B (1922) Argonauts of the Western Pacific. G. Routledge & Sons, London, UK; E.P. Dutton & Co., New York, USA (Italian Version: Bronislaw Malinowski (2011) Argonauti del Pacifico occidental. Riti magici e vita quotidiana nella società primitiva, Bollati Boringhieri, Milan, Italy)

Passive House database. http://www.passivhausprojekte.de

UNI 10750:2005 Services—Estate Agency—Service Requirements

Chapter 3
Navigation Instruments

How does the Passive House protocol work? What are the necessary skills? How is the design team composed? Are specific software and instruments necessary?

In Chap. 2 we have already seen that the construction of a Passive House, with supporting structure in cross-laminated timber (CLT), is economically sustainable and can meet the demands of my client: the next step, the most important challenge, is beginning to design it.

The task is quite daunting. To carry it out, it is necessary to understand—*in detail*—how a Passive House works and to make use of all the necessary instruments to get the project off on the right foot.

On the wave of enthusiasm, a name has been given to the building, taking reference from “Fiorita” (*flowering* in English) the name of the neighbourhood where it is located, we decided to call it: *Fiorita Passive House*.

Just like in novels about sea adventures, I felt like a young captain of the vessel to which the shipowner (the Zoffoli family) had entrusted an important mission: navigating valuable cargo through basically uncharted waters.

My role required me to enlist the crew, obtain the sextant, astrolabe and all other navigation instruments, to make a careful study of the nautical maps and also, to prepare myself for any encounter with sea monsters (bureaucracy, energy calculations, technical details).

The route foresaw:

- the study of the “Passive House standard”, the design protocol, identifying all the requirements necessary for obtaining the international certification;
- the choice of the necessary collaborators (crew) with the relevant skills for dealing with the various aspects of the project;
- the evaluation of the Building Energy Performance simulation tools and software to adopt in order to follow what is laid down in the protocol and in the design and verification of the technical details;
- the choice of the right construction company (the “shipwrights”).

Meeting the requirements of the Passive House standard is an ambitious goal, for which it is necessary to invest a great deal of time and energy in the design stage,

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_3

with the purpose to verifying the compatibility of each design choice with the thermophysical and energy characteristics laid down by the protocol.

The project must be designed in great detail: both for what concerns the construction choices (supporting structure, curtain walls, dividers, etc.), and for anything involving the technical systems: heating, ventilation and air-conditioning (HVAC), domestic hot water (DHW), wiring, lighting, lift, etc., including pipelines, ducts), identifying the effects of each choice with respect to the energy performance of the building, in the verification of the transmittances and of the thermal bridges, as well as the air tightness of the building.

In order to manage this complexity to the best of our abilities, it is necessary to acquire, right from the beginning, all the necessary knowledge to be able to win the challenge.

As Herman Melville wrote in Moby Dick:

> Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations (…). (Melville 1851, Chapter XXXII Cetology p. 81)

3.1 How a Passive House Works

The Passive House standard is an internationally recognised design protocol for the realisation of buildings with near zero energy consumption and high levels of indoor comfort. It can be applied regardless of the building's type, function or construction system. It was established in 1988 by a research project of Dr. Wolfgang Feist and Prof. Bo Adamson, (http://passivehouse.com). In 1991, Dr. Wolfgang Feist built the first Passive House in the district of Kranichstein in Darmstadt, Germany, demonstrating that it was possible to build buildings with near zero energy consumption. The building, constantly monitored, has an energy demand for heating of 9 kWh/m^2 per year that has maintained itself constant even until today, 25 years after its construction.

In the Acts of the 20th International Passive House Conference of Darmstadt, published by the Passive House Institute on 27 April 2016, Dr. Wolfgang Feist says:

> The inhabitants of the first Passive House building in the Darmstadt city district of Kranichstein first moved in 1991. 25 years of user experiences are available, as well as measurement reports and specific values relating to the durability of the separate systems. Statistical evaluation has shown a stable heating consumption of less than 9 kWh/(M^{2}y) on average - this is less than a tenth of the consumption in conventional residential buildings in Germany. A further airtightness test, thermographic imaging for detecting thermal bridges and sampling the insulation were part of the follow-up investigations. The outcome was clear: "Even today, everything functions exactly as it did the first day. The passive systems are simply less susceptible to faults", (says Dr. Wolfgang Feist, Director of the Passive

House Institute, 20th International Passive House Conference (2016), Conference in Review, "Passive House Conference demonstrates sustainable solutions for new constructions and retrofits", 27 April 2016, p. 1).

To realise a Passive House, it is necessary to plan the building using the Passive House Planning Package (PHPP) software. Once the necessary knowledge has been acquired, the designer can build a Passive House in an independent manner, without resorting to consulting or relations with the Passive House Institute. However, in the event that one seeks to apply for certification, and thus obtain the Passive House certified plaque, it is necessary to contact the Passive House Institute (http://passivehouse.com) that has its headquarters in Darmstadt, Germany, directed by the same Dr. Wolfgang Feist, or from one of the International Passive House Association (IPHA) affiliates, (www.passivehouse-international.org). Currently, there is only one affiliated IPHA institute in Italy, ZEPHIR (Zero Energy and Passivhaus Institute for Research, www.zephir.ph), directed by Francesco Nesi, PhD in Physics, to whom we have turned to request the certification. The certification is completely voluntary: we have requested it to demonstrate the quality of our work to the Zoffoli family and to future tenants of the building.

The Passive House standard establishes performance requirements that involve the technical and thermophysical characteristics of the building, in order to achieve an overall energy performance that ensures near zero energy consumption and high levels of indoor comfort. In particular:

- Energy demand for space heating and cooling $\leq$ 15 kWh/m^2/year;
- Heating load $\leq$ 10 W/m^2;
- Building Energy Performance in primary energy demand $\leq$ 120 kWh/m^2/year, heating, cooling, ventilation, domestic hot water, lighting, auxiliary electric consumption and domestic appliances;
- Airtightness of buildings $n_{50} \leq 0.6$/h.

In 2015, the categories Passive House Classic, Plus or Premium were introduced that can be achieved in relation to the renewable primary energy (RPE) demand and the amount of renewable energy generated.

The design and technical constructive solutions that allow one to achieve the above values are:

1. envelope—external walls, ground floor slab and covering—very well insulated using thick layers of insulation until achieving parameters of thermal transmittance (magnitude that expresses the thermal insulating capacity) of $U \leq 0.15$ W/m^{2}K;
2. reduction of the thermal bridges, trying to insulate without interruption the envelope of the building including foundations, projections, terraces, cornices;
3. windows with transmittance of $U_w \leq 0.8$ m^{2}K and glazing of the glass (g) (indicates the ratio between the global thermal energy transmitted from the pane of glass and the incident on it) with values lower than 0.50–0.55;
4. taking advantage of the passive energy resources such as the correct exposure to the sun, to take the utmost advantage of the heat produced by solar radiation that

passes through the windows during the winter months. During the summer months seeking to avoid overheating and the thermal gains produced by the body heat of the inhabitants (about 100 Wh per inhabitant), the same is true for the heat emitted by household appliances (for example, about 1.2–2.5 kWh/year for a dishwasher);
5. airtightness of the building in order to avoid losses of energy due to air leakage. The result is tested by the Blower door test. An airtight building envelope prevents the humid internal air from exiting through the fissures, where it could create interstitial condensates and encourage the formation of moulds, with consequent damage to the structures;
6. use of controlled mechanical ventilation with heat exchanger and post-treatment battery, which allows the expulsion of the exhausted air from the rooms, transferring it with the warm air emitted that is taken from the outside.

The design data relating to the previous points, both dimensional and physical–technical, are calculated using the final construction design of the building, to then be inserted in the Passive House Planning Package (PHPP), a spreadsheet in Excel format that creates a physical–technical simulation of the design, through dimensional, plant and thermophysical inputs.

The calculation of the energy demand according to the PHPP is carried out in relation to the local climatic data. The climatic data must be recognised as valid by the Passive House Institut (http://www.passiv.de), which uses climatic data processing companies such as Meteonorm (http://www.meteonorm.com). They can be requested directly from the Passive House Institut or established affiliates. The climatic data are geolocalised with respect to the site in which the building is located; they are taken from the surveys of the local meteorological stations for a period of ten years and concern: air temperature, temperature of the cloudless night sky, humidity and solar radiation. The Passive House standard can be used in any climatic context. The requirements of each component of the building will vary according to the climatic conditions of the rooms. In very hot climates you will pay attention to strategies for passive cooling such as shading and an envelope with high values of thermal lag.

For very cold climates it is essential to maximise the solar gains and an envelope with high transmittance. In the intermediate bands, where there are cold winters and warm summers, the question gets complicated, because it is necessary to consider both conditions with the same attention.

Once the climatic data has been inserted in the PHPP along with the dimensional and physical–technical parameters of the building/system, it is possible to verify if the energy balance of the building respects, and to what extent, the parameters of the standard, or if it becomes necessary to make changes to the project in order to comply with the required parameters. In this context, the PHPP is a true design tool.

On the construction market, there are building products certified as "components suitable for passive buildings". The certified products are usually windows, doors, ventilation systems and construction systems. Using a certified product simplifies the design because the thermophysical data are directly supplied by the manufacturer; otherwise it is necessary to simulate these parameters by means of modelling software.

If, on the one hand, a certified product can simplify the work of the designer/consultant, on the other, the cost of these components is generally higher than the average of the products present on the Italian market (verified personally); since the market for certified components is still young and there is not much competition: the cost of the certified product tends to increase; therefore, it is necessary to evaluate the convenience of this choice from time to time.

For example, in the design for the new building in Via Ariosto, to keep costs reduced, we used a frame which is not certified, therefore making it necessary to calculate through software the parameters such as the U_f (window frame transmittance) and the laying Ψ (Ψ is the length-related transmission coefficient, i.e. the value of the thermal bridge that exists between the frame and the building envelope). On the other hand, we have had to install a certified ventilation system because otherwise it would have been necessary to reduce its efficiency.

To achieve a Passive House, one must integrate with the various aspects of the design, also the technical construction solutions and thermophysical evaluations necessary for achieving the required performance: to do this it is necessary to obtain the appropriate skills. Normally, these aspects are taken care of by a consultant who has attended the course to become a “Certified Passive House Designer”. It is a special course of 88 h organised by IPHA affiliated structures. One obtains the title of “Certified Passive House Designer” in two ways: by passing the final examination or by bringing a building to certification. Enrolment in the course is not mandatory: if one knows the subject matter, it is possible to autonomously follow the design protocol and request the certification of the building which has been designed.

The role of the Certified Passive House Designer is to extrapolate the data from the architectural project to then insert them in the PHPP, calculate the thermal bridges, verify the gains produced by solar energy and verify the conformity of the project during the execution of the works.

Based on my experience, it is necessary that the consultant works closely with the architectural designer so as to verify, step by step, every detail of the project in relation to all quality requirements: aesthetic, economic and functional. It is necessary to continually discuss the technological choices adopted so as to define those that are capable of satisfying all the requirements.

At the end of the works, in case you want to request Passive House certification, it will be the consultant himself or herself that will transmit all the material that is necessary to obtain certification (PHPP, final construction design, reports, report of the Blower door test, details and calculations of the thermal bridges, photographs of the construction site with the metric scale of reference) to the Institute of reference. In this case, the work of the consultant will be verified by a Passive House certifier that, in the event of a positive outcome, will release the internationally recognised Passive House certification and a plaque will be affixed to the building (Fig. 1).

Fig. 1 Plaque that identifies the Passive House certification of the building *Fiorita Passive House*

3.1.1 Energy Efficiency

On the basis of the 7.1 version of the PHPP that was used for designing the building: the Fiorita Passive House has an energy demand for heating equal to 10 and 4 kWh/m^2/year for cooling. The primary energy required is 93 kWh/m^2/year (heating, cooling, dehumidification, domestic hot water, electric current and auxiliary current) of which 53 kWh/m^2/year is the quota relative to household appliances.

The values obtained from the PHPP correspond to the requirements provided for by the Passive House standard.

The result is obtained thanks to the energy efficiency of the devices used. The thermal dispersions of the building are so reduced that there is no need for a traditional climate control system, radiant floor heating, fan coils, etc., but all that is needed is controlled mechanical ventilation (CMV with the heat exchanger and post-treatment battery).

The free energy inputs such as solar radiation, the heating load produced by the tenants, household appliances and recovered from the exhausted air, make up a large part of the supply of the energy needed to heat the spaces. The remainder may be offset by a post-treatment battery connected to the controlled mechanical ventilation and powered by a heat pump.

The heat pump releases hot or cold water, in relation to the need to heat or cool the discharge air introduced from the outside that circulates through the battery. This possibility is indicated by the PHPP when the heating load is ≤ 10 W/m^2 of usable surface and the cooling load is ≤ 8 W/m^2.

The demand for primary energy is due to the following energy uses: heating, cooling, domestic hot water, auxiliary electrical energy and other household appliances must be ≤ 120 W/m^2/year, value which must result from the PHPP based on the entered design data. Therefore, it is advisable to use appliances with an elevated energy class and LED lighting.

The building's energy demand can be satisfied by any non-renewable energy source (natural gas, LNP, biomass, electric grid, district heating, etc.) or by renewable energy (photovoltaic, solar, wind, etc.).

A 14 kW photovoltaic system was installed in the roof of the *Fiorita Passive House*, producing 108 kWh/m^2/year, exceeding the building's 93 kWh/m^2/year primary energy demand: in substance, on the basis of the results of the PHPP 7.1, in an annual budget the building produces from renewable sources more energy than it consumes (Fig. 2).

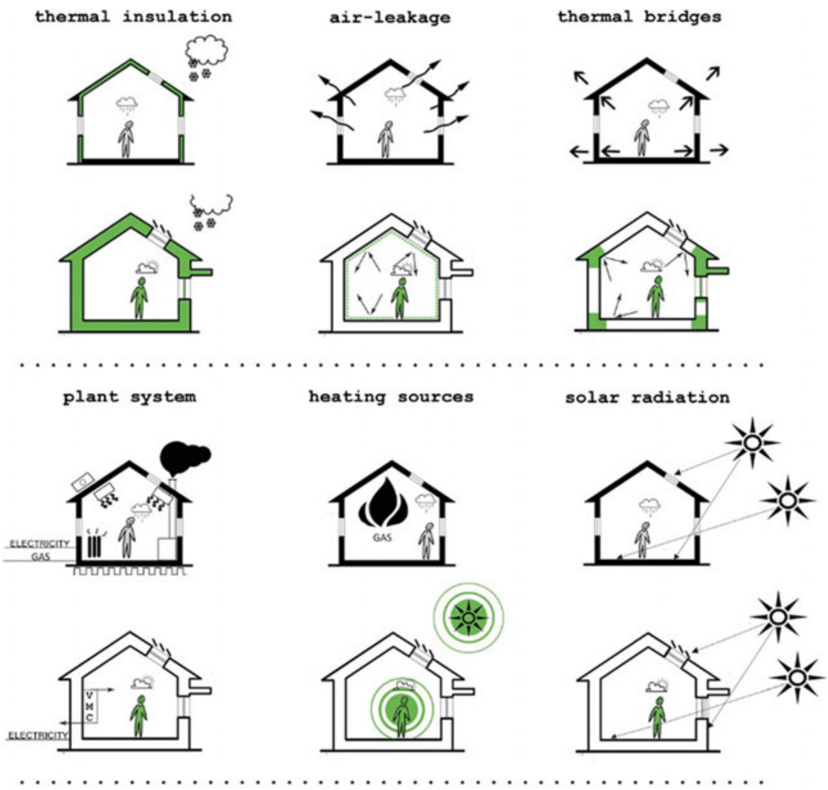


Fig. 2 Comparison between a traditional house (above) and a Passive House (below)

3.1.2 High Indoor Thermal Comfort

A Passive House reaches higher comfort standards compared to traditional buildings. In traditional buildings, it is common to record "*sudden changes in temperature*" near the windows or in relation to the diverse orientation of the spaces.

For example, if we sit close to a window we feel cold during the winter and hot during the summer; we feel colder in a room that is positioned to the north rather than one to the south, or when passing from a room located in a basement to one under the roof. These problems arise in buildings with envelopes that are not well insulated. The feeling of discomfort is due to the formidable differences of the internal surface temperatures, also with respect to the 20 °C recorded by the thermostat present inside the building (Fig. 3).

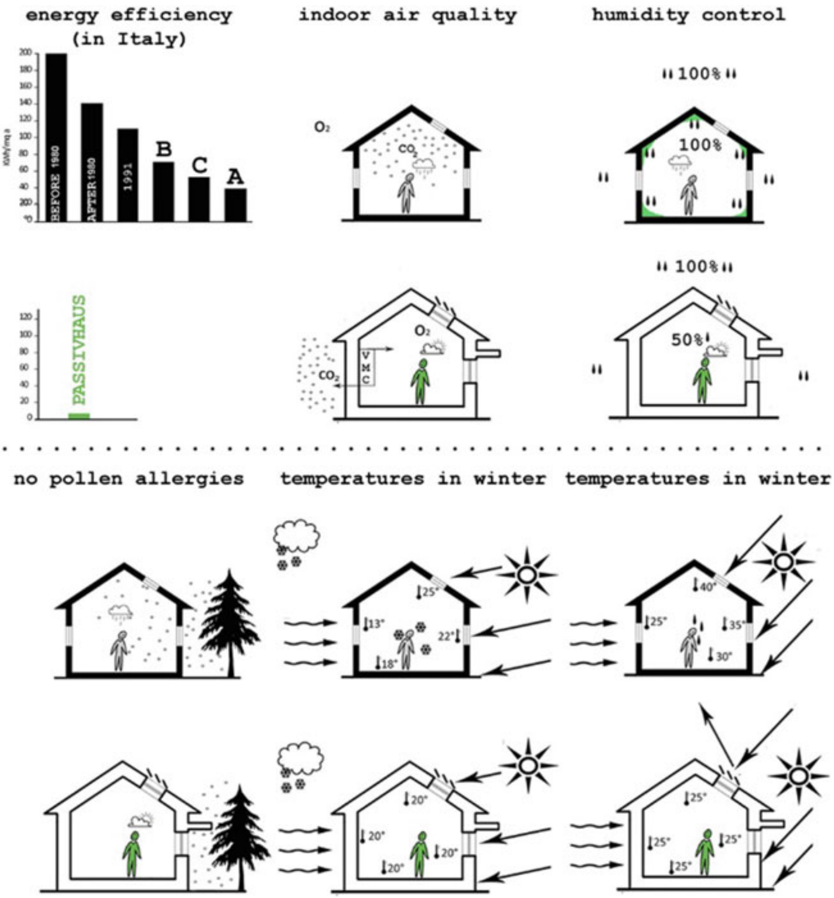


Fig. 3 Comparison between a traditional house (above) and a Passive House (below)

Taking the example of a room located in a poorly and scarcely insulated building, with an outside temperature of −5 °C and an internal one of 20 °C, we could record surface temperatures of 16 °C on the glass of the windows, 11 °C on the frame, 15.5 °C on the inner wall, 8.7 °C at the corner, 10.1 °C where the external wall meets the floor, 5.1 °C behind the cabinets. These temperature differences, in addition to the discomfort, can generate moulds and condensates.

These issues do not register in a Passive House because: the envelope has ample thickness of thermal insulation; there is protection of the thermal bridges and use of high-performance frames; all of this maintains the internal surface temperatures almost constant. Using the previous example and assuming that the same room is found in a Passive House, the following temperatures could be recorded: 17.7 °C on the glass, 16 °C on the frame, 19.5 °C on the inner wall, 17.8 °C in correspondence with the inner corners of the envelope, 16.5 °C behind the cabinets.

As regards the evaluation of the indoor thermal comfort of the Fiorita Passive House refers to the results of the monitoring campaign described in Chap. 10.

In every Passive House design, the internal surface temperatures are verified with the help of software for the calculation of the thermal bridges that verify, moreover, the generation of condensation or otherwise. Surface condensation occurs when the air comes into contact with a cold surface: with a temperature lower than the dew point temperature of the air that corresponds to the internal conditions of relative humidity. The presence of condensation favours the proliferation of fungal colonies that generate mould.

The insulated envelope correctly ensures minimum oscillations of the internal temperature during the arc of the year: generally 20 °C in winter, 25 °C in summer. These temperatures are always perceived in a comfortable way because the controlled mechanical ventilation (CMV) system, designed using the PHPP, maintains the relative humidity of the air around 50%, avoiding the formation of dry air.

The CMV exchanges the entire volume of the air of the internal environments every three hours, on average. In this way, the stale air is expelled from the building much more effectively than by means of a simple ventilation through the opening of the windows.

The continuous replacement of the rooms' air reduces the CO_2 which is generated in the internal environments. In domestic environments, the CO_2 is produced mostly by our breath. When the level of CO_2 increases in an environment, we have the perception of stale air and, above certain percentages, it can induce headaches. In a Passive House, the internal air is charged with oxygen and poor in carbon dioxide. With the expulsion of the foul air, even bad smells are reduced and one always has the perception of breathing clean air.

The perception of clean air is also caused by the capacity of the filters in the ventilation system to curb the entry of pollens, exhaust gases and other pollutants coming from the outside. The ventilation system introduces air at a rate so low, usually not more than about 3 m/s, as to not be perceived. The maximum permissible sound level of a system installed in a Passive House is equal to 25 dB(A). To comply with this limit, the air input and extraction channels are equipped with silencers that prevent the transmission of noise between rooms.

3.2 The Team: The Project Team and the Necessary Skills

The planning of a building is a complex issue that requires multidisciplinary skills. Normally, the design team is composed of the following main actors: architectural designer, structural designer, designer of the mechanical installations, designer of the electrical systems. To the team, in relation to the complexity of the project, one can add other actors that are involved in: safety coordination, geological analysis, acoustic design, specialised plant design, fire prevention planning and so forth.

During the execution of the building, the designers themselves, or other enabled figures, will handle the construction supervision in relation to the various skills; therefore, we will have: supervisor of the architectural works, supervisor of the structural works, supervisor of the works for the mechanical plants, etc.

The team is headed by a project coordinator, a role which is generally assumed by the architectural planner.

In my work experience, which takes place mainly in Italy, I have noticed that when buildings are designed using consolidated construction techniques that are known by the workers, the final construction designs are not very detailed. The final construction design stops at the scale 1:100–1:50, except in the design of the decorative and structural elements or those portions of the building envelope necessary for the calculation of the transmittances required by law, and in these limited cases, the scale arrives at 1:20–1:10. However, the culture of construction detail as a necessary instrument to guarantee the quality of the building under every aspect is not predominant, but only shared by those few designers who care about the quality in all aspects of design and do not rely exclusively on the experience of the workers.

The same approximation is also to be found in the design of the plants that, as a rule, appear too schematic, and the same is true in the design of structural nodes that do not foresee the potential formation of thermal bridges. If in traditional buildings one can easily note the habit of approximating the scale of the detail of the final construction design, trusting in the experience of the workers, this approach is absolutely not applicable in a Passive House.

The situation that I described in the previous lines refers to the Italian context, where I carry out most of my work. I do not exclude, indeed I hope, that in other contexts that I do not personally know attention to the construction detail is an established practice of the building process.

To design a Passive House, it is necessary that each actor of the building process does his or her part, investing the opportune time to develop final construction projects of accurate detail. Therefore, it is useful to identify capable designers who can prepare final construction designs in a scale of 1:20, 1:10 and 1:5 where, in addition to the functional layers that compose the building, all plant integrations will be visible (mechanical plants, plumbing, electrical, etc.).

Attention to the detailed construction drawing ensures comprehensive control of the various aspects of the design, allowing one to determine the cost of construction with a great deal of certainty and to check the quality of each component of the work. Moreover, it helps to highlight construction and interference problems that can be resolved during the design phase and not during the construction of the building. Such an approach is indispensable in the construction of a Passive House because we need to design each thermal bridge, the airtightness and interference of the building-plant system.

Once you have selected the collaborators suitable for this purpose, it is necessary to continue with an integrated design verifying, step after step, the interference between the various components of the building: envelope, structure, plant.

In addition to the actors of the building process of a traditional building, to build a Passive House further figures are required: the Blower door test operator and the Passive House Designer/Consultant (PHD/C).

The Blower door test operator tests the airtightness of the building. The test performed according to UNI EN 13829 is illustrated in a report declaring the result of the test. A Passive House must guarantee an airtight seal of n_{50} <0.6 1/h, value which must be tested and certified using the Blower door test after the construction is completed.

Normally, it is sufficient to carry out only one test to verify the requirement; however, it is appropriate to monitor the effectiveness of the airtightness with the Blower door test performed during the construction of the building so as to avoid errors. For example, in the construction of the *Fiorita Passive House*, we planned 3 tests: the first when the structure was completed, the second after installation of the insulation and door and window frames and the third when the entire building was finished.

The Passive House Designer/Consultant must fill in the PHPP, calculate the thermal bridges and carefully check every aspect of the building-plant system, both in the design phase and during construction, to verify the achievement of the Passive House standard. This is why it is opportune that the architectural designer, coordinator of the building process, is in continuous contact with the Passive House Designer/Consultant, so as to be able to evaluate all the design choices together.

Precisely for this reason, before starting the actual design phase, my colleague (and my companion in life) Arch. Margherita Potente, at that time a recent graduate, underwent training through a course for designers/consultants at ZEPHIR, an affiliated IPHA institution, to which she added several courses for the calculation of the thermal bridges. She came back from this training changed: while I sketched elevations of the new building in my notebook, she was filling hers with technical physics formulas.

Together, we evaluated every single aspect of the project, every detail of the construction, on several occasions redesigning the solutions that did not thoroughly convince us, until reaching the desired result, step-by-step combining energy efficiency, durability, construction quality and aesthetics. Needless to say, without her sitting at the desk next to mine, everything would have been much more difficult (or perhaps impossible).

And finally, even though such a thing is not required by the certification protocol or industry regulations, we decided to design a monitoring system to monitor the actual efficiency of the building. In charge of that aspect and for the collection and processing of the data was Arch. Kristian Fabri, friend and co-author of this book.

With the crew enlisted, the design team was thus composed:

- Arch. Stefano Piraccini: project coordinator, designer and supervisor of the architectural works and safety manager;
- Arch. Margherita Potente: Passive House Designer/Consultant, architectural designer;
- Eng. Loris Magnani: designer of the reinforced concrete structures and supervisor of the structural works;
- Eng. Elmar Mattei: designer of the wooden structures;
- Dr. Alessandro Bondi: Geotechnics;
- Eng. Leopoldo Piraccini: inspector during construction;
- Industrial Expert Alberto Betti, Arch. Margherita Potente: CMV designer and supervisor;
- Eng. Pietro Ducci: electrical plants designer and supervisor;
- Eng. Marco Boscolo: airtightness and Blower door test expert;
- Eng. Andrea Antimi: acoustic consultant;
- Arch. Kristian Fabbri: designer of the monitoring campaign.

A crew composed of one captain, nine men and a woman.

3.3 PHPP and the Other Software Used for the Project

To design a Passive House, we must adopt two instruments: the PHPP and software for the calculation of the thermal bridges. In addition to the first two, it is advisable to use software for the simulation of the shading on the three-dimensional model. The market offers various software suitable for the purpose, some of which communicate directly with the PHPP. We used Autodesk Ecotec© for the simulation of the shading and Dartwin Mold Simulator© for the calculation of the thermal bridges of the structural nodes and of the window and door frames.

The software for the simulation of the shading is an excellent tool for the preliminary design of the building. It is possible to set the climatic values of the reference site obtaining an actual simulation of the solar radiation during the entire year. Through a three-dimensional model of the surroundings it is possible to control the effect of the shading caused by the presence of trees or buildings: so as to identify the optimal position to place and orient the building. It is also useful for designing projections, darkening systems and for placing the windows in the positions of maximum solar input.

The software for the calculation of the thermal bridges is used in the final construction design and consists in the modelling of the structural node that you want to analyse. It is necessary to enter the construction detail by assigning to each functional layer the reference value of λ (λ thermal conductivity in W/mK) and the external temperatures acting on the node. This modelling software generates the value of the thermal bridge Ψ (Ψ is the length-related transmittance, expressed in W/mK, value that characterises the thermal bridge) which normally should be kept close to zero. If in the first simulation the Ψ values were not satisfactory, it is possible to use the software to adapt the type and thickness of the insulating components of the node so as to optimise the results. The Ψ values of each thermal bridge are data required by the PHPP: one of the variables that add to the "thermal exchange" item of the building's energy balance. If the energy balance does not meet the certification requirements: one of the possible strategies is to redesign the thermal bridges in order to obtain lower Ψ values.

The PHPP, the main design tool for the Passive House, is a spreadsheet, constituted of multiple sheets, executable with Microsoft Excel and compatible software that allows one to carry out a physical–technical modelling of the entire building in a semi-dynamic regime, so as to individuate when the Passive House standard has been reached.

The PHPP was put on the market in 1998 and since then has been constantly updated. Starting from the main sheets relating to the calculation of the heating demand with the annual and monthly method, for the distribution and supply of heat and the electricity and primary energy demand, the PHPP has been progressively expanded with sheets that control various aspects such as: characteristics of the windows, shading, heating load for the heating, analysis of the summer season, dehumidification, further specifics for the calculation of ventilation according to the type of building, production of renewable sources.

The sheets are compiled by inserting a multitude of data relating to the climatic context of the site and to the building-plant system. They can be inserted in a flexible way according to the various phases of the design, allowing backtracking whenever the need arises. A system of graphics and warnings identifies the weak points of the project, each time evaluating where it is more effective to intervene (Figs. 4, 5, 6, 7 and 8).

I conclude this section with a table that illustrates a general overview of the contents of the PHPP, solely for the purpose of indicating to the reader who has never used the software, the elements that will be necessary to check during the planning of the building. I shall not go into the specific notions that refer to the user's manual for the software, which I advise to integrate with the book by Lewis (2014).

The version used for the designing of the *Fiorita Passive House* is 7.1, and it is composed of 35 sheets: I will summarise the function of each individual sheet in the following Table 1.

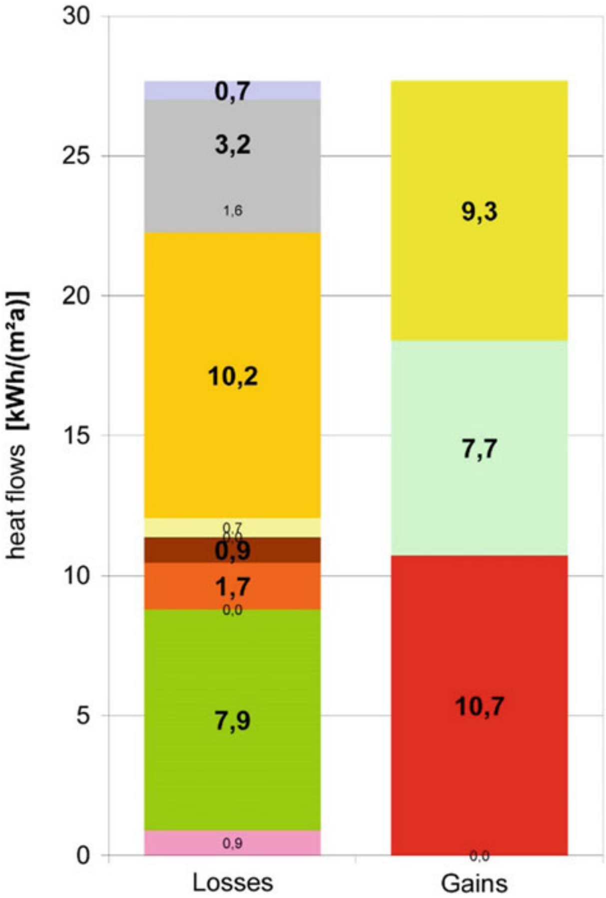


Fig. 4 Graph of the annual heating balance (PHPP 7.1) of the *Fiorita Passive House*. Column of the gains: annual heating demand (red); internal heat gain (light green); passive solar input (bright yellow). Column of the losses: negative thermal bridges (purple); walls towards the external air (dark green); roof (orange); floor slab (brown); walls towards unheated spaces (light yellow); windows (mustard yellow); doors (grey, lower value); ventilation (grey, greater value); unused free gain (blue)

3.4 How I Chose the Construction Company

If designing a Passive House is not a simple task, the same can be said of building one, especially if one intends, as in our case, to build it in Italy using a construction system in cross-laminated timber (CLT).

In Italy the building culture in brick and masonry is deeply rooted, and there are very few construction companies with a good knowledge of wood technology; fewer still are those who have experience in the construction of a Passive House.

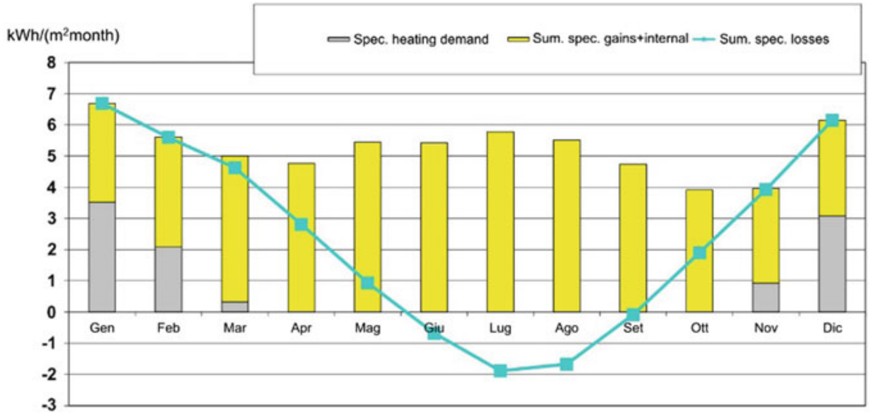


Fig. 5 Graph of the specific losses and gains, heating balance of the *Fiorita Passive House* (PHPP 7.1)

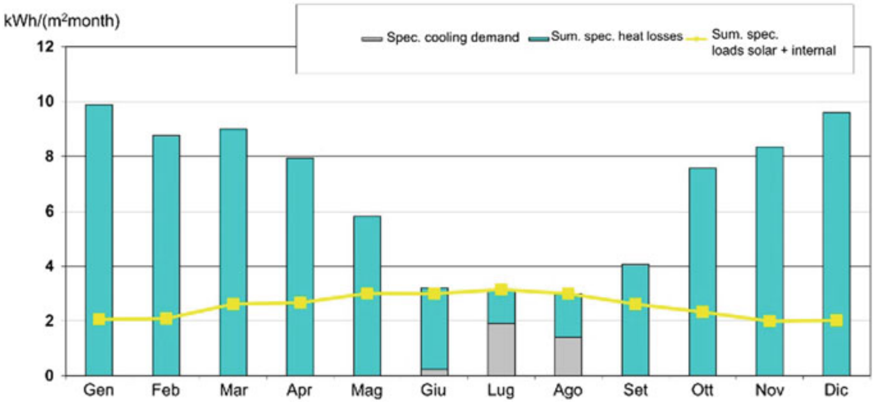


Fig. 6 Graph of specific losses, specific load, usable cooling demand of the *Fiorita Passive House* (PHPP 7.1)

The near totality of construction companies that build wooden buildings is located in Northern Italy, on the border with Germany and Austria, where the material is abundant, along with a deeply rooted technological culture of timber construction as well as certified forests for production. The region where there is a greater concentration of companies operating in the sector of constructions in wood is Trentino Alto Adige.

They are firms that have gradually developed their construction process, operating throughout Italy using mostly standardised technologies and generally preferring the frame system to CLT, which is more costly. Their main experience is linked to the alpine environment, where the important problem of overheating in the

Specific building demands with reference of the treated floor area					
	Treated floor area	317,4	m²	Requirements	Fulfilled?
Space heating	Heating demand	10	kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	7	W/m²	10 W/m²	yes
Space cooling	Overall specifi. space cooling demand	4	kWh/(m²a)	15 kWh/(m²a)	yes
	Cooling load	6	W/m²	-	-
	Frequency of overheating (> 25°C)		%	-	-
Primary energy	Heating, cooling, dehumidification, DHW, auxiliary electicity, lighting, electrical appliances	93	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating ad auxiliary electricity	53	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity	108	kWh/(m²a)	-	-
Airtightness	Pressurization test result n50	0,4	1/h	0,6 1/h	yes
Passivhaus?					yes

Fig. 7 Extract of the verification sheet (PHPP 7.1) that shows the attainment of the Passive House standard of the *Fiorita Passive House*

Specific building characteristics with reference to the treated floor area						
	Treated floor area m²	320,3		Criteria	Alternative criteria	Fullfilled?²
Space heating	Heating demand kWh/(m²a)	11,5	≤	15	-	yes
	Heating load W/m²	8	≤	-	10	
Space cooling	Cooling & dehum. demand kWh/(m²a)	10	≤	15	15	yes
	Cooling load W/m²	10	≤	-	11	
	Frequency of overheating (> 25 °C) %	-	≤	-		-
	Frequency of excessively high humidity (> 12 g/kg) %	0	≤	10		yes
Airtightness	Pressurization test result n_{50} 1/h	0,4	≤	0,6		yes
Non-renewable Primary Energy (PE)	PE demand kWh/(m²a)	149	≤	-		-
Primary Energy Renewable (PER)	PER demand kWh/(m²a)	74	≤	60	74	yes
	Generation of renewable energy (in relation to projected building footprint area) kWh/(m²a)	125	≥	-	42	

² Empty field: Data missing; '-': No requirement

Fig. 8 Extract of the verification sheet (PHPP 9.6a), used for the certification of the building by the ZEPHIR Institute. The indicated values differ with respect to those obtained by us in the planning phase using the PHPP 7.1 (see previous figure). These differences, although not substantial for the purposes of the achievement of the Passive House standard, are due to the use by the certifying institute of the PHPP 9.6a version put on the market after the construction of the building and amending, with respect to the previous version, some calculation methodologies, optimising the analysis in the summer season

summer season is not an issue: therefore, it is not necessary to adopt construction systems that ensure a high thermal lag.

A frame structure normally has a smaller mass than a structure in CLT, therefore ensuring lower levels of thermal lag. The structure in CLT helps to improve the thermal lag of the envelope; precisely for this reason, it seems to be more suitable in climatic situations where there are problems of overheating in the summer.

Cesena, in the province of Forlì-Cesena, located in North-central Italy, at 44 m above sea level, has a Mediterranean climate tending to temperate sub-continental, with cold winters and hot summers, and is located about 400 km from the Alps. In this climate, a structure in insulated CLT can ensure optimal efficiency both during

Table 1 Contents of the 35 sheets of PHPP 7.1

Sheet name	Brief overview
Verification	General data of the building and, in relation to the functional typology, selection of the calculation method. In the sheet, there is a table of verification of the necessary requisites for a Passive House: energy demand for space heating ≤ 15 kWh/m^2/year, heating load ≤ 10 W/m^2; energy demand for space cooling ≤ 15 kWh/m^2/year cooling load; Building Energy Performance in primary energy requirement ≤ 120 kWh/m^2/year (heating, cooling, ventilation, domestic hot water, lighting, auxiliary electric consumption and domestic appliances); Blower door test results $n_{50} \leq 0.6$ 1/h. During the compilation of the successive sheets we shall return on various occasions to the "verification" sheet to monitor the progress of the design
Surfaces	Dimensional data of the building towards unheated areas: usable surface, volume and dispersing surface are the main data requested. Enter the energy performance of all the components of the envelope, and the losses due to thermal bridges are calculated with specific software. In addition, enter the data of solar radiation, the orientation of the building, the inclination of the external façades and the shading
U values list	Database of the *U* values of the most common stratigraphy (external walls, roof, etc.) and of the certified Passive House construction systems
U values	Enter the λ values and the thicknesses of the stratography of the envelope so as to determine the *U* values, calculated according to EN ISO 6946 of the external walls, slabs on the ground, roof, etc
Ground	The variables relating to the type of ground and reference λ_{ground}, to the interference with the underground and basement areas of the building or the presence of aerated floor slabs
Windows	Calculation of the *U* value of each window in relation to various parameters such as: geometry, orientation, type of frame (U_f), glass (U_g and glazing g), glass edge (Ψ), length-related coefficient of the installation thermal bridge (Ψ). A diagram summarises the solar gains and losses
Type of windows	Database of the windows used in the design and other certified Passive House products
Shading	The calculation of the shade coefficients through the insertion of data relating to: adjacent buildings, overhangs, parapets of the windows. The shading coefficients will vary the data of the "windows" sheet
Ventilation	The project of the ventilation supply through three methods of which we will consider the pejorative: (1) the relationship between the surface area of the building and number of persons (20–30 m^3 per person); (2) calculation of the air extraction for each room in relation to the number of bathrooms (40 m^3/N), kitchens (60 m^3/N), storerooms (20 m^3/N); (3) air exchange 0.3 volumes/hour. The sheet keeps the air quality under control: through the values that have been entered, it is possible to avoid the phenomena of discomfort due to dry

(continued)

Table 1 (continued)

Sheet name	Brief overview
	air by controlling the moisture and velocity of the air. The necessary ventilation supply allows one to locate the adequate controlled mechanical ventilation system to then enter the relevant technical data on the sheet. The calculation of the air flow, starting from the ventilation requirements of recovery and discharge, is in conformity with DIN 1946–6. The air exchange rate for infiltrations and the actual efficiency of the heat recovery are evaluated also through the input of the result of Blower door test
Additional ventilation	Use in case there are multiple ventilation systems, as in the case of multi-residential buildings
Annual heating demand	Calculation of the specific annual heating demand according to the energy balance described in the standard EN ISO 13790: losses from transmission + losses from ventilation − h (solar supplies + internal gains). It is indicated if the building has a heating demand ≤ 15 kWh/m^2/year. A graph identifies the elements of criticality where it is necessary to intervene
Monthly heating procedure	Similar to the previous sheet, a graph illustrates the specific losses on a monthly basis, through a balance between heating demand and the sum between the solar gains and the internal gains
Heating load	Calculation of the nominal heating load based on the energy balance of a reference day with maximum losses from transmission + maximum losses from ventilation − h (minor solar gains + internal gains). Verify if the controlled mechanical ventilation alone is sufficient to heat the environments, basing itself on the day of the year with a lower heating load. In case the requirement is not verified, the integration of an additional heating system will be necessary (radiating panels, radiators, fancoils, etc.)
Summer	Verification of the behaviour of the building in the summer season and, if possible, cooling with controlled mechanical ventilation alone. Enter the specific capacitance (Wh/K/m^2 of usable surface): an approximate parameter selected in relation to the construction system used, and the temperature overheating limit, which is normally equal to 25°. Enter if you intend to use night ventilation by opening the windows, if there are auxiliary cooling plants or if, during the summer, to increase the air exchanges to facilitate the discharge of the internal loads
Summer shading	Enter the dimensional parameters and reduction factors of the solar gains due to shading or overhangs for each window
Summer ventilation	Estimate of the air exchange rate for natural ventilation during the summer period. Entered rough values in relation to the natural ventilation in summer, such as time and duration of the opening of the windows
Cooling	Verification of the specific annual space cooling demand ≤ 15 kWh/m^2/year. A graph identifies the elements of criticality where it is necessary to intervene

(continued)

Table 1 (continued)

Sheet name	Brief overview
Cooling system	Calculation of the energy demand for dehumidifying and choice of the cooling procedure. Enter the technical data relating to the post-treatment battery and the heat pump and any auxiliary systems for cooling and ventilation
Cooling load	Calculation of the cooling load of the building, of the frequency of overheated hours as a measure of the summer comfort. It checks if the controlled mechanical ventilation is sufficient to cool the building. Calculation of the daily average cooling load of the building
DHW + distribution	Calculation of the heat loss for distribution of domestic hot water (DHW) and auxiliary heating installations and calculation of the heating demand for DHW and heat storage losses. Enter the technical data and dimensional characteristics of the domestic hot water distribution system and heating plant auxiliaries. Moreover, it is necessary to check the insulation of the ducts in relation to the diameter, length and whether or not the duct is located inside or outside the building
Solar DHW	Calculation of the daily average cooling load of the building
Electricity demand for dwellings	Calculation of the electricity demand of passive buildings for residential use through a database of household appliances in the building, of the related technical data, and their positioning inside or outside the heated envelope
Electricity demand for non-residential use	Electricity demand for non-residential use
Auxiliary electricity demand	Calculation of the auxiliary electricity demand and the corresponding primary energy demand
Primary energy	Choice of plants for the generation of heat, calculation of the primary energy and equivalent CO_2 emissions for the results achieved. Enter the data relating to the energy generator for climate control, heat pumps, or any boilers, photovoltaic, district heating systems, etc
Energy-efficient ventilation system with heat recovery	Calculation of the efficiency of the combined heat and DHW generator solely in the case of using an energy-efficient ventilation system with heat recovery in accordance with the conditions laid down for the design
Heat pump	Calculation of an energy-efficient ventilation system with heat recovery (if used) consisting of two distinct heat pumps, one slaved to DHW production and a separate one for heating
Boiler	Calculation of the efficiency of heat generation with standard boilers (if used) under the conditions laid down for the design
District heating	Calculation of the final energy and primary energy demands (heat)

(continued)

Table 1 (continued)

Sheet name	Brief overview
Climatic data	Climatic data of the site on which the calculations of the sheets are based: “annual heating demand”, “windows”, “heating load”, “monthly heating procedure”, “summer”, “cooling”,” cooling plant”, “cooling load”
Internal heating supply	Calculation of the internal gains based on the sheets: “electricity demand” and “auxiliary electricity demand”
Non-residential internal heating supply	Calculation of internal gains for non-residential buildings based on the “electricity demand for non-residential use” sheets and the number of people in the building
Non-residential usage profiles	Enter and select the usage profiles to use for the calculation of the electrical requirements and of the internal gains
Data	Table of the factors of primary energy according to GEMIS and databases of other factors

the summer and the winter, also for the construction of a Passive House that employs controlled mechanical ventilation as a single system of climate control.

In my case, with the choice of a company coming from Northern Italy I am ensured of vast expertise in constructions in wood, but there are some factors on the negative side: coordination difficulties due to distance, standardisation of the construction systems and an experience predominantly linked to a climate which is different from the one where I would have to operate.

On the other hand, in my local context, the construction companies who have started to make buildings in wood, mostly single family dwellings, are only two, with not many years of experience.

The choice of a local company, which is located just a few kilometres away from my design studio and the construction site, allows a continuous presence of the technical supervisors on the field, useful for obtaining rapid intervention whenever it is deemed necessary. In addition, by not using standardised construction systems, it is possible to agree upon the construction technology for each design that the designer considers the most effective.

Knowledge of the technology for construction in wood is not the only feature to keep in mind: it is opportune to identify a construction company with building experience in regards to airtightness, constructions with high energy efficiency and sensitivity to the matter of thermal bridges (it has happened to me many times, in the construction site, to be stared at with unbelieving eyes because I would ask for the insertion of thermal insulation in the foundation).

What would have happened in the event of a negative result of the Blower door test? Who would have incurred the necessary expenditure for investigations, certainly destructive, capable of identifying and, hopefully, resolving the air leaks? How can we ensure the correct laying of insulation in a capillary manner?

In the construction of a Passive House, even a small mistake of execution may compromise the responsiveness of the building to the results of the design.

I have therefore deemed it opportune to insert the following two clauses into the contract:

- the general contractor, in the event of a negative result of the Blower door test, undertakes to carry out all the operations necessary for guaranteeing the airtightness with $n_{50} \leq 0.6$ 1/h, without requiring additional compensation from the contracting party;
- the foreman undertakes, before the beginning of the work, to attend the course for “Certified Passive House Tradesperson” (CPHT) and to pass the examination with positive outcome.

The first point holds the contractors accountable for an execution that is attentive to the issue of airtightness; ensuring that the contracting party (in my case the Zoffoli family) does not incur extra costs that would be necessary to rectify execution errors; simplifies the work of the project supervisor.

The second point requires the foreman, a key figure for the coordination of the construction, to acquire the practical knowledge necessary for the construction of a Passive House.

The “Certified Passive House Tradesperson” (CPHT) course is organised by the Passivhaus Institut of Darmstadt and promoted by all the affiliated IPHA institutes and has a 32 h duration and involves passing a final examination. It provides the construction personnel with sufficient awareness how a Passive House functions, and it gives all the indications on the construction operations necessary for the successful execution of the building. I have therefore asked ZEPHIR, the IPHA affiliated institute present in Italy, to organise the course in Cesena, along with my collaboration in the promotion in the territory in order to reach a satisfactory number of persons enrolled in the course.

To individuate the company that would be in charge of building the *Fiorita Passive House*, we invited four firms to a tender: two local ones and two from Trentino Alto Adige. Each company was provided with the following documents:

- the final construction design of the building, that illustrates the design in every detail;
- the tender specifications, that illustrate the type of materials and the application techniques;
- the metric calculation, that identifies each individual intervention and the respective quantities involved.

The contract was awarded on the basis of the most economically advantageous offer to the company *Zero Energy s.r.l.*: a local firm that has proven itself to be up to the task and which has addressed the construction with incredible enthusiasm. The foreman, Silvano Mazzoli, attended the CPHT course, as did the technical supervisor Eng. Andrea Fagioli and the second foreman, Abramo Ceredi, although this was not required in the tender contract.

The work was carried out in conformity with the final construction design. The construction site was punctuated by continuous coordination meetings between: construction supervisors, Certified Passive House Designer, foreman and reference tradesmen, so as to verify all those works which are of more difficult execution and, through the competence of each subject, to search for the most effective solutions.

References

DIN 1946-6 (2009-05). Ventilation and air conditioning Part 6: ventilation for residential buildings —general requirements, requirements for measuring, performance and labelling, delivery/acceptance (certification) and maintenance

EN 13829:2002. Thermal performance of buildings—determination of air permeability of buildings—fan pressurisation method

EN ISO 6946 2008. Building components and building elements—thermal resistance and thermal transmittance—calculation method

EN ISO 13790:2008. Energy performance of buildings—calculation of energy use for space heating and cooling

Lewis S (2014) PHPP illustrated: a designer's companion to the passive house planning package. Riba publishing, London, UK

Melville H (1851) Moby dick, or the whale. Harper & Brothers, New York, USA

20th International Passive House Conference 2016. Conference in review, passive house conference demonstrates sustainable solutions for new constructions and retrofits, 27 April 2016, p 1

UNI 10339:1995. Air-conditioning systems for thermal comfort in buildings—general, classification and requirements—offer, order and supply specifications

Websites

www.passivehouse-international.org. Consulted on 09 Apr 2017
www.zephir.ph, Consulted on 09 Apr 2017
www.meteonorm.com, Consulted on 09 Apr 2017
www.autodesk.com, Consulted on 14 Apr 2017
www.dartwin.it, Consulted on 14 Apr 2017
https://products.office.com/it-it/excel, Consulted on 15 Apr 2017
http://passivehouse.com/04_phpp/04_phpp.htm, Consulted on 15 Apr 2017

Chapter 4
Form and Structure

Can a Passive House have any form? How can one optimise the form and energy efficiency? How does one design a Passive House in cross-laminated timber (CLT)? Do the foundations have to be insulated?

Having come to this point, we have a clearer idea of what a Passive House is and we know what tools we need to start designing it. At this initial stage, the difficulty lies in conceiving a suitable form for the purpose and designing an envelope that is sufficiently high-performance. There are no limits on the dimension or form in the design of Passive House; however, to reduce the costs of resolution of the thermal bridges and the greater thickness of the insulation, it is good practice to limit dispersing agents and projections. In addition, given that free solar energy gains ("free energy") are a positive element in the winter but a negative one in the summer ("overheating risk"), it is beneficial to place the windows in such a way as to ensure the input of solar radiation in the winter and to facilitate shading in the summer.

To give a more precise idea of how effective these contributions are, Allen (1980) writes:

> (…) a square foot (= cm^2 929.03) of land at 45° latitude, in a location with a 50% incidence of cloud cover, receives about 75 kilowatt-hours of direct solar radiation each year. (…) The normal internal operating temperature of the human engine is just under 99 °F (37 °C), a temperature that must be maintained within narrow tolerances in order to avoid metabolic malfunction. But our bodies are only about one-fifth efficient in converting food energy to mechanical work. They must give off four times as much heat as they use in order to maintain a stable internal temperature. An adult working at a desk produces excess heat at about the same rate as does a 100-watt lightbulb. The same person walking generates two to three times as much heat and, when exercising strenuously, six to ten times. (Allen 1980, pp. 12, 20)

The design of a building is divided into three phases:

The *preliminary design*, consisting in designing—roughly—the volume of the building, the internal distribution of the environments and their function;
the *definitive design*, consisting in the revision of the preliminary one by adapting every dimensional and technical solution to the norms and legislation of the sector;

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_4

the *final construction design*, consisting in the drafting of final construction elaborations, with in-depth detail of every single construction element in order to carry out the work.

At each design phase, it is important to identify which parameters to keep in mind for designing a Passive House.

To get off on the right foot, if we were to follow the advice in the manuals for building Low Energy buildings step-by-step, the preliminary design should have as its aim the reduction of the dispersing surface and the construction of a compact building (cube-sphere). However, in my honest opinion, this indication should not limit the functional or compositional aspects of the work in the preliminary design phase, any choice can still be verified using the Passive House Planning Package (PHPP) in the subsequent design phases, eventually eliminating those architectural solutions that prove to be problematic in terms of dispersion or which entail higher costs.

In the *definitive design,* it is appropriate to determine the thickness of the opaque enclosure components: exterior walls, roof and floor slabs on environments without climate control. To do this, it is necessary to provide a stratigraphy draft in order to determine the energy performance of each individual component.

The energy performance of the opaque components of the envelope is related to the conductivity of the materials used and to their thickness. The thickness is a datum that must be kept under control to verify consistency of the definitive design to construction parameters such as surface area, volume and height of the building. It is advisable to design the perimeter walls, roof and floor slabs on cold environments that settle at precautionary transmittance values (U) lower than $0.15\ \mathrm{W/m^2}$ k. This is merely a suggestion; that's not to say that higher values are incompatible, their effectiveness or interaction with other parameters of the building will always be through the calculation of the energy performance of the building.

In climatic contexts such as that of the Mediterranean, characterised by cold winters and hot summers, one has to also consider the parameter of thermal lag. In our case, to prevent overheating in the summer season, we designed components of the envelope capable of reaching thermal lag values of ≥ 16 h. The thermal lag and transmittance values are a function of the stratigraphy of the components of the envelope and can be calculated using common thermophysical modelling software.

In the *final construction design,* we enter fully into the meaning (and complexity) of a Passive House, with the calculation of the thermal bridges, the focus on airtightness, the choice of windows, etc. In this phase, it is necessary to use the PHPP as a design tool to verify if all the choices adopted (envelope, systems, heating supply, etc.) allow us to obtain the desired result. In the event of a negative assessment, it is possible to intervene, for example, by increasing the thickness of the insulation, or optimising the thermal bridges, using more efficient fixtures, improving the solar gains, etc., until the calculation of the energy performance of the building. The "verification" sheet will indicate when the energy performance of a Passive House has been obtained.

It is appropriate that the energy performance of the building resulting from the final construction design achieves the Passive House requirements with ample safety margins, to prevent any minor changes during construction caused by erroneous evaluations in the design phase bringing the building below the certification parameters.

For example, starting the realisation of the work with an energy demand for heating and cooling <15 kWh/m²/year and primary energy <120 kWh/m²/year leaves very narrow tolerance margins.

In this chapter, I will analyse the functional process that brought us to defining the form of the *Fiorita Passive House* and how this form is determined by a structure in CLT. Throughout the three design phases (preliminary, definitive, final construction designs) each morphological and technological solution is defined step-by-step. The first steps are the following:

1. identifying the correct form;
2. adapting it to technical regulations of the sector and to other functional aspects;
3. defining the structure in CLT;
4. designing the foundations;
5. designing the structure in elevation.

Given that every construction and formal solution has been refined through a design process aimed at energy efficiency, *from my point of view*, in the design of a Passive House, one should avoid formal solutions of a purely decorative nature if they can generate thermal bridges or increase the dispersing surface.

Take note! This does not mean renouncing attractiveness. Ideally, any design solution, except in truly extreme cases, may be able to reach the requirements requested for a Passive House, but an approach that is not functional can lead to a significant increase in costs. In addition, a functional design approach invokes a primary aesthetic perception: come to think of it, everything that we perceive in nature as "beauty" has been produced through the same process. Every organic form and detail, such as those of a flower, a bee or the cells of a honeycomb, clearly depend on the structure of the organism itself and can never be considered as decorative accessories: their form is always linked to their function. On the contrary, the creations of man are always imperfect when you observe them in the light of the functional integrity of nature.

On the other hand, I only had to elaborate a project that tied the form to the function: having to insert eight real estate units where previously there were four, minimising the thickness of the external walls in order to optimise the small amount of usable floor space, containing costs, and, last but not least, reaching the Passive House standard, this was the only way to ensure the survival of the project and, alas, that of the designer (Fig. 4.1).

In this regard, Neutra (1954) writes:

> Primitive s as well as moderns try first to realize their purposes throught technological inventiveness and functional design. Then, not completely gratified by the results, they supplement the slow and laborious satisfactions of imperfect instrumentalism with wishful

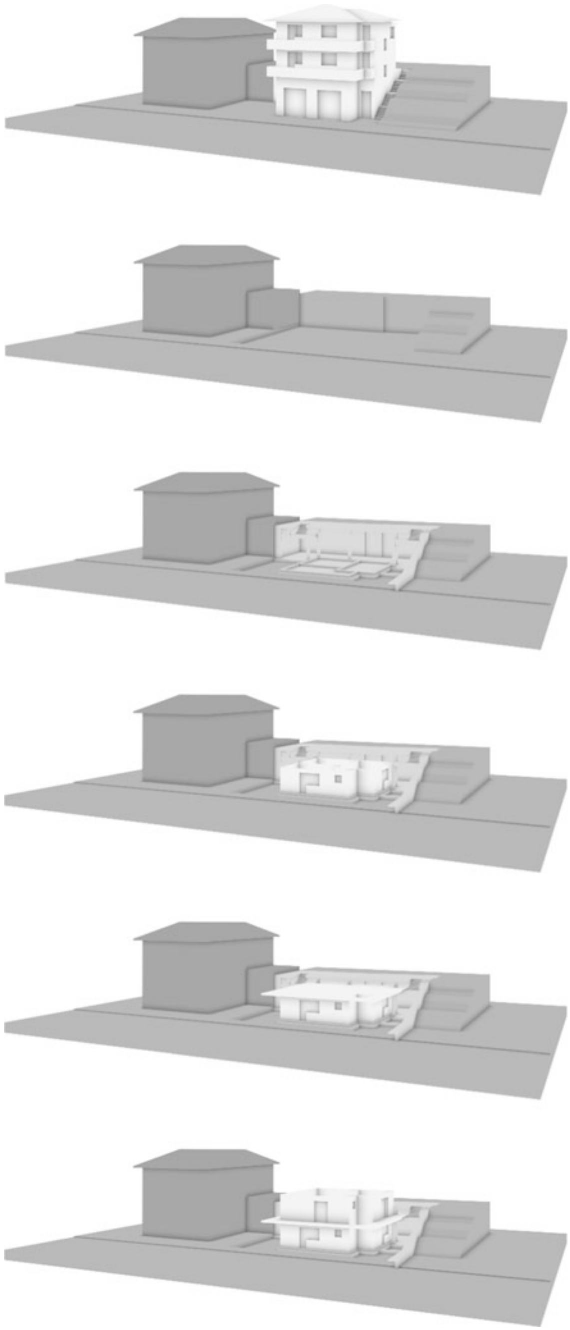


Fig. 4.1 Construction phases of the *Fiorita Passive House*

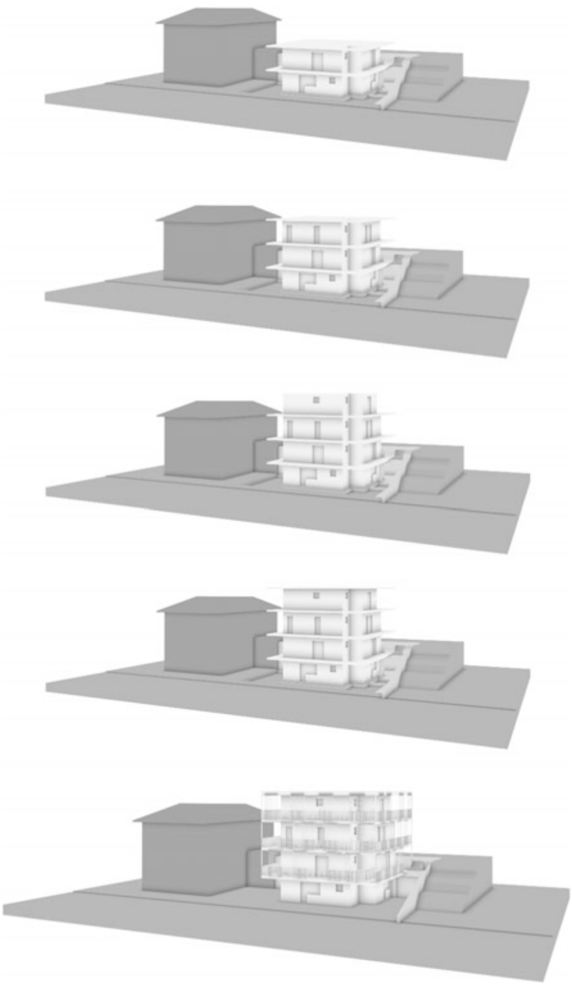


Fig. 4.1 (continued)

magic and symbolic imagery. Where rationally purposed design falls short, may bolster our confidence, our feeling of security. But as we attain greater functional efficiency in design, we can gradually find a purely naturalistic approach, dispensing with supernatural augmentation. Our design then tend to acquire in some measure the differentiated complexity as well as the economy of the unimpeachable functionalism that impresses us in nature. (Neutra 1954, p. 101)

4.1 Preliminary Design: The Correct Form

The ideal form of a Passive House is a compact one (less dispersing surface) that allows the maximum exploitation of solar radiation in the winter and the maximum shading during the summer. However, this is not always possible: due to regulatory and compositional issues, orientation of the lot, conditions put on the content, etc.

In my case, the legislation governing the intervention of building retrofitting with demolition and reconstruction of an equal volume, that would be carried out in Via Ariosto to build the *Fiorita Passive House*, obliges us to maintain the plot of land occupied by the building unchanged. The preliminary design has to deal with this strict constraint. As for the old building, the *Fiorita Passive House* would have had a particularly wide north face, the one on Via Ariosto, and a reduced south face, that of Via Liguria.

The form of the building should be monitored through the calculation of energy performance using the PHPP, where one enters the geometric data of the building, its orientation and the dimensional and thermophysical characteristics of all its components. The form of the envelope, characteristics of the materials and solar radiation are a function of energy efficiency.

The form plays an important role, both in terms of containment of the dispersing surface and management of the solar radiation, also in relation to the materials used to characterise the surface. In this regard, for the calculation of energy performance, one enters the data concerning shading elements and windows to determine the efficiency of the thermal loads due to solar radiation. Moreover, in regions characterised by hot summers, to control overheating, additional data are requested, such as:

the exterior absorptivity, which depends on the colour of the surfaces;
the exterior emissivity, which depends on the capacity of the material to reflect the sun's rays;
the reduction factor of the shading, in relation to the urban density in which the building is located.

Because of the regulatory constraints and the orientation, I didn't find myself with a good starting point for designing a Passive House. This condition is aggravated by a Mediterranean climate tending to temperate sub-continental characterised by summer and winter seasons that are very different from one another (Fig. 4.2).

4.1.1 Winter Season

The sun plays a crucial role, especially during the winter season, where it is necessary to maximise the solar heating gains. If we are operating in the northern hemisphere, it is appropriate to prefer the south face, which is more exposed to solar

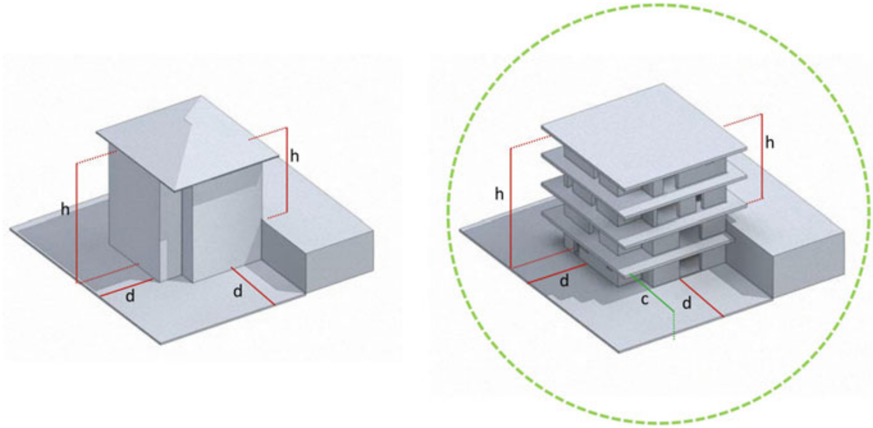


Fig. 4.2 Comparison between the volume of the previous building (left) and that of the new project (right). The dimensional parameters that relate to the height of the building and the distance from the borders must remain unchanged

radiation. On the contrary, in the southern hemisphere, the sun prefers the north face. Therefore, with such a large north face, I could say that I was definitely in the wrong hemisphere.

Also, to increment solar heat gain, it is necessary to observe the surrounding situation so as to check how shadows are cast in the winter season by trees or neighbouring buildings. The presence of obstacles can reduce the solar heat gains: the gains are produced through the passage of the radiation from the windows' glass or simply by incidence on the opaque parts of the envelope (exterior walls, roofs and floor slabs in cold environments).

The orientation, the dimensional data of the windows, the glazing (g) of the glass (the ratio between the thermal energy globally transmitted from the pane and the incidence on it) and the geometric data of the elements that cause shading, are used to calculate the energy gains from solar radiation.

The form of the building (orientation, opaque and transparent surfaces, inclination of the components of the envelope) must therefore maximise the exploitation of the solar radiation.

In my case, the situation was further reduced by the presence of a building of equal height located to the east and by the presence of tall trees on the western front. In addition to the neighbouring building, also the evergreen trees of the *Pinus Pinea* species obstruct the entrance of the solar radiation during the winter. If they had been deciduous trees the situation would be greatly improved, since they would create shadowing in the summer season, only when it is useful for limiting overheating. One cannot be lucky all the time (Fig. 4.3).

From a first analysis it is evident that the new building would have had particularly poor solar gains. In this situation, it was all the more necessary to limit energy losses, so we decided to contain the dispersing surface by designing a

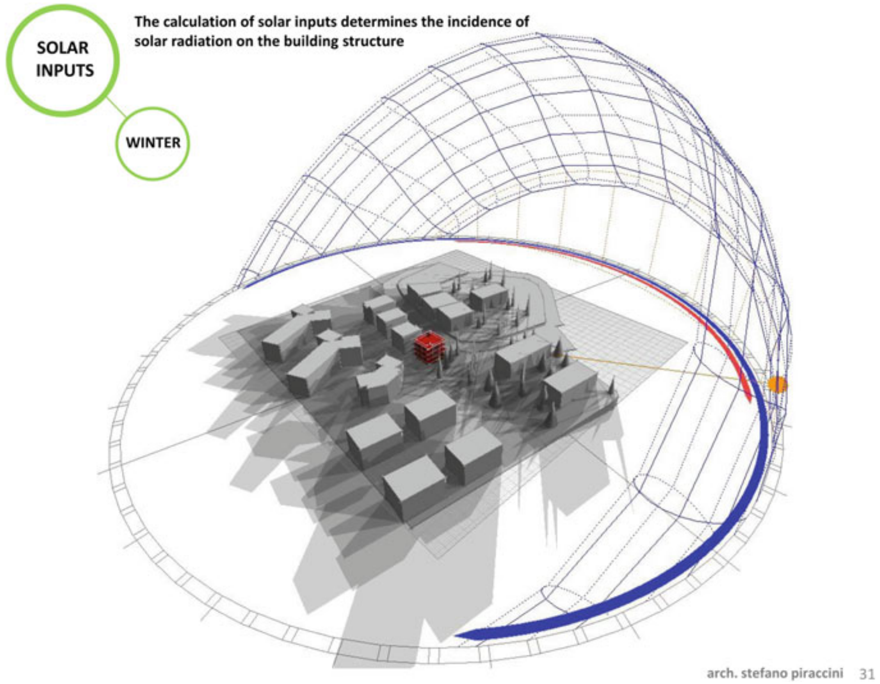


Fig. 4.3 Simulation of the solar radiation in the winter season processed with the Autodesk Ecotec© software

building with a compact volume, as much as was possible, given the legal obligation to preserve the exterior outline of the existing building.

The *Fiorita Passive House* has a compact shape that encloses the climate-controlled envelope: every element in subtraction compared to an ideal cube is due to the constraints of the outline. The roof is flat to limit the dispersing surface, which would be greater in the case of a sloping roof.

4.1.2 Summer Season

Another issue is the control of irradiation in the summer season that, in climatic contexts such as the reference one, must be analysed with the same accuracy as the winter season, especially in our climatic context of reference.

To limit the effects of overheating, it is important that the form of the building, which includes overhangs and shielding, performs the function of solar shielding, especially near the windows. The shielding should allow the input of solar radiation during the winter, so as to maximise the heat gains and heat the indoor environments, while at the same time it should prevent its entrance during the summer so as to reduce the internal thermal loads which, if excessive, create overheating when they cannot be disposed of by the controlled mechanical ventilation (CMV).

Therefore, the form of the building will have to adapt to the different inclination of the sun during the seasonal cycles. At the latitude of Cesena, on 21 June (the summer solstice), day of maximum inclination of the sun with respect to the horizon, the solar radiation assumes, in relation to the horizontal plane, an inclination of 69.11°, datum that settles at 22.37° on 21 December (the winter solstice), day of minimum inclination with respect to the horizon.

These evaluations may be carried out using a solar diagram, specific software or free tools such as the site http://www.sunearthtools.com/ (Figs. 4.4 and 4.5).

The presence of vertical elements such as the neighbouring building situated to the east or the trees located on the west side, act as effective shielding in the summer, limited to the first and in the last hours of the day. In these hours the sun, still close to the horizon, emits solar rays with a low inclination. The question changes during the hottest hours of the day, the central ones, where the summer sun, high on the horizon, generates shadows of limited dimensions that are no longer effective as shields.

By way of example, if we place a cube on a table, turn off the lights and simply illuminate it with a flashlight resting on the surface of the table, this will produce extremely long shadows that will project onto any other object present on their path. If, on the contrary, we light the cube from above, the shadow you will get is significantly smaller, leaving any other object present on the table illuminated. In these cases, to resolve the problem, horizontal shielding is needed: a system of projections whose size is calculated to guarantee access to the radiation in the winter and to provide shading in the summer.

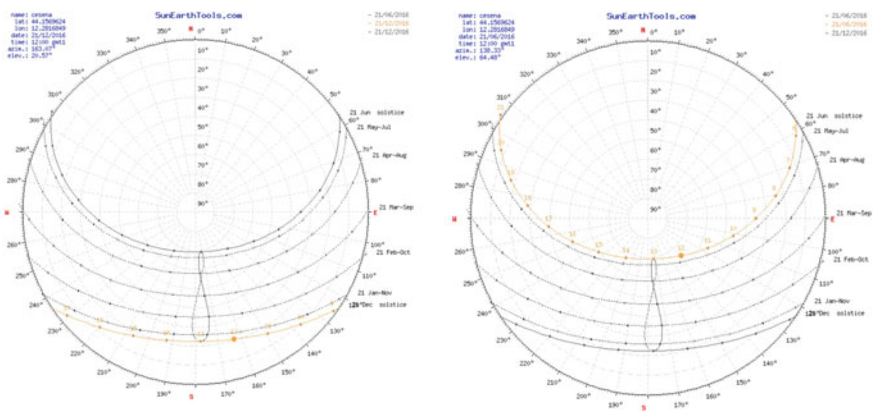


Fig. 4.4 Solar radiation in the city of Cesena at 21 December (graph on the left) and 21 June (graph on the right) processed by the site http://www.sunearthtools.com/

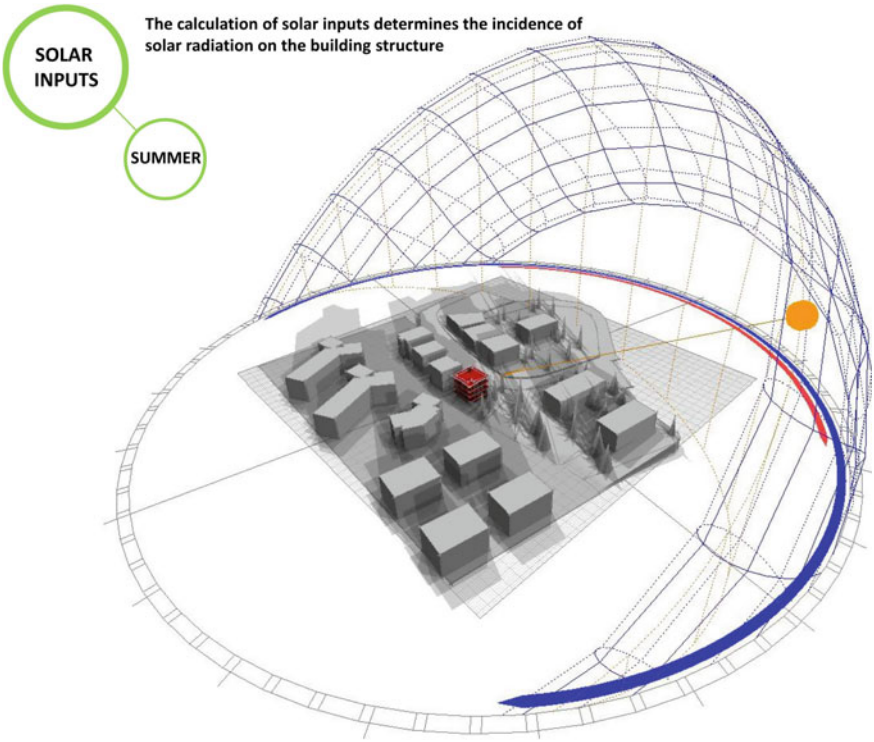


Fig. 4.5 Simulation of the solar radiation in the summer season processed with the Autodesk Ecotec© software

Therefore, to the compact envelope of the *Fiorita Passive House* was added a system of terraces that, on the one hand, have the function of solar shading, on the other, they become an effective instrument for the distribution of the entrances to the real estate units. An excellent solution not only in functional terms, but also in relation to the surface: the urban legislation, in fact, allows the system of terraces to be excluded from the calculation of the volumes on the building site. We could then use the available volume exclusively for the apartments, saving on all the access and connection paths.

We had killed two birds with one stone. Certainly, the overhang generates a thermal bridge, but it appears as an indispensable functional element: we will evaluate how to solve the thermal bridge further on (Fig. 4.6).

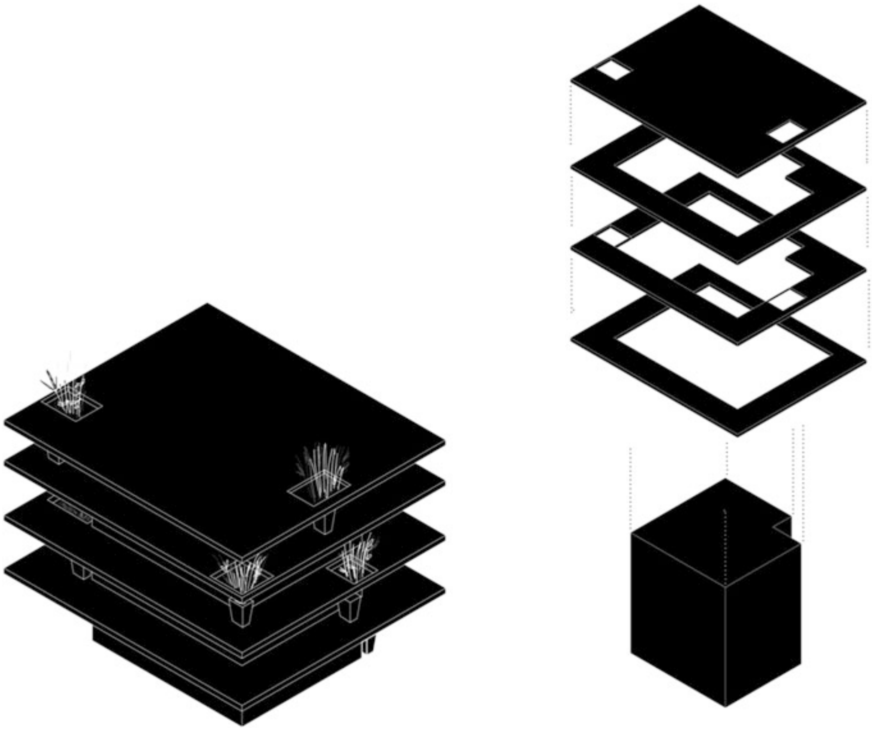


Fig. 4.6 Integration of the terraces in the compact volume of the building

4.2 Definitive Design: Other Functional Aspects

The form of the building defined in the *preliminary design* has been tested with the Autodesk Ecotec© software. Through a three-dimensional model of the building and its surroundings, the software performs a simulation of the incidence of the solar radiation and of the shadows that are cast throughout the entire year-long period. Using this instrument, we placed, where possible, the windows in the positions of the façades capable of guaranteeing the maximum solar gains (Figs. 4.7, 4.8 and 4.9).

In addition, we verified that the system of overhangs does not always guarantee the shading of the façades during the summer months preceding or subsequent to the summer solstice. To solve the problem, a brise-soleil system was added, composed of sliding vertical panels, parallel to the plane of the façade. The brise-soleil consists of panels in an expanded metal frame which can be placed against the façade, creating shading in the desired position. The system, extended also to the northern face, increases the privacy of the indoor spaces, a necessary requisite considering the high urban density of the district in which the building is located.

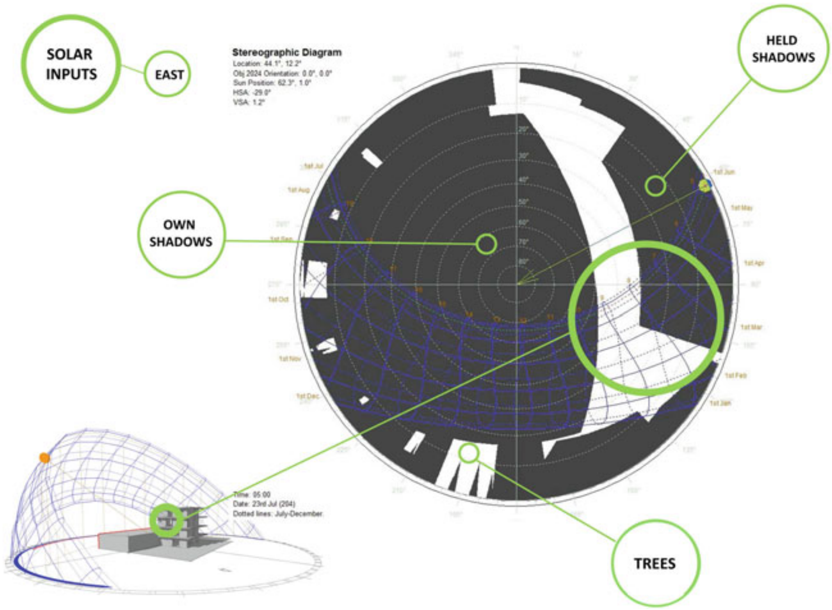


Fig. 4.7 Example of the calculation of the solar radiation on the eastern front with Autodesk Ecotec© software

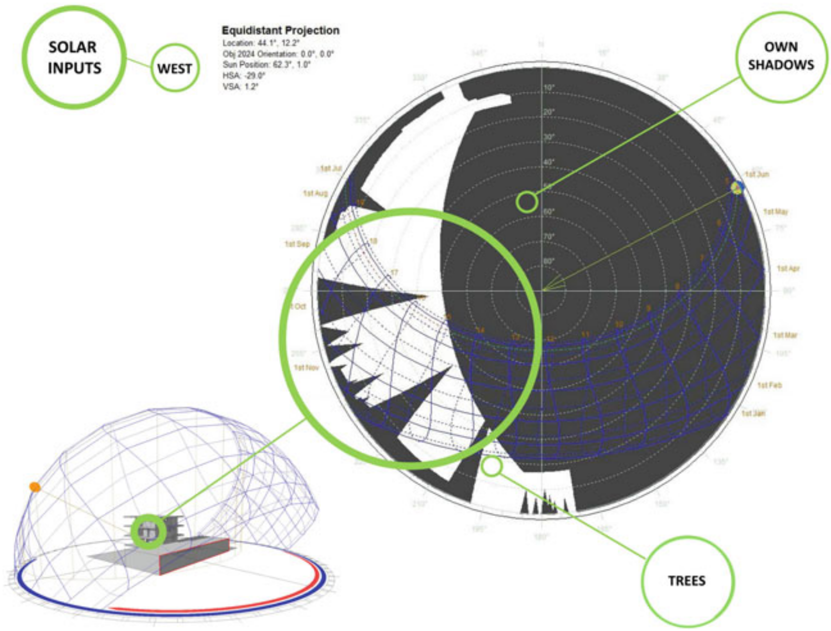


Fig. 4.8 Example of the calculation of the solar radiation on the western face with Autodesk Ecotec© software

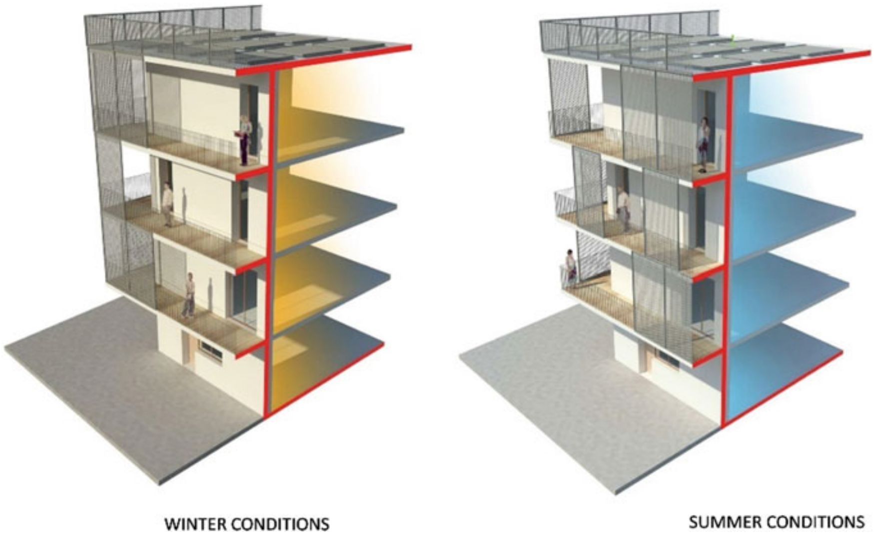


Fig. 4.9 Operation of the brise-soleil in the winter and summer seasons

What remains now is to make the small adjustments necessary to obtain a definitive design of the building, adapting every aspect (heights, size of the rooms, lighting ratios, etc.) to the legislation, regulations and technical standards. To do this, among other aspects, it is necessary to determine the thickness of the walls and the roof with some precision in order to draw up plans, sections and elevations with an adequate degree of detail.

To obtain these data, it is necessary to carry the evaluations of the energy stratigraphy of the envelope towards spaces without climate control. In this regard, in the *definitive design* of the *Fiorita Passive House* we have devised an envelope with transmittance values ($U \leq 0.15$ W/m^2 k) and thermal lag (≥ 16 h) with external walls having a thickness of 40 cm, and a roof that is 50 cm thick.

Through a preliminary verification with the PHPP, entering the geometric data of the definitive project, the transmittances of the envelope and the hypothesised precautionary values for what concerns thermal bridges, air tightness, plants, etc., the building seemed to fulfil the Passive House requirements.

To be sure about it, all that remains is to investigate it further with the final construction design. This is the most important and extended part of the design phase, and I will describe it starting from next paragraph until the end of this book.

I will begin by describing the structure.

4.3 Structural System

The point of departure for a final construction design is the definition of the load-bearing structure. For the structure of the *Fiorita Passive House*, as has already been mentioned, we have used CLT for the entire climate-controlled envelope where the eight apartments are located. CLT has been used both in the construction of the vertical load-bearing walls (external and internal walls and partitions), as well as in the floor slabs and roof. CLT, like other structural systems in wood, must not remain in direct contact with the ground; therefore, the foundations of the building consist of a foundation in reinforced concrete. The interactions between the structure in elevation in CLT and the foundation must be carefully evaluated in order to avoid contact with water and protect the thermal bridge of the attachment of the building to the ground.

In the constructions in CLT, all portions of the structures in direct contact with the ground are made with reinforced concrete elements that ensure an effective durability, since the wood would deteriorate in a short time span. Therefore, in the *Fiorita Passive House*, the semi-underground portion of the building that houses the garage and technical compartments was built with wet construction systems. This portion of the building is not climate controlled; therefore, it has little relevance to the design of a Passive House. The two bodies of the building are divided by a structural joint that cancels any interaction of a structural type.

In this book, I intend to describe the technological aspects relating to the construction of a Passive House with its structure in CLT; therefore, the questions relating to aspects of the structural dimensions will not be addressed.

CLT is a panel of fir wood composed of boards which are arranged parallel to each other with at least three crossed layers, and it is used in the realisation of structural systems composed of load-bearing walls. The panel can also be used to produce the horizontal structural elements such as floor slabs or overhangs; it is a structural system with high levels of prefabrication: the panels are made in the production plant, cut and shaped with numerically controlled machines, according to cutting patterns drawn upon the basis of the structural final construction design (Figs. 4.10 and 4.11).

Poortions of the building façade are made—or even entire façades—with the holes for the doors, windows, and all of the passages for the integration of the plants, the same applies to the panels used for the floor slabs. The panels, then transported to the site after the realisation of the foundations, are juxtaposed with the use of a lifting system (crane or truck-mounted crane), anchored in advance with long screws positioned crosswise and subsequently with metal anchorage plates. The first vertical panels are lowered and then anchored to the kerbs of the foundation to achieve the vertical structure of the ground floor. Subsequently, the horizontal panels are laid, which form the horizontal structure of the floor slab of the first floor. One proceeds in the same manner to produce the subsequent floors.

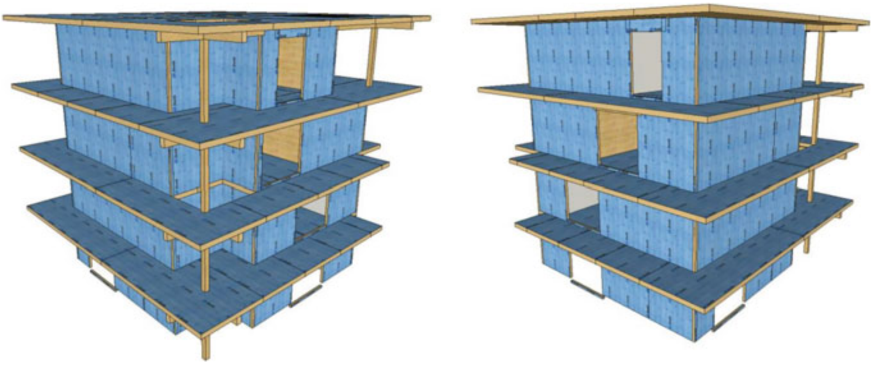


Fig. 4.10 Model of the structure in CLT

Fig. 4.11 Lifting a panel in CLT that has been shaped in the production plant

The structure is then assembled, in the same way in which a student of architecture would build a model of a multi-storey building using balsa wood panels cut with a cutter. This structural system has excellent anti-seismic performance, as reported in Boeri et al. (2012):

> (…) under the safety profile, in the event of an earthquake the load-bearing structures of crossed layers of panels offers high performance characteristics demonstrated by experimental tests. A test model in real scale 7.5 × 15 × 23 m and a weight of 120 tonnes, was tested with favourable results at the vibrating platform of the NIED (National Research Institute for Earth Science and Disaster Prevention) laboratories at Miki near Kobe in Japan. (…) The building passed all the tests, remaining perfectly vertical, without presenting any damage or need for repairs, but only a requiring a resetting of the mechanical joints for connection between the floor slabs and internal walls. The building has been subjected to the actions of the following earthquakes:
>
> – Jma Kobe in 1995, Kobe earthquake (once at 33% of the maximum intensity, once at 50% and twice at 100% of its maximum intensity);
> – Kashiwazaki in 2007, Niigata-Ken Chuetsu-oki earthquake (once at 50% intensity and once at 100% of its maximum intensity);
> – Nocera Umbria in 1977 Umbria-Marche, earthquake, (once at 100% of its maximum intensity). (Boeri et al. 2012, p. 78)

In addition to the safety profile, an important feature of this construction system is its rapid execution: the structure in CLT of the *Fiorita Passive House* was assembled in just 10 days (Fig. 4.12).

The high amount of prefabrication of the system allows precision, quality of the product and speed of execution, but requires, at the same time, extremely accurate and detailed planning. Given the characteristics of the material, any variations in the course of the work, such as making holes, can be extremely difficult to do through the use of cutting tools that are commonly used in construction sites. Therefore, before beginning the production of the system, one must verify all the interferences that involve other functional layers of the envelope and the interior partitions, and other interference with: plants, thermal bridges, water seal, airtightness and so forth.

Jered Diamond in Collapse: How Societies Choose Failure or Success (Diamond 2005), writes:

> (…) The (mining) industry is currently the leading toxic polluter in the U.S., responsible for nearly half of reported industrial pollution. Of western U.S. rivers, nearly half have sections of their headwaters polluted by mining. (…) Metals and metal-like elements in the ore itself - especially copper, cadmium, lead, mercury, zinc, arsenic, antimony, and selenium - are toxic and prone to cause trouble by ending up in nearby streams and water tables as a result of mining operations.
>
> (…) the world could meet its timber needs sustainably from a small area (20% or less) of those forests if they were well managed. (…) Those concerns about the long-term future of their own industry impelled some timber industry representatives and foresters in the early 1990s to launch discussions with environmental and social organizations and associations of indigenous peoples. In 1993 those discussions resulted in the formation of an international

Fig. 4.12 Lifting of the panels in CLT and laying on the foundation's kerb

> non-profit organization called the Forest Stewardship Council (FSC), which is headquartered in Germany and funded by several businesses, governments, foundations, and environmental organizations. (…) The forest certification movement has spread rapidly around the world since the FSC's launching in 1993, to the point where at present there are certified forests and chains of custody in about 64 countries. (Diamond 2005, pp. 460, 461, 483, 488)

CLT is a material that is assembled dry and it presents important aspects under the profile of environmental sustainability. The construction phases of a building built with this material do not require water, as opposed to buildings in reinforced concrete or masonry. Steel, cement, stone and the clay, which forms the bricks, are extracted from the earth, causing land change and pollution of the catchment basins. On the contrary, wood comes, at least those products present in the Italian market, from FSC certified (Forest Stewardship Council) forests for the production of wood. The FSC is an international certification that guarantees sustainable use of the wood resource, identifying nine criteria for proper forest management:

felling of the trees at a pace that can always be sustained, because it allows new trees to replace those that are cut;
integral protection of particularly valuable forests, such as ancient ones;
long-term conservation of biodiversity, of nutrients, of the integrity of the soil and of other functions of the forest ecosystem;
protection of the catchment basins;
maintenance of banks that are sufficiently extended along streams;
a long-term management programme;
waste disposal plants and systems for the disposal of chemicals outside the forest area;
compliance with the norms in force;
recognition of the rights of the indigenous communities and the workers of the forest areas.

Compared to the pollution produced by the mining industry, it is my opinion that, choosing wood as a building material contributes to pursuing the same objectives in terms of sustainability, linked to energy saving and to the reduction of emissions in the atmosphere, of a Passive House.

Using wood in the building of a Passive House, and therefore also CLT, even ensures great advantages in terms of energy performance: both for obtaining good transmittances of the envelope with reduced thicknesses, but above all, for reducing the thermal bridges. In this regard, it should be pointed out that steel, in relation to the percentage of nickel, has a transmittance which varies from 29 to 105 W/m^2 K, a stone wall, equal to reinforced concrete, has about 2.3 W/m^2 k, while a wall in solid brick has 0.7 W/m^2 k. In contrast to the other construction materials, fir wood has a transmittance of just 0.10–0.12 W/m^2 k if orthogonal to the fibres and of 0.15–0.27 W/m^2 k if parallel. Since CLT is produced in crossed boards of fir, it has a transmittance of about 0.12 W/m^2 k. These values indicate to us how the dispersions generated by a thermal bridge, for example, a terrace or a cornice, are considerably reduced in the case of a structure in CLT. This does not mean that we can wash our hands of the thermal bridges, but it certainly simplifies their resolution (Figs. 4.13, 4.14, 4.15, 4.16 and 4.17).

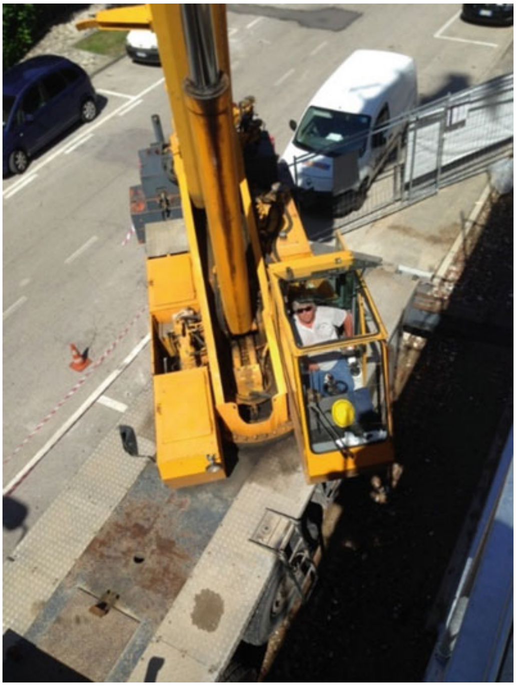


Fig. 4.13 Truck-mounted crane used for lifting the panels in CLT

Fig. 4.14 Circular holes present in the vertical panel and the rectangular one present in the horizontal panel were carried out in the production plant to allow for future plant integration (ventilation machine and drainage system of the sanitary wastewater)

Fig. 4.15 Hole to allow the passage of a downpipe

Fig. 4.16 Preparing for the lifting of a panel in CLT

Fig. 4.17 Internal view of the structure in CLT

4.4 Wet Foundations and Structures

Wood has a poor relationship with water and humidity; therefore, both the foundations of the building and the portions in contact with the ground have been made with a wet system. The laying of a wooden structure that is not protected from moisture or from rainwater or, in more extreme cases, is in direct contact with the ground can cause extensive damage. For this reason, the durability of a building in wood starts from the foundations.

The plot of land where the construction will take place is located on a slope: the higher part to the south, Via Liguria, is approximately 4 m higher than the Via Ariosto side (Figs. 4.18 and 4.19).

In order to optimise the surface area of the plot of land to the greatest extent possible, the building's foundation and the external spaces were kept at the lower level of Via Ariosto. Therefore, in order to contain the ground pressure on Via

Fig. 4.18 Section of the building: the wooden structure in black; the reinforced concrete structure in grey

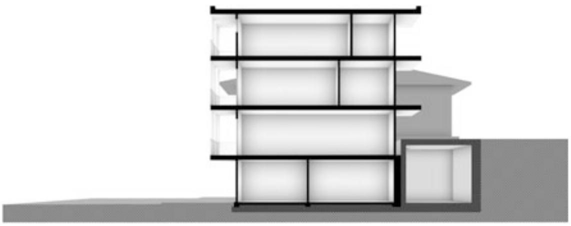


Fig. 4.19 Panels in CLT resting on the kerbs of the foundation

Liguria (south) and on the park with trees (west), micro stakes and a supporting wall in reinforced concrete were made, which support the ground at a higher level along the south and east faces.

Once an excavation of the area was carried out, a 5 cm layer of lean concrete was poured, creating a support surface for the foundation.

After the outline of the building was traced on the lean concrete bed and the pipes for the discharging of wastewater were laid, the reinforcing irons and the wooden formwork were laid, for the subsequent layer of concrete, with a waterproof additive.

A construction solution used in the Passive House envisages the use of insulation placed under the foundation, interposed between the lean concrete layer and the foundation, usually in cellular glass or extruded polystyrene foam with high compressive strength (≥ 700 kPa at 10% deformation DIN EN 826), even in the long term (≥ 250 kPa at 50 years at 2% deformation UNI EN 1606), with capillarity null and moisture resistance. This construction technique facilitates the solution of the thermal bridge of the connection to the ground of the building, the point in which the external wall connects to the floor slab, and it is possible to avoid the discontinuities with the insulation placed within the external walls.

In the construction of the *Fiorita Passive House,* we used a different technical solution: the insulation—*extruded polystyrene foam with compressive strength of 500 kPa at 10% deformation*—was positioned on the extrados of the foundation, below the substrate for the plants. In this case, the insulating layer may have a lower compressive strength and usually lower costs.

The cement base of the reinforced concrete foundation has a thickness of 0.40 m, and a system of kerbs placed in correspondence to the resting points of the vertical panels in CLT. The form of the kerbs is designed in accordance with the structural designer, in order to absolve the following requirements:

Fig. 4.20 Dry structure and wet structure

receiving the loads of the structure in elevation;
ensuring the anchoring of the corner metal plates required for the fixing of the panels in CLT;
optimising the thermal bridge of the attachment of the building to the ground;
ensuring the water seal and waterproofing (Figs. 4.20, 4.21 and 4.22).

The horizontal surface of the kerbs must be perfectly coplanar to ensure effective support of the panels in CLT: these kerbs will, in fact, bear the entire structure of the building.

Therefore, it is necessary to check the elevation of the kerbs and the plane of the foundation structure in CLT, to ensure that, when the structure has been completed, the building is not higher or lower than foreseen in the design.

Fig. 4.21 Internal kerbs

The perimeter kerbs, in contact with the ground, are sealed on their vertical and horizontal surface, with a bitumen-based sheath to avoid the capillary infiltration of the water from the soil. The same material is used to protect the horizontal surface of the remaining kerbs. This solution contributes to the protection against capillary infiltration.

The coplanarity of the kerbs should not be compromised by the application of the bitumen-based sheath, which must be free from bulges and abundant overlapping.

Once one has performed the works of waterproofing of the kerbs of the foundation, the perimeter of the concrete bed, for its entire height, is insulated with slabs of XPS (extruded polystyrene) with compression strength of 500 kPa at 10% distortion, $\lambda = 0.036$ W/mK and a thickness of 0.20 m. This processing is necessary to protect the thermal bridge, an issue which we will analyse with greater attention in the subsequent chapters.

Before covering the ground with kerbs and foundation, the outer face of the insulation is protected by a membrane which is embossed in high-density polyethylene, with the purpose of protecting the insulation from contact with the ground and improving the water resistance of the entire system (Fig. 4.23).

Above the foundation and its waterproofing systems, in direct contact with the support wall that sustains the embankment of Via Liguria, the structure in reinforced concrete was built, therefore with the wet system, for garages and technical rooms. It is a vertical structure of pillars and supporting walls in reinforced concrete, which supports a floor slab composed of beams in reinforced concrete and predalles floor slabs. The covering of the underground garage is carriageable and is used for the car parks present inside the plot of land and accessible from Via Liguria. This portion of the building is not climate controlled: it is a technical body

Fig. 4.22 Insulation of the external kerbs

that, in addition to the garages, hosts the plants compartment. The spaces used as residence are exclusively within the climate-controlled envelope made with the structure in CLT (Fig. 4.24).

Fig. 4.23 Detail of the panels in the XPS used for insulating the foundation kerb

Fig. 4.24 Verification of the orthogonality of the laying of the panels in CLT

4.5 Structure in Elevation

The installation of the panels in CLT on the kerbs of the foundation is carried out after the reinforced concrete that constitutes the concrete bed of the foundation has reached the sufficient degree of maturation: about 28 days from the last pouring. The panels that constitute the structure of the ground floor have a thickness of 12 cm and are lifted and positioned on the kerb of the concrete bed of the foundation. All are numbered according to the laying scheme set up by the manufacturer on the basis of the final design project (Fig. 4.25).

The panels are lifted with a truck-mounted crane, positioned on the kerbs and shored up. In the vertical contact surfaces of each panel two strips of butyl sealing tape (Butyl Band produced by Rothoblaas) are applied, to ensure airtightness. In that respect a strip was used consisting of black butyl adhesive with the interposing of a mesh in polypropylene filament that limits the over-extension of the product. The butyl tape seals the vertical joints of the panels, ensuring thermal and acoustic insulation, water seal and airtightness (Fig. 4.26).

Each vertical panel is then fixed to the next one using long screws positioned crosswise at 45° also in correspondence with the vertical joints. It is necessary to continually check during assembly for the orthogonality of the walls and partitions and their coplanarity in all directions, ensuring, moreover, all the measures

Fig. 4.25 Worker studying the laying diagram of the panels in CLT

Fig. 4.26 Application of the butyl tape along the vertical joints of the panels in CLT

indicated in the laying diagram. Any adjustments can be carried out by tightening or loosening the screws positioned crosswise. Once the vertical structure of the ground floor is finished and all of the anchoring has been carried out, the elements system stands in an independent manner due to the box shape of the system.

Before installation of the horizontal panels in CLT constituting the structure of the floor slabs, a sound insulating joint (Rothoblaas Track®) is applied on the top of the vertical panels. This is a product made of EPDM (Ethylene-Propylene Diene Monomer®) which restricts the transmission of vibrations between wood and wood due to treading. The same product is also applied below the vertical panels that constitute the successive floors of the building (Figs. 4.27, 4.28, 4.29 and 4.30).

Fig. 4.27 Application of screws positioned crosswise in correspondence with the vertical corner joint

Fig. 4.28 Metal plates for the anchoring of the panels in CLT to the foundation kerb

Fig. 4.29 Application of the sound insulating joint

Fig. 4.30 Laying of the panel in CLT which constitutes the first-floor slab

Once the horizontal panels of the first-floor slab have been laid, one proceeds with the laying of the vertical panels that constitute the supporting walls of the first floor. For the realisation of the successive floors, one proceeds with the same system until the laying of the horizontal panel of the roof.

Lastly, on each floor the panels are further attached with mechanical anchorage: HBS and VGZ type screws, straight or positioned crosswise, TCN, TTN and VWT type plates.

The system is so rapid that the entire structure in CLT of the *Fiorita Passive House* was assembled in just 10 days.

Once the wooden structure is finished, it is important to deal with the water seal; therefore, a waterproofing sheath is applied on the horizontal panels used for the roof and terraces, and on the vertical panels that constitute the attachment of the building to the ground. In this regard, it is necessary to pay special attention near external doors and French doors, where in this case we have applied a strip of larch wood, covered in a waterproofing sheath, to allow a subsequent laying of the fixture to avoid infiltrations.

Once the structure has been secured against the action of rain water, one proceeds with the application of tapes for airtightness, applied for the protection of each disconnection such as wood–wood joints and in correspondence with the metal plates (Figs. 4.31, 4.32, 4.33, 4.34, 4.35 and 4.36).

Fig. 4.31 Waterproofing of the roof slab panel in CLT

Fig. 4.32 Laying of the strip in larch wood in order to ensure the application of the waterproofing and the subsequent installation of the French doors

Fig. 4.33 Application of waterproofing sheath on the terraces and on the strip in larch wood used for the anchorage of the French doors

Fig. 4.34 Application of waterproofing sheath on the terraces

Fig. 4.35 Application of waterproofing sheath at the joint between the foundation kerb and the vertical panels in CLT

Fig. 4.36 Completed structure

References

Allen E (1980) How buildings work: the natural order of architecture. Oxford University Press, New York (Italian version: Allen E (1983) Come funzionano gli edifici, Edizioni Dedalo SRL, Bari, Italy)

Boeri A, Longo D, Piraccini S (2012) Il progetto dell'involucro in legno. Dario Flaccovio, Palermo, Italy

Diamond J (2005) Collapse: how societies choose to fail or succeed. Penguin, USA (Italian version: Diamond J (2005) Collasso: come le società scelgono di morire o di vivere, Giulio Einaudi editore s.p.a., Turin, Italy)

EN 1606 (2013–05) Thermal insulating products for building applications—determination of compressive creep

EN 826 (2013–05) Thermal insulating products for building applications—determination of compression behaviour

Neutra RJ (1954) Survival through design. Oxford University Press, New York (Italian version: Neutra RJ (2015) Progettare per sopravvivere, Comunità editrice, Roma/Ivrea, Italy)

Website

http://www.sunearthtools.com/. Consulted on 17 Apr 2017

Chapter 5
Building Envelope

How are the perimeter walls, the floor slabs and the roof made? What materials should one use? What are the thermophysical parameters that one has to keep under control? What requirements must the windows have?

We have now built the structure of the building: it is time to deal with the opaque and transparent components of the envelope:

1. external walls;
2. floor slabs in cold environments;
3. windows.

To design them, we must achieve energy efficiency without sacrificing something at every functional requirement; therefore, it will be appropriate to design the components of the envelope considering the integration of the plants, water seal, airtightness, the desired aesthetic appearance and acoustic insulation, by carefully evaluating the technical characteristics of the materials used and preparing ourselves to integrate each component with abundant layers of thermal insulation.

5.1 Requirements and Characteristics

The external walls and floor slabs on cold environments are composed of various materials organised into functional layers. Can you picture a wafer biscuit? Well, it has a similar structure. By way of example, the external masonry of the *Fiorita Passive House*, on the first, second and third floors, is composed of the following functional layers:

– exterior cladding in wood;
– barrier against the wind;
– fibreglass panel;
– water vapour barrier;

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_5

– panel in wood fibre;
– three-layer spruce panel in CLT (cross-laminated timber), mineral wool panel, plasterboard.

Alberto Domínguez, in the magazine El Mundo of 24 August 2015, in an article entitled “The last mystery of Escobar: his daughter Manuela” cites an interview with Escobar’s son Sebastian:

> (…) to keep my sister warm when she was shivering from the cold in a house where we were hiding, my father once took the only thing he could to keep Manuela warm: a sack full of dollars. He torched two million dollars. (Domínguez, August 24, 2016, p. 7)

Dollars are not a good insulating material, and they have conductivity that is too high; moreover, they burn too quickly. Therefore, it is a good idea to be familiar with the thermophysical properties of the materials that are used, and this is not only true in conditions where our survival or that of our loved ones is threatened, as in the case of Escobar, but also in the construction of a Passive House.

To design the opaque components of an energy-efficient building envelope, it is good to have an understanding of the thermophysical parameters that characterise each material:

– conductivity λ (W/m K—UNI 6946 and UNI 10351) expresses the property of the material in heat conduction. It is determined by the heat flow that traverses a surface having a unitary area and thickness, subjected to the difference in temperature of 1 K.
– thermal resistance R (m^2 K/W—UNI 7345 and UNI EN ISO 6946) indicates the ability of the material to oppose the passage of heat. It is determined by the ratio between the thickness of the layer considered and its thermal conductivity.
– heat capacity C_{p} (kJ/kg K) indicates the ability of the material to accumulate heat. It is determined by the amount of energy necessary to increase the temperature of the material by 1°.
– density ρ (kg/m^3—UNI EN ISO 9251) indicates the ratio between the mass and the volume of the material.

Each of these parameters is variable, since many thermophysical magnitudes influence the performance of the components of the building envelope, such as the following:

– the overall thermal transmittance U (W/m^2 K—EN ISO 6946) expresses the thermal insulating capacity of the wall. It is the heat flow that traverses a unitary surface subjected to a temperature difference equal to 1 K. This quantity depends on the thermal conductivity (λ) and on the thickness of the individual layers of the component. The lower the U value of the component, the greater its insulating capacity.
– the decrement factor F_{d} (%—EN ISO 13786) expresses the component from the internal towards the percentage of reduction of the heat flow that traverses external environment. The higher the F_{d} value, the lower the heat flow that traverses the component.

- the thermal lag φ (h—EN ISO 13786) is the interval of time necessary for the heat flow from solar radiation to traverse the component from the external part towards the internal part. The greater the interval, the greater the delay with which the external heat is transmitted internally.
- the periodical thermal transmittance (YIE) (W/m^2 K—EN ISO 13786) is the capacity of the component to offset and decrease the heat flow that traverses it within 24 h. The smaller the value, the greater the ability to offset the heat flow.

Of all these parameters, the PHPP (Passive House Planning Package) software in version 7 (2012), the one that we used to design the building, merely requires for each material the values λ (thermal conductivity) and the thickness, in order to check the overall thermal transmittance and to design components with U values normally ≤ 0.15 W/m^2 K.

The PHPP 7 calculates the behaviour of the building in the winter season through some variables, the same level of attention, in my opinion, is not reserved for the calculation in the summer season, equally important in my climatic context of reference, where the summers are hot and humid (However, later versions of the software such as PHPP 9, available at the time of writing this book, have optimised the calculation in the summer season).

In the winter period the envelope energy performance is evaluated in a steady state, taking as reference the thermal transmittance values, in the summer and intermediate months the operation of the components of the envelope is determined in a dynamic state according to EN 13786. If one operates in contexts characterised by hot summers, as in our case, it is important to keep them under control to limit overheating in summer.

In the planning of the *Fiorita Passive House*, we have designed components of the external envelope with thermal lag values >16 h. The thermal lag is calculated on the day of the year that has the maximum radiation and southern exposure.

5.1.1 Thermohygrometric Requirements

The water vapor traverse the functional layers of the wall, so to prevent the possible formation of interstitial and superficial condensation, the EN ISO 13788 standard tells us how to carry out a thermohygrometric verification of all the outwardly exposed components, the ground and the unheated areas.

All material is determined by a water vapour resistance value μ, which indicates the ability of the material to be permeable or impermeable to vapour flows that traverse the envelope from the internal part to the external part. Low μ values indicate permeable materials (μ = 5–10 wood fibres, μ = 1–2 mineral fibres, cellulose, flax, coconut, sheep wool), while high μ values indicate materials that are impermeable to vapour (μ = 20–200 polyurethane and extruded polystyrene, μ = 100,000 vapour barrier).

This verification is not performed by the PHPP.

Given that the Italian legislation provides that the absence of surface condensation and interstitial calculation should be verified, it is done through the use of thermophysical software which calculates, according to EN ISO 13788, the Glaser Diagram, which records the temperature trend and the water vapour pressure and saturation inside the structure.

In a correctly designed component of the envelope, the vapour line does not intersect during any month the line of saturated vapour and, in this way, it prevents the formation of condensate. On the contrary, if the two lines intersect, a quantity of vapour equal to the area of intersection between the two lines forms condensate, and if the condensate does not evaporate, it can encourage the emergence of moulds.

5.1.2 Sustainability of the Building Materials

In the *Fiorita Passive House* project, we have tried to consider environmental sustainability as a prerequisite for every design choice: we are constructing a building with nearly zero energy consumption and we have chosen wood, a renewable material, to build the structure. Therefore, we seek to apply the same principle to the choice of the insulating materials, evaluating how we can use materials, wherever possible (and it is not always possible), of mineral or biological origin, avoiding products of petrochemical origin.

This does not mean that the insulation materials of petrochemical origin are not suitable for the construction of a Passive House; indeed, normally they have elevated performance characteristics in terms of thermal conductivity, less in terms of thermal lag, but are more economical than insulation of biological or mineral origin as well as being water-resistant.

The Passive House protocol defines an energetic standard: it does not enter into the merits of the environmental sustainability of the products which are used in the construction. The choice is left to the designer and client: in relation to the design ethic and to the necessary technical characteristics for the first and normally, to the budget for the second.

For these reasons, for the perimeter walls and internal partitions, we used insulation made of wood, glass or mineral fibres, taking advantage of their characteristics in terms of thermal conductivity and density to ensure optimum efficiency of the vertical components of the envelope both in the summer and winter.

We have, instead, used insulation materials of petrochemical origin for the components of the envelope that have contact with water, such as the ground floor slab and the roof slab. EPS (sintered expanded polystyrene) and XPS (sintered extruded polystyrene) insulating materials are cheap, water-resistant and have high-performance thermal conductivity, usually superior to insulation of mineral or biological origin. XPS, in particular, is resistant to loads and therefore can be used below screeds and with a cement base, ground soil and the foundations of the building.

In this field of application, an insulating material of biological origin would not have had the suitable characteristics in terms of water and compression resistance; on the contrary, we could have used insulation in cellular glass, coming from recycled glass, but unfortunately, our budget did not allow it.

5.2 Walls

In the *Fiorita Passive House* design, we have three types of walls against cold environments: the first two are in direct contact with the external environment, while the third is bordered with the unheated garage. UNI 8290-1 classifies these components as "external vertical closures"; however for simplicity of language, we will continue to call them "walls".

Each type is composed of a series of functional layers that have to meet specific requirements: a system of internal covering useful for the installation of the plants, a layer in CLT (cross-laminated timber) that has a structural function, a thermal insulation layer and an external cladding system that determines the aesthetic appearance of the façades of the building.

The types differ from one another in regard to the cladding system used and to the characteristics of the insulating layers, and they are the following:

(a) external wall with wood cladding, used for the portions in contact with the external environment, used on the first, second and third floors;
(b) external wall with ceramic slab cladding, used for the portions in contact with the exterior of the ground floor of Via Ariosto and on the small portion in contact with the ground on Via Liguria;
(c) external wall cladding with EIFS (exterior insulation and finishing system), a term that identifies plastering, generally siloxane, performed on an insulating panel, used only in the ground floor in correspondence with the unheated garage.

(a) ***External wall cladded in wood***

The wall cladded in wood is the most used wall type in the design. It has a total thickness of 42.4 cm on the first floor and 40.4 cm on the second and third floors. The difference is due to the thickness of the panel in CLT which, for structural reasons, is reduced by 2 cm in the upper floors of the building.

To the panel in CLT, an internal coating is applied, having a layer structure composed of studs in sheet metal filled in by panels of high-density plasterboard. Compared to common panels composed of gypsum additive with glass fibre, vermiculite, waterproofing and wood flour and incorporated between two sheets of cardboard, those used are distinguished by having a density greater than 1000 kg/m^3 compared to 700–800 kg/m^3 of the commonly used panels. A higher density of the panel optimises mechanical and shock resistance, limits the water absorption capacity and reduces that annoying “hollow” effect, which can be perceived by tapping the wall surface with one’s knuckles.

The panels are attached to the system of studs in sheet metal, fixed in turn on the panel in CLT, with screws and small metal plates protected with rubber joints to prevent the dissemination of noise. Once the fixing operations are completed, the panels are stuccoed at the joints and the heads of the screws and then plastered to receive the coating of paint.

During assembly, in the 5-cm space created by the system of studs, a panel of mineral wool with a thickness of 4 cm is placed (Figs. 5.1 and 5.2).

The system of an internal covering in plasterboard allows the insertion, in the cavity, of the distribution network of the system engineering (cables, ducts, etc.); however, in the design of the *Fiorita Passive House*, we have limited this possibility; the project of the external walls has been elaborated with the aim of minimising their thickness to the advantage of a greater usable surface of the apartments; therefore, with cavities of only 5 cm occupied by 4 cm of mineral wool, any plant integration (pipeline, wiring, duct) would have resulted in the reduction, even if limited, of the thermal insulation.

The distribution network of the technical plants (heating/cooling duct and pipeline, wiring, etc.) is located in the internal walls made of plasterboard, with a layer of mineral wool interposed between the two sheets of plasterboard, with the sole function of acoustic insulation; in this way, the plant integration does not involve the formation of thermal bridges.

On the external side of the panel in CLT, a 10-cm-thick wood fibre panel is applied by adhesive bonding, as well as a subsequent panel of fibreglass with a water vapour barrier. Adhesive bonding has been carried out on the perimeter of the

Fig. 5.1 Metal structure for the laying of the plasterboard

Fig. 5.2 Internal wall covering

panel and on three points in the centre, more or less equidistant between one another. An effective bonding reduces the risk that the presence of air infiltrations reduces the insulating capacity of the panels. Fastening anchors were not used since they would have led to local thermal bridges. The application of insulating panels without the aid of anchors has been favoured by the conformation of the design: the presence of the terraces has divided the overall height of the building for each floor. In different contexts, with greater heights of the faces, a workmanlike application of the insulating layers without the application of anchors would have been difficult to achieve (Fig. 5.3).

Fig. 5.3 Bonding phases of the wood fibre

The fastest parameter for evaluating the thermal lag of a material is its density. The density of a material is directly proportional to thermal lag: an important feature when operating in contexts determined by hot summers. The panel in fibreglass (35 kg/m^3) has a lower density than the panel in wood fibre (16 kg/m^3). This choice was evaluated using common FISA construction software, where we found that the coupling of the two insulating panels of different densities guarantees optimal thermal lag results.

The panels of fibreglass that we used are fitted with a water vapour barrier placed on one of the sides. The correct position of the water vapour barrier within the stratigraphy is verified by the Glaser Diagram: usually one always sees its positioning on the "*hotter*" side of the insulation, the one directed towards the inside of the building (Figs. 5.4, 5.5 and 5.6).

> Even if this methodology of installation is widely recognised by installers, during the supervision of the works, I realised that the first panels were applied on the reverse side (!). The matter had escaped the attention of the foreman, who had immediately solved the problem by inverting the panels.

In the lower part of the wall, for a height of 30 cm, the insulation made of wood fibre and fibreglass has been replaced by a 20-cm panel in XPS, since it is more water-resistant. The panel in XPS was in turn covered by a plywood sheet on which

Fig. 5.4 Fibreglass with water vapour barrier towards the outside (incorrect installation)

a waterproofing sheath has been applied, connected to the one used for waterproofing the terraces (Fig. 5.7).

The fibreglass panels have been interposed between studs made of fir wood treated in an autoclave with the dimensions of 12 × 5 cm. The studs are fixed by means of metal anchors in correspondence with the two ends of the horizontal

Fig. 5.5 Fibreglass with water vapour barrier towards the inside (correct installation)

panels in CLT, which constitute the structure of the terraces. This technical solution allows the elimination of the metal connections between the studs and the vertical panel in CLT; in fact, to connect the studs to the panel in CLT, the metal connections would have traversed 20 cm of insulating material, creating a thermal bridge.

The system of studs is necessary, so as to give more support to the applied insulating panels through bonding, and, at the same time, they serve as a support system for the ventilated cladding in natural larch slats. This technical solution involves a 2-cm-thick ventilated cavity, within which was placed, in direct contact with the insulating panels, a wind barrier membrane.

This is a two-layer membrane of breathable heat-sealed polystyrene that has a polyurethane coating resistant to UV rays, necessary for protecting the insulating panels from the sun and from the infiltration of moisture. The product is joined by means of an adhesive tape having equal characteristics in acrylic material with UV stabilised polyethylene support.

The membrane is fastened using a stapler (in the manner of work in upholstery) in adherence to the insulating fibreglass panels and to the system of studs, as indicated in the construction details. This application ensures the functioning of the ventilated cavity, allowing the wood cladding to have hygrometric exchanges towards the external environment on both sides of the slat (Figs. 5.8 and 5.9).

Fig. 5.6 XPS panel at the base of the wood fibre panels

During the supervision of the works, I found that the first application of the product was placed only on one side of the studs. The membrane was stretched between one stud and the next one. This incorrect application eliminates the effectiveness of the cavity: the slats in larch wood in direct contact with the membrane on their internal side reduce their hygrometric exchange with the surrounding environment, favouring the emergence of dimensional deformations and rot. The problem has been resolved by removing the membrane and applying it in the correct manner.

Fig. 5.7 Waterproofing in the point of contact of the wall with the terrace. The waterproofing sheath will be covered by an aluminium slat

The slats which constitute the cladding in larch wood have a rhomboidal section (2 × 10 cm). Natural larch wood, not protected by preservative systems (painted products, treatment in autoclave, etc.), has good durability against fungal attacks and resistance to attacks by wood-boring insects. The diamond shape of the slats favours the surface sliding of the rainwater, reducing phenomena of stagnation that can generate rot; for the same reason, screws with small heads were used for fastening, while on the lower layer of the cladding, in contact with the floors of the terraces, the wood slats are replaced at a height of 15 cm by a slat in painted aluminium applied to the plywood support coated with a waterproofing sheath. The attachment to the ground is sensitive to the action of the splashes of rainwater that repeatedly hit the floor and the lower parts of the wall.

Fig. 5.8 Wind barrier membrane (incorrect installation)

The durability of the wood cladding is also favoured by the presence of the terraces that protect the material from the rays of the sun in the summer and from the direct action of the rainwater.

The wall has a transmittance of 0.11 W/m^2 K and a thermal lag equal to 19 h: values that indicate excellent performance both in the winter and in the summer. The component has been calculated using the Glaser Diagram which does not detect the presence of interstitial or superficial condensates in any month of the year (Figs. 5.10, 5.11 and 5.12).

(b) ***External wall cladded in ceramic slab***

The wall cladded in ceramic slab is the wall type used at the attachment of the building to the ground; it is present at the ground floor of Via Ariosto and below the raised floor of Via Liguria and has an overall thickness of 40.4 cm.

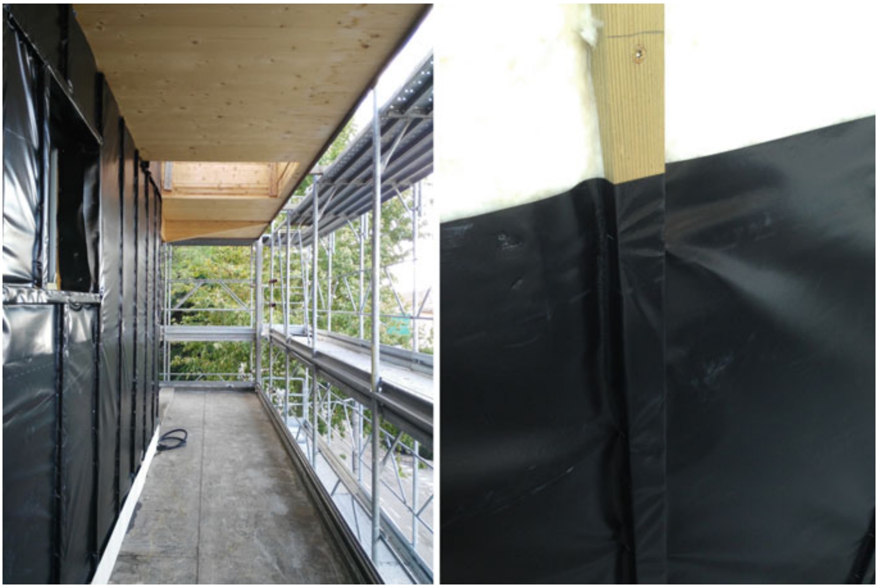


Fig. 5.9 Wind barrier membrane (correct installation)

Fig. 5.10 Waterproofing in the point of contact of the wall with the terrace. The waterproofing sheath will be covered by an aluminium slat

Fig. 5.11 Aluminium slat

The system of internal cladding is constituted of a structure in sheet metal covered in plasterboard and insulated with mineral wool. The metal structure is anchored on the internal side of the panel in CLT, while insulating panels of wood fibre and fibreglass are applied on the external side.

These functional layers are unchanged with respect to the wall cladded in wood. The only difference concerns the system of external cladding where ceramic slab was used, so as to ensure greater durability of the building's façades that are in contact with the ground, since they are more subject to the action of rainwater and shock. The external cladding system consists of the following:

- studs in sheet metal;
- panel in fibre cement;
- ceramic slab sheet.

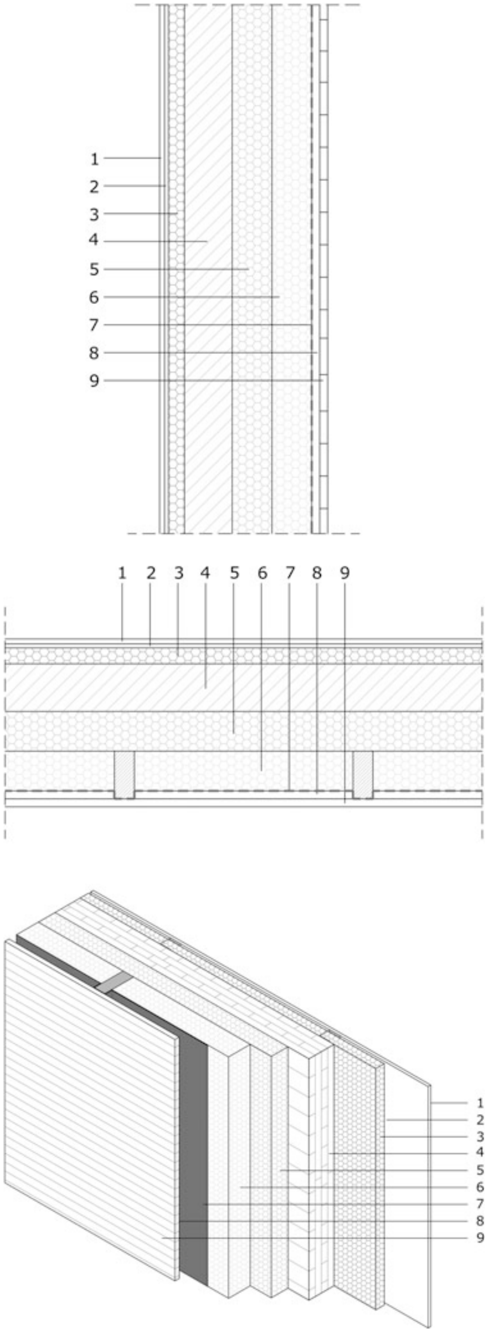


Fig. 5.12 Section and axonometric view of the wall cladded in wood:
(1) plasterboard; (2) air flow; (3) mineral wool; (4) cross-laminated timber (CLT); (5) wood fibre; (6) fibreglass; (7) wind barrier; (8) air flow; (9) larch wood

The studs in sheet metal replace those in wood used for the wall cladded in wood. They are profiles marketed in various sizes, commonly used to make structures with the dry method in plasterboard panels, plaster fibre, etc. Those used have a C-section, a width of 11 cm, and were positioned at a distance of 60 cm. The 10-cm panel of fibreglass is placed in the cavities.

The lower part of the studs is fixed to the foundation's kerb, while the upper part of the panel in CLT constitutes the terrace. In order to avoid the presence of local thermal bridges, there are no intermediate mountings which interfere with the wood fibre panel placed adjacent on the inner side. The sheet metal ensures greater durability to contact with water: a risk that is present in the attachment of the building to the ground. For the same problem, in the lower part of the wall, for a height of 30 cm, the insulators made of wood fibre and fibreglass have been replaced by a 20-cm panel in XPS, since it is more water-resistant.

The stud system is applied to a 1.25-cm-thick panel of fibre cement. This is a panel in lightened concrete, reinforced with fibreglass, designed to be applied in the external environment with good performance in regard to mechanical strength and durability.

On the panel in fibre cement is applied, through a 0.6-cm-thick layer of glue for flooring, the ceramic slab, produced in large format sheets measuring 100×300 cm and with a thickness of 0.3 cm. The sheet in ceramic slab covers the entire surface of this type of wall, ensuring high durability of the component against the action of external agents.

The wall has a transmittance of 0.12 W/m^2 K and a thermal lag equal to 18.3 h: values that indicate excellent performance both in the winter and in the summer.

The result of the Glaser Diagram shows the formation of a small amount of interstitial condensate between the sheet of ceramic slab and the panel in fibre cement. The phenomenon that is recorded from December to April with a maximum peak of 0.0013 kg/m^2 in the month of February is mainly caused by the ceramic slab being impermeable to vapour. The amount of condensate produced is modest, and the phenomenon occurs in correspondence with water-resistant materials; moreover, the various types of software used for the processing of the Glaser Diagram have calculated that the small amount of condensate produced completely evaporates in the subsequent months (Figs. 5.13, 5.14, 5.15, 5.16, 5.17 and 5.18).

(c) ***Wall cladded in EIFS***

The wall cladded in EIFS (exterior insulation and finishing system) is used only on the ground floor, on the wall that divides (with an overall thickness of 38.9 cm) the living space and the unheated garage. Compared to previous typologies, the internal system of cladding remains unchanged: it is composed of plasterboard, structure in sheet metal with interposed mineral wool, fixed to the panel in CLT.

The differences concern the layers present on the external side of the panel in CLT where it is applied by gluing a 20-cm-thick single insulating panel in EPS (expanded polystyrene).

Fig. 5.13 Application of the sheet metal studs

The insulating material is finished externally with skimming in which a fibreglass mesh is embedded; subsequently, one applies a siloxane-type finishing layer to level, preceded by a fixative which regulates the absorption of the finish, ensuring an effective support.

The wall has a transmittance of 0.12 W/m^2 K and a thermal lag equal to 13.01 h: values that indicate excellent performance in the winter and sufficient performance in the summer. Compared with the previous typologies, the thermal lag is reduced by about 5 h: a value lower than the 16 h hypothesised during the definitive design phase. However, the difference is negligible considering that the wall, bordering on

Fig. 5.14 Application of the studs on the foundation's kerb

an internal environment, is not in direct contact with the solar irradiation. The lower efficiency in terms of thermal lag is due to the reduced mass of the EPS. For this typology, the calculation of the Glaser Diagram has been omitted since it is not in contact with the external environment (Figs. 5.19 and 5.20).

Fig. 5.15 Application of the studs on the panel in CLT of the terrace

5.2.1 Floor Slabs

In the design of the *Fiorita Passive House,* we have three types of floor slabs on cold environments (i.e. "unheated"). The first two types relate to roof and floor slabs, while the third concerns the ground floor slab. UNI 8290-1 classifies these components as "external horizontal closures"; however for the sake of simplicity, we will continue to call them "floor slabs".

Fig. 5.16 Application of the fibreglass panels and cladding with panels in fibre cement

Each type is composed of a series of functional layers that have specific functional requirements: a structural function, passage of the plants, heat insulation, sound insulation, water tightness, screed distribution of the static loads, flooring, etc. The types are defined as follows:

(a) *roof slab* identifies the roof of the building. It has a flat shape and is used for the installation and maintenance of a photovoltaic system that covers the entire surface;
(b) *terrace floor slab* concerns a small portion of the floor slab of the third floor where there is a narrowing of the perimeter of the external, leaving a portion of

Fig. 5.17 Cladding in ceramic slab

the interfloor slab outside. This portion of the slab is placed in continuity with the wooden terraces;

(c) *ground floor slab* made directly on the foundation in the cement bed of the building.

(a) ***Roof slab***

The roof slab, with a thickness 58.8 cm, defines the flat roof of the building. All the functional layers are applied to the exterior surface of the 20-cm-thick panel in CLT which remains visible on the inside of the building. On the external surface of the

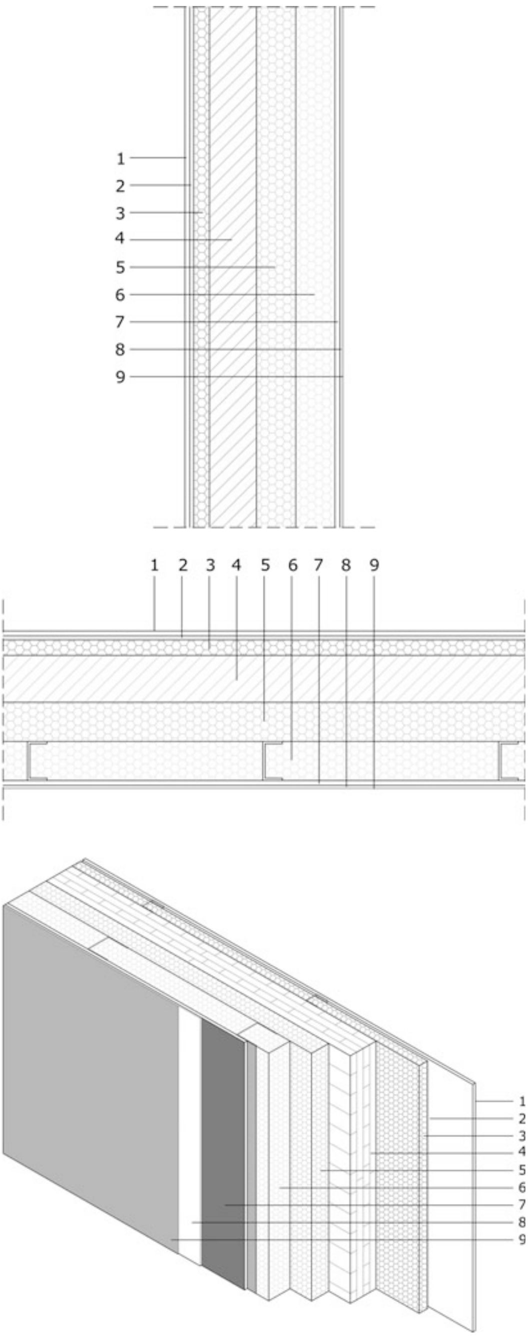


Fig. 5.18 Section and axonometric view of the wall cladded in wood: (1) plasterboard; (2) air flow; (3) mineral wool; (4) cross-laminated timber (CLT); (5) wood fibre; (6) fibreglass; (7) fibre cement; (8) lime mortar and cement; (9) ceramic slab

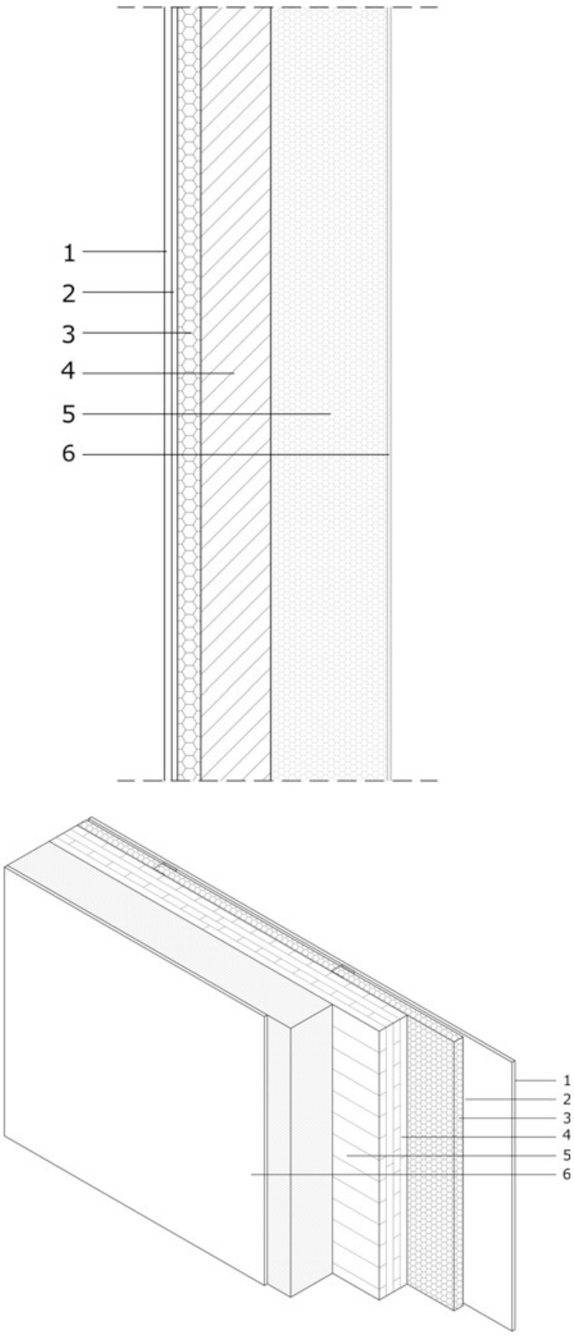


Fig. 5.19 Section and axonometric view of the wall cladded in EIFS: (1) plasterboard; (2) air flow; (3) mineral wool; (4) cross-laminated timber (CLT); (5) sintered expanded polystyrene (EPS); (6) glue-based skimming

Fig. 5.20 Inspection hole on the wall cladded in EIFS to check the thickness of the panel in EPS

panel in CLT, a bitumen-based waterproofing sheath is applied. The sheath serves a double function: it keeps the wood free from contact with rainwater during the construction of the building while, upon completion, it acts as a water vapour barrier.

Subsequently, two 12-cm-thick panels in XPS are applied, for a total of 24 cm of thermal insulation. The insulating material is laid dry, without the use of adhesives or other fastening systems. The insulation is protected by a sheet of PVC (polyvinyl chloride), adequately sealed with adhesive tape to ensure continuity. A 6-cm-thick sand- and cement-based screed with a waterproofing additive is laid on the sheet.

The PVC sheet serves the function of a separator layer: it limits the cohesion between the insulation and the screed, allowing each material to thermally expand in an independent manner.

The screed has a triple function: it distributes the loads, creates the appropriate slopes for the drainage of rainwater and increases the mass of the entire component, improving the energetic behaviour in the summer season.

Finally, as the roof covering, a bitumen-based sheath with a reflective white surface is applied. It is a bitumen-based sheath strengthened with a composite reinforcement of glass film and polyester, impregnated with an acrylic coating having high reflective capacity. The sheath is applied with the use of a flame, and it has overlaps of approximately 10 cm. A flat roof is particularly prone to the overheating produced by radiation in the summer. The use of a product with a reflective surface and an adequate mass of the entire component limits the effect.

The roof slab has a transmittance of 0.09 W/m^2 K and a thermal lag equal to 23.46 h. This is the component of the envelope with high-performance results that indicate excellent performance both during the winter and the summer.

The component has been calculated using the Glaser Diagram which has detected the formation of interstitial condensation under the roof covering and under the screed. The phenomenon that is recorded from November to April has a maximum peak of 0.0023 kg/m^2 in the month of February, mainly caused by the roof covering having very low permeability to vapour. Therefore, as recommended in the technical data sheet of the material used as roof covering, small "ventilation stacks" were installed that intercept the layer concerned in the phenomenon, allowing the condensation to evaporate (Figs. 5.21, 5.22, 5.23 and 5.24).

(b) ***Terrace floor slab***

The terrace floor slab covers a limited portion of the floor slab of the third floor, where there is a narrowing of the perimeter of the external walls, leaving a portion of it outside. It is a portion used as a terrace, in that it is connected to the terraces. It has an overall thickness of 53.2 cm, and its stratigraphy is similar to that of the roof slab.

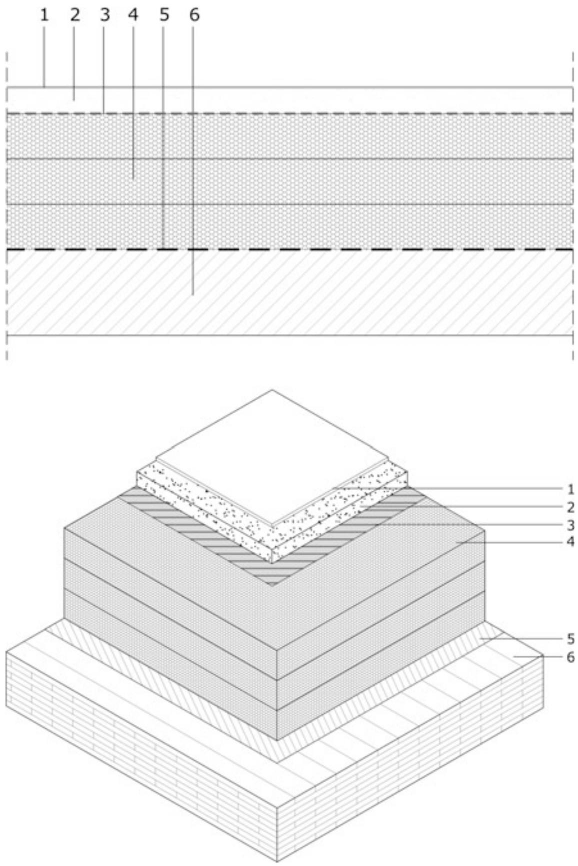


Fig. 5.21 Section and axonometric view of the roof covering: (1) bitumen-based sheath; (2) cement screed; (3) polyvinyl chloride (PVC); (4) extruded polystyrene foam (XPS); (5) waterproofing sheath; (6) cross-laminated timber (CLT)

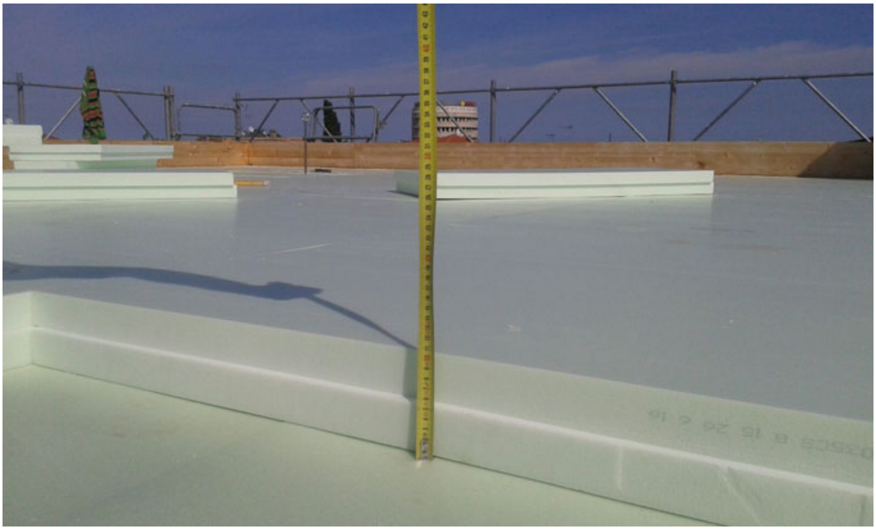


Fig. 5.22 Installation of the panels in the XPS

Fig. 5.23 Laying of the bitumen-based sheath with reflective white surface

Fig. 5.24 Installation of photovoltaic panels on the roof covering

The 20-cm panel in CLT constitutes its load-bearing structure, and it remains in view on the inner side of the building. On the panel in CLT, a bitumen-based waterproofing sheath is applied, in continuity with the one used in the terraces. The waterproofing sheath has the dual function of water seal, important during the construction of the building, as well as serving as a water vapour barrier.

Subsequently, two panels in XPS are applied, the first 12 cm thick and the second 8 cm, for a total of 20 cm of thermal insulation. The insulating material is laid dry, without the use of adhesives or other fastening systems.

Above the insulation a membrane made of PVC is placed to allow the subsequent laying of an 8 cm slab of reinforced concrete with a welded mesh and waterproofing additive. The PVC has a function of separator layer that allows the insulation and the screed to thermally expand without interacting.

In order to ensure an effective water seal of the system, a second bitumen-based waterproofing sheath is applied above the slab. The sheath is then covered by a screed of sand and cement, to which is added a waterproofing additive and an anti-shrinkage mesh. The screed, with an average thickness of 5 cm, has the function of levelling the floor and creating appropriate slopes for the drainage of rainwater.

Finally, the flooring was made with 0.3 cm thickness composed of an epoxy and a cementitious component. The resin, in addition to defining the aesthetic appearance of the flooring, has excellent water-repellent properties.

The terrace floor slab has a transmittance of 0.14 W/m^2 K and a thermal lag equal to 23.03 h, performance results with values that indicate good performance both in the winter and in the summer.

The component has been calculated using the Glaser Diagram which has detected the formation of a small amount of interstitial condensation in correspondence with the membrane in PVC. The phenomenon can be observed between December and March with a maximum peak of 0.0013 kg/m^2 in the month of February. However, given the modest quantity of condensate produced, the extension of the terrace amounting to only 9 m^2, the use of water-resistant material, the problem was considered negligible: the condensate will evaporate in the subsequent months (Figs. 5.25 and 5.26).

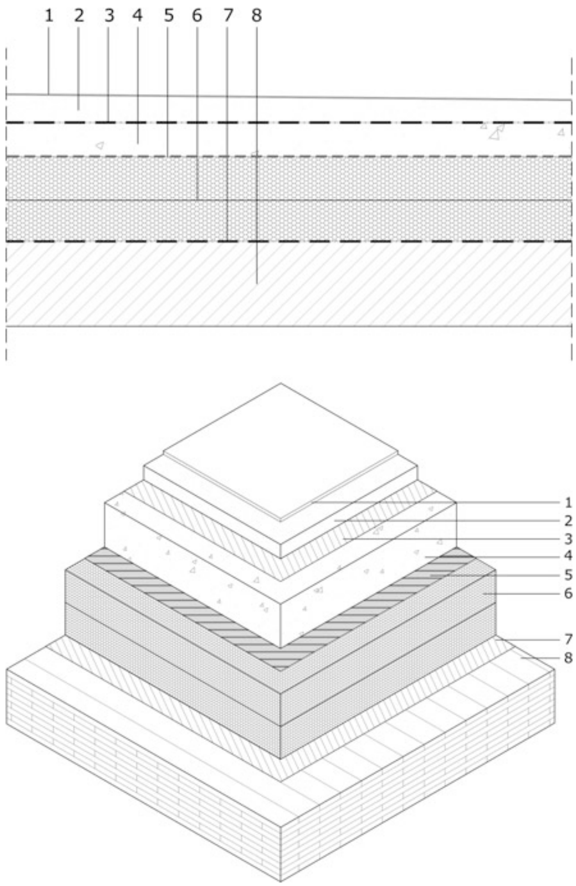


Fig. 5.25 Section and axonometric view of the terrace floor slab: (1) resin; (2) cement screed; (3) waterproofing sheath; (4) reinforced concrete; (5) polyvinyl chloride (PVC); (6) extruded polystyrene (XPS); (7) waterproofing sheath; (8) cross-laminated timber (CLT)

Fig. 5.26 Difference in height between the terrace floor slab and the terrace. The surfaces will be subsequently treated with resin flooring

(c) ***Ground floor slab***

The ground floor slab is made directly on the cement bed of the building, and the entire component has a thickness of 80.3 cm. The foundation of the cement bed with a thickness of 40 cm rests on a layer of lean concrete (a mixture with less cement) with a thickness of 5 cm. The foundation and the layer of lean concrete, in agreement with the Passive House certifying body, have not been included in the PHPP, since they are considered negligible for the purposes of calculation of the transmittance of the entire component, towards the ground.

On the cement beds, two 8 cm panels of XPS are positioned with the dry system for a total of 16 cm; a membrane in PVC is then applied on the insulation, followed by a lightened screed of 12 cm composed of a cement-based compound with a synthetic-based polystyrene foam additive. The membrane in PVC acts as a separator layer, allowing the insulation and lightened screed to thermally expand without interfering.

In the ground slab, as in the interfloor slabs, the lightened screed layer has the function of integrating the plants; therefore, it is not advisable to skimp on its thickness, in order to simplify the laying operations of the pipes.

The plants (plumbing, electrical systems, controlled mechanical ventilation (VMC) discharges of wastewater) are placed on the membrane in PVC and then covered by the pouring of the lightened base.

The integration of the various plant networks may involve specific situations where the pipes will surmount each other, in this case it is appropriate to ensure that their overall thickness does not exceed that of the lightened screed, given that these situations are difficult to predict during the final construction design phase: *with the thickness of the base, it is a good idea to be sure there is extra space*. In traditional construction sites, when this situation occurs, it is not uncommon to have to recover the missing centimetres by reducing the thickness of the insulating material whenever the pipes surmount each other. This, obviously, is totally inadvisable in a Passive House.

The interferences between the various plant networks increase in buildings such as the *Fiorita Passive House*, composed of small- to average-sized apartments, where the density per square metre of the plants is high.

A 6-cm-thick sand- and cement-based screed is laid on the lightened screed, which is supplemented with a fibreglass mesh that reduces the risk of cracking. This is a screed for the distribution of the loads on which flooring in resin is applied.

The resin is constituted of a 0.3-cm layer applied by spatula directly on the screed and composed of a mixture of an epoxy and cementitious compound.

The ground slab has a transmittance of 0.18 W/m^2 K. The transmittance, although below the 0.16 W/m^2 K hypothesised in the preliminary design phase, is sufficient to obtain the positive result of the PHPP.

This choice has been agreed together with the certification body that suggested that we maintain higher transmittance of the ground slab, so as to more rapidly dispose of the internal heat loads produced in the three studio apartments on the ground floor. In fact, given the reduced surface and the low dispersions of the envelope, the studio apartments risked having problems of the disposal of the internal thermal loads during the summer period, with possible discomfort due to overheating.

The component has been calculated using the Glaser Diagram which does not detect the presence of interstitial or superficial condensates in any month of the year (Figs. 5.27, 5.28 and 5.29).

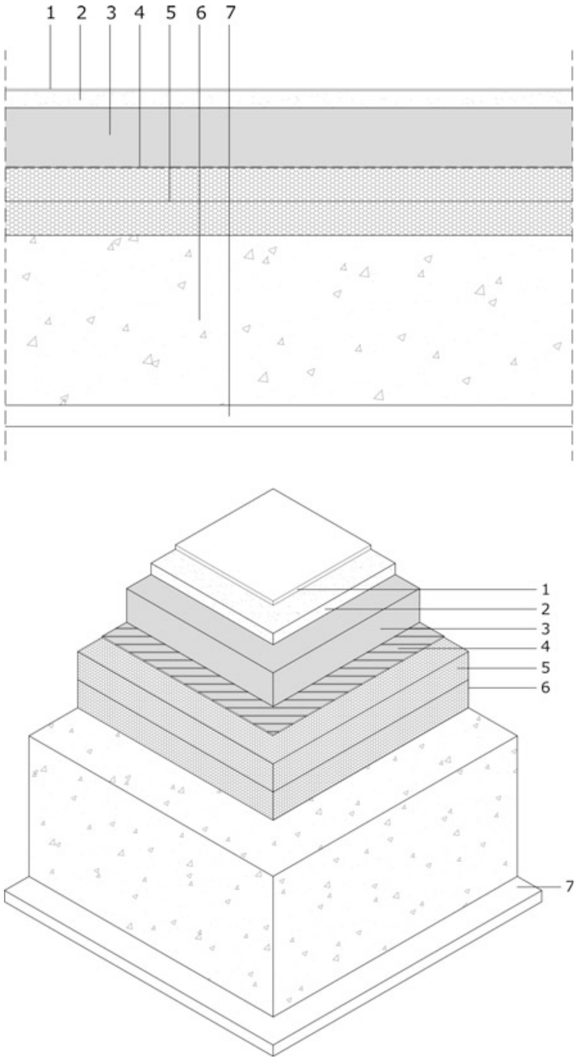


Fig. 5.27 Section and axonometric view of the ground slab: (1) resin; (2) cement screed; (3) lightened screed; (4) polyvinyl chloride (PVC); (5) extruded polystyrene (XPS); (6) reinforced concrete; (7) lean concrete

Fig. 5.28 Ground slab prior to the installation of the insulating panels

5.3 Windows

To choose the kind of windows that are suitable for a Passive House, it is a good idea to follow three parameters that are able to give us a rough indication: air-tightness, with $n_{50} \leq 0.6$ V/h, transmittance $U_w \leq 0.8$ m^2 K, and solar factor of the double-glazing unit g = 50–55%. The transmittance of the window and solar factor of the glass are indicative: they must be assessed using the PHPP to verify their compatibility with the other variables of the building.

For example, if a building has an extremely efficient opaque envelope, has zero thermal bridges and is located in a mild climate, probably the PHPP would be verified even by using frames with transmittance values of the window that are not particularly excellent in regard to performance. On the contrary, in the presence of an opaque envelope of average efficiency, thermal bridges not completely resolved and a cold climatic context, it would be necessary to use windows with particularly low transmittance.

Always with the use of the PHPP, we will understand, in relation to the heat gains produced by radiation, how to identify the type of glass, varying, for example, the solar factor g; increasing the g factor will increase the solar gains caused by solar radiation. Therefore, in a Passive House it is necessary to take full advantage of the dual function of the windows: collaborating in the efficiency of the envelope by reducing the thermal losses and ensuring adequate thermal gains from solar radiation.

The first function is performed by a good transmittance of the window; the second, by the type of exposure to the sun's rays and the capacity of the double-glazing unit to allow or disallow the heat gains produced by solar radiation.

Fig. 5.29 Ground slab after the installation of the insulating panels. All the interstices between the panels will be subsequently filled with polyurethane foam

To verify the performance of the windows, the PHPP, in addition to the dimensional parameters, requires the following energy parameters:

- the solar factor of the glass *g* indicates the ratio between the overall thermal energy transmitted from the pane of glass and that incident upon it: the capacity of the glass to reduce or lessen the thermal gains produced by solar radiation. The *g* value is directly proportional to the thermal gains: high *g* values allow high gains and vice versa.
- the value U_g indicates the light transmittance of the double-glazing unit.
- the value U_f indicates the transmittance of the frame.
- the value $\Psi_{glazingedge}$ (W/mK UNI TS 11300) is a line-based coefficient relative to the *thermal bridge of the glass edge*, caused by the change of the heat flow

which traverses the point of contact between the glass and the frame, it is mainly due to the spacer (in steel, aluminium or plastic) that separates the panes of glass of a double-glazing unit.

- the value $\Psi_{installation}$, is a line-based coefficient relative to the thermal bridge of installation of the window, caused by the change of the heat flow which traverses the point of contact between the frame and the wall.

The value U_w is not required because it is calculated through the values U_g and U_f; while the values U_g, U_f and $\Psi_{glazingedge}$, are usually indicated by the manufacturer in the technical data sheets of the window, for the value $\Psi_{installation}$ finite elements must be calculated through a software modelling of the thermal bridges. Its value changes in relation to the type of window and type of wall in which the window is installed.

The calculation is simplified by using Passive House certified windows: in this case, it is possible to select the $\Psi_{installation}$ values available within the PHPP or in the certification report. The airtightness of the frames, to meet the requirement $n_{50} \leq 0.6$ V/h, depends on two factors:

- airtightness between the movable and fixed frames of the window;
- sealing between the window and the wall.

The first requirement is determined through EN 12207, which defines five classes of air permeability: from 0 to 4. The best is Class 4, which identifies a frame with excellent airtightness; it is possible to identify the class of a window or door frame through the product's technical data sheet.

The second requirement depends on correct installation, using expanding butyl tapes and suitable adhesive tapes to ensure the airtightness between the frame and the wall. In this regard, we have used a type of tape with acrylic adhesive and filamentous reinforcement without chlorine, solvents, formaldehyde or emollients. Any problems of installation can be detected through the blower door test and resolved by improving the taping or applying more force on the mechanical anchorage of the frame. We will return to this theme in subsequent chapters, when we address the subject of airtightness.

In the *Fiorita Passive House* design, we used frames such as Top 90 produced by the company Finstral. They are door and window frames made of PVC with triple glass, equipped with a particularly efficient glass spacer, with Class 4 air permeability.

The true triple type is low emissivity with solar factor g (0.62) and U_g (0.60 W/m^2K). If the solar factor is particularly high, given the poor exposure and the presence of elements at the contour which produced shadows on the building, it was necessary to maximise the few solar gains available. Such a high solar factor g can lead to problems of overheating in the summer, which we resolved with the presence of overhangs and shields that are adequately calculated to shade the façade during the hotter months.

The same type of frame was used to produce both the windows and the French doors. For the entrance doors to the apartments, a version of the frame was used that, in place of glass, uses a panel in PVC.

For architectural requirements, the entrance doors have been coupled to the windows, to the ground floor and to the French doors, to the remaining floors.

The values U_f, solar factor g and $\Psi_{glazingedge}$ have been transposed by the technical data sheets of the door and window frames, while the value $\Psi_{installation}$, being that the frame is not Passive House certified, had the finite elements calculated, modelling the frame with Mold Simulator, the software that we used for the calculation of the thermal bridges.

The software was also used to calculate the U_f resulting from the sum of the two frames, in correspondence with the coupling between the entrance door and windows or the entrance door and the French doors (Figs. 5.30, 5.31, 5.32, 5.33 and 5.34).

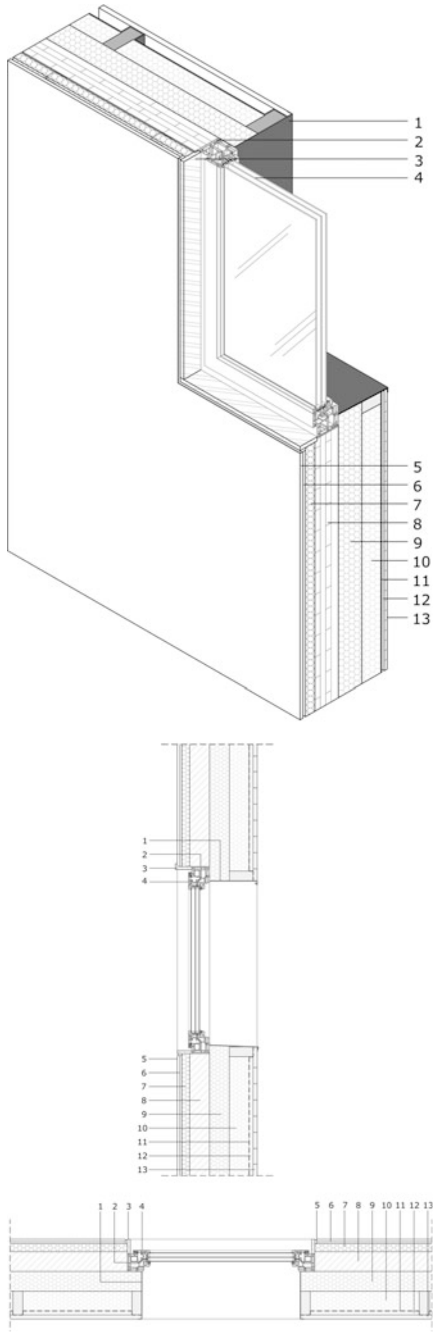
Fig. 5.30 Window integrated into the entrance door

Fig. 5.31 Thermal insulation covers the frame of the fixture to limit heat loss

Fig. 5.32 Window inserted in the panel of CLT without using the subframe

Fig. 5.33 French door integrated to the entrance door

Fig. 5.34 View and section of a window: (1) outer frame in painted aluminium; (2) expanding butyl tape; (3) wooden frame; (4) PVC frame; (5) plasterboard; (6) air; (7) mineral wool; (8) CLT; (9) wood fibre; (10) fibreglass; (11) wind barrier membrane; (12) air; (13) larch planks



References

Domínguez A (2015) L'ultimo mistero di Escobar: sua figlia Manuela. El Mundo 24/08/2015, Madrid, Spain

EN 12207 (2000) Windows and doors—air permeability—classification

EN ISO 13786 (2008) Thermal performance of building components—dynamic thermal characteristics—calculation methods

EN ISO 13788 (2013) Hygrothermal performance of building components and building elements—internal surface temperature to avoid critical surface humidity and interstitial condensation—calculation methods

EN ISO 9251 (1998) Thermal insulation—heat transfer conditions and properties of materials—vocabulary

EN ISO 7345 (1999) Thermal insulation-physical quantities and definitions

EN ISO 6946 (2008) Building components and building elements—thermal resistance and thermal transmittance—calculation method

ISO 13786 Thermal performance of building components—dynamic thermal characteristics—calculation methods

UNI 10351 (2015) Building materials and products—hygrothermal proprieties—procedure for determining the design values

UNI TS 11300-1 (2014) Energy performance of buildings—part 1: evaluation of energy need for space heating and cooling

UNI TS 11300-2 (2014) Energy performance of buildings—part 2: evaluation of primary energy need and of system efficiencies for space heating, domestic hot water production, ventilation and lighting for non-residential buildings

UNI 8290-1 (1981) Residential building—building elements—classification and terminology

Chapter 6
Building Physics and Thermophysical Performance

6.1 Introduction

"*If you cannot measure it, you cannot improve it*", the motto of William Thompson Lord Kelvin, suggests how strong and decisive of a role evaluation and measurement plays in the realisation of a project. In the case of the *Fiorita Passive House*, measurement—i.e. the matter of keeping under control, in the various phases of the building design, the specifications as well as its monitoring—has played a decisive role also in the choice of the architectural and technical building solutions that were adopted. The design has undergone continuous revision, continual reiteration, in the definition of the architectural choices—in the broadest sense of the term that includes the design of the environments, the aesthetics—which are the technical choices made in the design phase—that must take account of the feasibility and the possibility of realising in the construction site what has been planned, bearing in mind the cost of these processes—and the measurement of the energy performance (in this specific case with the help of PHPP spreadsheets or modelling software such as Ecotect or Dartwin) or of the individual thermophysical parameters.

In this chapter, we intend to go into detail explaining some terms and concepts used in the previous and the following chapter according to their physics meaning and the technical regulations.

This book describes, in the manner of a logbook, the voyage that has led to the construction of the *Fiorita Passive House*, with the consequent difficulties, due in particular to the application of the concepts learned in the specialised manuals and brought to fruition in a concrete, actual case. In various situations, reality has proven itself to be different from how it had been described in the books. As is true in every journey, what remains impressed in the mind of the visitor is not the same as what is written in the tourism guidebooks. To describe the process, it was necessary to use some terms and concepts derived from Building Physics, taking for granted that the reader is familiar with this terminology, just like, to continue with

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_6

the analogy of the tourism guidebook, it is not necessary to explain the meaning of words like “street”, “square”.

The objective of this chapter is to provide the reader with a deeper understanding of the concepts related to the more specific terms with regard to Building Physics and Building Energy Performance, with the same approach of the book: a logbook with some annotations in the margin.

In general, the subject can be divided into two areas:

– the description of the *thermophysical data (Building Physics)*, i.e. those physical quantities that describe the properties of a material or of a technological solution, such as the transmittances (U), the thermal bridges (Ψ), the phase displacement;
– the explanation of the calculation of the *Building Energy Performance*, i.e. the set of equations and calculation algorithms that allow one to determine the building’s energy needs as well as those of the technical systems;

added to these are:

– the airtightness, a specific requirement that has had an important role in defining the technical and construction choices of the Passive House;
– the technical systems, in particular the controlled mechanical ventilation and the heat pumps used for HVAC (Heating, Cooling and Ventilation) of the *Fiorita Passive House*.

6.2 Building Physics

The study and analysis of the thermophysical data allows one to check if the technological solution that has been chosen, for example, the stratigraphy of an opaque vertical closure or the connection between the floor slab and the wall, allows the satisfaction of the minimum requirements laid down by the legislation and/or by regulations to achieve the objectives of energy performance provided for by the design protocols[1] such as that of the Passive House standard, through the use of the PHPP spreadsheet.

The Building Physics parameter “translates”, or in other words, simplifies the laws of thermokinetics into a numerical value, calculated according to the technical regulations, which allow the evaluation of the physical behaviour of the technical solution. In the simplest manner, the transmittance value (*U*), repeatedly cited in the book, is the synthesis of the energy exchanges by radiation, convection and conduction of a building’s stratigraphy, calculated according to the standards. It is not necessary that the designer understands the notions of thermokinetics, but he or she

[1]The Passive House standard is a design standard that defines a protocol and a method. It is important to specify that certification is voluntary.

must be able to understand the physical “meaning” of such a value, the units of measurement and the physical phenomena that it describes. In this way—in the opinion of the author—the designer disengages from the unquestioning acceptance of the technical-construction solutions that satisfy compliance, and is able to choose technical solutions and products in autonomy, according to his or her own design choices. Continuing the analogy with the route of navigation, if the captain knows the winds and the sea, he can also decide to travel on new routes and not just follow the well-known ones. The Building Physics principles that allow one to control the energy performance of the building, eliminating the risk of condensation, mould and mildew, ensuring the Indoor Air Quality and indoor comfort, are:

- thermal transmittance U, measured in W/m^2 K;
- conductivity λ, measured in W/m K;
- thermal bridges Ψ, measured in W/m K;
- solar transmittance for non-scattering glazings (g) or windows with scattering glazing and/or solar shading devices ($g_{\mathrm{gl+sh}}$);
- effective solar collecting area of glazed elements (m^2) and effective collecting area of opaque building elements.

*6.2.1 Thermal Transmittance (*U*)*

The thermal transmittance, usually identified with the letter U and measured in W/m^2 K, expresses the quantity of heat flow per second or the power exchanged (W) for each square metre of surface (m^2) and for every degree of temperature difference (in degrees Celsius °C, or in degrees Kelvin K). For example, a transmittance of 1 W/m^2 K, with an indoor–outdoor temperature difference of 25 °C, corresponds to the thermal exchange of 25 W per square metre of surface area.

The thermal flow is defined by EN ISO 7345 as the “quantity of heat transferred to or from a system, in the unit of time”.

The heat flow may be horizontal (from the inside to the outside), upwards (towards the ceiling) or downwards (towards the floor on the ground or on another room or outside).

The technical application of the laws of thermokinetics, for the construction sector, given that most of the technical solutions refer to elements where the surface area is the largest size, considers that the passage of heat occurs in one dimension (1-D). This “simplification” is applicable only in the case of homogeneous planar surfaces, while we cannot apply it for other geometric configurations where there is not a predominant dimension, such as the thermal bridges.

The thermal transmittance expresses the ability of the element or of the stratigraphy, to conduct heat; it is evident that the greater the transmittance value, and, at the same temperature, the greater the quantity of heat that flows through it. In contrast, the lesser the transmittance value, the lesser the quantity of energy exchanged. Transmittance allows us to measure the insulation capability of the technological solution, and its value depends on the building element. In the case of opaque closures, external walls, foundation or roof slabs, etc., the literature, the design practice and the technical legislation, indicates as reduced transmittance values those having U lower than 0.5–0.30 W/m^2 K, they are "very poor" values (i.e. they allow the passage of a great deal of energy), U greater than 1 W/m^2 K, referable to uninsulated buildings, while considered as "excellent" (allowing little passage of energy) are values of U lower than 0.20 W/m^2 K, bearing in mind that the minimum reachable value is approximately 0.12–0.10 W/m^2 K, i.e. difficult to obtain within the scope of the materials used in the construction sector.

The thermal transmittance is the result of the calculation of the sum of the resistances of the individual materials, and it is directly proportional to the thermal conductivity λ (ability of the material or materials to conduct heat) and inversely proportional to the thickness of the material or materials. The calculation is performed according to the EN ISO 6946 standard.

In the case of windows and transparent elements, the calculation of the transmittance U_{w} (the subscript w indicates windows) depends both on the characteristics of the individual elements, that is, it depends on the geometry of the glass component (A_{g} = glass area in m^2, A_{f} = frame area in m^2) and on the transmittances of the glass (U_{g} where g is glass, in W/m^2 K) and of the frame (U_{f} where f is the frame, in W/m^2 K). The transmittance U_{w} is, therefore, a weighted average that takes account of the area and transmittance of the glass, of the frame and of the thermal bridge (Ψ is linear thermal transmittance. Measured in W/m K) that is created in the connection between the window and the window frame. The calculation is performed according to the EN ISO 10077 standard.

The thermal transmittance of the glass (U_{g}) depends on the characteristics of the glass, which can be single glass (U_{g} = 4.90–5.00 W/m^2 K) or a double-glazing unit, i.e. two or more panes of glass interposed by a cavity which can contain air or other gases such as argon or krypton which increase their insulation. The average values of the transmittance of the double-glazing units are approximately U_{g} = 1.8–2.0 W/m^2 K, which can be reduced in the case of low-emission glass (U_{g} 1.10–1.4 W/m^2 K) or in the case of high-performance glazing with triple chambers and argon or krypton gas ($U_{\mathrm{g}} < 1.0$ W/m^2 K up to a minimum value of approximately 0.6 W/m^2 K).

The low-emission windows consist of panes of glass whose surface is treated during the production phase of the glass, with metal iodides which increase the optical and infrared properties that favour the reflection of the infrared component of the solar radiation.

The windows and panes play a further role that relates to the passage of light and solar radiation, a factor that can be positive during the winter season, while it can be negative during the summer season due to the passage of the solar radiation through the glass. To reduce the passage of solar radiation, we must refer to another physical property that characterises the glass, the solar factor g.

6.2.2 Thermal Resistance (R_T)

The linear thermal resistance (R_T) expresses the resistance to the passage of heat of an element and may be associated with a single material, as the ratio between the thickness (d) and the thermal conductivity $\lambda(R = d/\lambda)$, or to the entire wall or other building element (obtained as the sum of the individual resistances). The thermal transmittance is obtained by means of the inverse of the total thermal resistance $U = 1/R_T$ and is measured in m^2 K/W. Transmittance and thermal resistance are calculated according to the EN ISO 6946 standard, which defines the standardised values of the indoor and outdoor thermal resistances, of the ventilated and non-ventilated air cavities and of the attics.

6.2.3 Thermal Conductivity (λ)

The thermal conductivity (λ), measured in W/m K, is the physical magnitude which expresses the properties of the individual material (brick, wood, plastics, glass, etc.), to be traversed by the heat.

Conductivity is a property of the material, and its value is determined by means of experimental laboratory tests, the results of which are given in the technical documentation and certification of the construction products, in particular of the thermal insulating materials. In turn, it depends on the homogeneity of the materials that can be continuous (e.g. metals) or discontinuous, porous, isotropic or anisotropic. The standards of the industry define the criteria for measuring the conductivity in the laboratory, according to various criteria and measuring instruments, usually on specimens of material whose dimensions are defined by the same standards. The technical data sheets and product claims of conductivity take account of the average value given by the sequence of the measurements carried out: in essence, the test consists in inserting the specimen between two plates, one of which emits heat that is defined and known (or is located at a defined temperature) and evaluating the value of the temperatures on the two sides of the specimen. Given that the quantity of heat ($q = \lambda$ * grad$T$) is linearly dependent on the conductivity (λ) and on the temperature (T) difference, if one knows the quantity of heat and the temperature difference, it is possible to determine the conductivity.

The values supplied by the manufacturer of the materials give the declared conductivity value (λ_d) and the value of the design (λ_p) to use for the calculations.

The value of the conductivity depends on the material; metals have a high value of thermal conductivity (aluminium $\lambda = 320$ W/m^2 K), while the insulation materials have values lower than $\lambda < 0.040$ W/m K; generally, the insulating materials available on the market have values between 0.020 W/m K < λ < 0.040 W/m K.

6.2.4 Thermal Bridges

The thermal bridges, indicated with the letter Ψ (psi) for the *linear thermal bridges* measured in W/m K, or χ (csi or Xi) for the *point thermal bridges* measured in W/K, express the quantity of heat flow per unit length that traverses a geometric configuration in three dimensions and that cannot be expressed with the transmittance. The heat flow traverses the building elements in three dimensions, *x*, *y* and *z*, but in the case of elements for which one dimension prevails over another, for example, in the walls where the area is much greater than the thickness, it is possible to express the thermophysical magnitude that characterises the passage of heat, referring it to a single dimension: the thickness of the wall.

This simplification cannot be adopted for all the geometries, for example, in complex geometric situations such as angles of intersection between two walls or between the horizontal floor and the wall. It is not possible to simplify it in a single dimension, and therefore it is necessary to express the heat flow that traverses the structure in three dimensions; to do this, we use the "*linear thermal bridge*" that, with a single value, refers to the length of the intersection between the wall and the floor slab, expressing the heat flow in three dimensions.

The EN ISO 10211 standard defines the criterion for calculating the linear thermal bridge, and this parameter must be multiplied by the characteristic dimension of the thermal bridge which, in the case of the linear thermal bridges, is the length of the thermal bridge. For example, in the case of a thermal bridge of a pillar, the characteristic dimension *L* is given by the length (height) of the pillar. The standard provides the following definitions:

> thermal bridge: part of the building envelope where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions;
>
> linear thermal bridge: thermal bridge with a uniform cross-section along one of the three orthogonal axes;
>
> point thermal bridge: localised thermal bridge whose influence can be represented by a point thermal transmittance);
>
> three-dimensional geometrical model: 3-D geometrical model: geometrical model, deduced from building plans, such that for each of the orthogonal axes perpendicular to that axis cross-section the changes within the boundary of the model. (EN ISO 10211)

The thermal bridge is a zone of the building envelope in which the heat losses are higher than those of the neighbouring components; it is identified through a discontinuity linked to the geometry of the building envelope or to the different types of thermal insulation. In addition to causing an increase of the dispersions, in the zone where there is a thermal bridge, phenomena such as mould and surface condensation can occur, which might worsen the healthy state of the internal environments and reduce the thermal insulation of the building envelope. The main discontinuities in the building envelopes are:

- geometric discontinuity, caused by the different geometries of the closures, such as in the case of a corner of two vertical walls, of a niche, of a recess or of a variation in the thickness of any building element;
- point geometric discontinuity, caused by the intersection of three flat surfaces such as in the case of the apex of the corner between two walls and the floor slab;
- thermophysical discontinuity, of the different characteristics of thermal insulation of the materials that compose the building element, such as in the case of a pillar inserted in a wall; in this case, it is not possible to consider only the heat flow which traverses the wall but it is necessary to evaluate the additional losses due to the different thermal insulations between the two materials;
- geometric and thermophysical discontinuities, caused by the presence of both geometric discontinuity and that due to the different insulation materials; a typical example of this type of discontinuity is that of the intersection between the balcony and the external vertical wall;

to these are added other thermal bridges such as:

- the installation of the frames and the connection between the frame (fixed and mobile) and the wall, the presence of skylights in the roof, point elements such as artificial lighting on the external walls;
- or the mounting systems of the shading elements and the like, which constitute elements of point discontinuity that may be evaluated or neglected, depending on their physical size; the EN ISO 10211 standard defines the criteria for the consideration of such elements.

The thermal bridges are calculated by means of software on finished models that determine the result according to the EN ISO 10211 standard, or in the case of the calculation of the energy of existing buildings, it is possible to adopt simplified procedures with the use of atlases of the thermal bridges. These values vary in relation to the level of accuracy of the calculation, and they provide the designer with a rough evaluation criterion.

The design of new buildings and in particular of buildings with low energy, Nearly Zero Energy Buildings (NZEB) or Passive Houses, therefore with excellent energy performance, with building envelopes well insulated and with high thermal performane of the transparent closures (window and door frames, etc.), require calculation according to the finished models following the EN ISO 10211 standard. In these types of buildings, it may happen that the incidence of thermal exchanges due to thermal bridges is also equivalent to 1/3 of the thermal exchanges for transmission through the building envelope, while, in general, for existing buildings such percentage is always lower than 15%; for this reason, in the design of NZEB or Passive House buildings, particular attention is required in the design of this part of the building envelope, both from the point of view of the thermophysical performance and during construction. The thermal bridges cannot be eliminated, that is, there are always going to be thermal bridges, but they can be "*corrected*" minimising the impact of the heat flow that traverses these elements. The values of the linear thermal bridge ψ are equivalent to $\Psi < 0.1$ W/m K, and for low energy buildings the values are lower than $\Psi < 0.01$ W/m K. In some cases, the value can be negative, and this depends on the mode of insertion of the measures in the calculation software, or in the case of measures taken gross of the walls, the values can be negative.

In this regard, the chapter on the thermal bridges describes the difficulties encountered in the design phase and during construction in order to limit the impact of the thermal bridges both in the calculation and during construction, and therefore in their actual behaviour. The calculation software of the finished elements has been a useful tool during the design phase, precisely for verifying, step-by-step, the value of the linear thermal bridge (W/m K).

Relative to the above, in fact, consider that the thermal bridge is an element of discontinuity both as regards the thermal flow and for the passage of water vapour through the construction elements (migration of the water vapour). The risk of the formation of condensation of the water vapour inside the building closures depends on the vapour permeability of the materials and on the surface and interstitial temperatures of each layer. If such temperatures are close to the dew point or lower, there may be the risk of the formation of condensation. The thermal bridge can present a risk because the heat flow is greater and therefore the interstitial temperatures are lower; the "correction" of the thermal bridges allows one to verify and avoid this problem.

6.2.5 Solar Transmittance (g_{gl}) and Shading Devices (g_{gl+Sh})

The thermophysical data that allow the evaluation of solar heat gains and therefore allow one to reduce or increase them are related to the penetration of solar radiation inside the building, with the consequent risk, especially in the summer, of overheating.

The "solar transmittance" or "total solar energy transmittance" (solar factor) indicated by the letter (g_{gl}) in parentheses and calculated according to the EN 410 standard is a parameter that defines the properties of the glass used for the transparent closures, windows, doors, glass façades, etc., and is given by the ratio between the quantity of radiant energy (visible and infrared) that passes through the glass compared to the incident energy: the higher the value of the solar factor (g_{gl}) the greater is the quantity of solar radiation that enters within the building and vice versa.

The range of values of (g_{gl}) of the glass available on the market is between 0.40 for low-emission windows and about 0.95 for single ultra-clear windows.

In the choice of the panes, it is therefore best to use glass that has values of $65 < (g) < 80$ that ensure the correct natural illumination of the environments (light transmission) and the reduction of the solar heat gains in the calculation of the thermal energy to subtract in the summer.

The passage of the solar radiation through the transparent closures (windows, skylights, French doors, etc.) also depends on the adoption of shading systems, mobile or fixed. The effect of the shading devices is evaluated with the symbol ($g_{gl + sh}$) which allows the determination of the shading factor $F_{sh, gl}$ given by the ratio between the values of transmittance of total solar energy of the window with and without shading ($F_{sh, gl} = g_{gl + sh}/g_{gl}$) and which expresses the proportion of energy reduced thanks to the presence of the shading systems.

In the absence of reliable design data or, however, of more precise information, the effect of movable shading devices can be evaluated through the EN 13363-1 and EN 13363-2 standards. In the evaluation of the design or in the evaluation standard, one takes into account only the effect of the mobile shading devices applied in an integral manner. This is not the place for a detailed description of the shading systems and their characteristics, for design purposes and for the designer what counts is the knowledge that the presence of shielding, fixed or mobile, reduces the amount of solar radiation entering through the transparent closures, that this quantity depends on the geometrics, on the material selected, on the transparency, etc., and that it is possible to establish it in relation to the characteristics of the shading devices and to the mode of opening and closure even in the case of automation. In the case in which the shading closures are automated, the criteria for defining the value of $F_{sh, gl}$ in the case of Building Automation and Control Systems (BACS) are calculated according to the EN 15232 standard.

6.2.6 Solar Heat Gains Elements

The solar heat gain - i.e. the quantity of energy that "enters" into the building thanks to solar radiation - can be a positive element in the winter, because it allows the reduction of the amount of energy to be supplied with the technical systems during the daytime period; but it is very negative in the summer, in particular in the Mediterranean area, given that it can cause overheating and thus may require the use of a cooling system; given that a unit of energy to subtract for cooling "*costs*" much more than that for providing a unit of energy, it is important that the design avoids the risk of "overheating" due to solar radiation.

To calculate the quantity of solar heat gain, reference should be made to those elements that the technical legislation defines as solar heat gains elements, i.e. the elements of the building envelope, opaque and transparent, affecting the passage of the solar radiation within the building.

The thermophysical reference parameter is the "*effective collecting area*", expressed in m^2, which expresses the area equivalent to the amount of solar radiation that would traverse an element of the building envelope (window, wall, etc.), if this element were not present: the effective collecting area allows one to determine the equivalent surface of the building envelope through which the solar radiation passes directly.

This area varies according to whether one refers to an opaque or transparent element (glazed elements):

- in the case of *effective collecting area of opaque building elements*, the area (m^2) is directly proportional to the surface (of the wall, of the roof, etc.) of the transmittance and of the "*absorption coefficient for solar radiation*" (α) that depends on the colour of the surface. The value of α is equal to 1 in the case of a black body (the black body is a concept of thermokinetics that expresses an ideal body that absorbs the entire amount of incident radiation) and to 0 in the case of a perfectly transparent body (the absolute vacuum). Italian standards give a value of 0.3 for a surface of a light colour (white plaster, ochre walls, etc.) and 0.9 for a dark colour (dark grey, red, purple, etc.).
- in the case of *effective collecting area of glazed elements*, the area is directly proportional to the size of the glass, to the solar transmittance (g_{gl}) and to the presence of shading elements due to the presence of external obstacles, such as other buildings, trees, and by the fixed shading elements (overhangs, balcony, terrace, etc.) or mobile elements (curtains, mobile brise soleil, etc.).

6.2.7 Phase Displacement and Dynamics Parameters

To the thermophysical data referred to above, associated with the individual materials or with a combination thereof, it is necessary to add a series of parameters relating to the dynamic behaviour of the building envelope; parameters which, however, are not covered in the calculation of energy performance through the use of steady-state calculation methods, that consider the energy exchanges that occur in conditions of equilibrium, but only, precisely, in the case in which we use dynamic calculation methods. The use of dynamic calculation methods is helpful in the case of energy diagnosis or in the case of research, and in any event where it is necessary to evaluate the energy and/or comfort parameters, or the indoor environment parameters, instant by instant, by comparing the calculated data with those measured or monitored in reality; or for use in the case of highly specialised design for research or for the laboratory.

The professional activity that involves the design and construction of buildings, and the relevant legislation and technical legislation provides for the use of the steady-state standards and methods of calculation.

Despite this, it is useful to keep in mind that the building envelope has a dynamic behaviour and that the intensity of the solar radiation varies depending on the time of day and the day of the year; it is, therefore, useful to refer to some parameters linked to the building envelope and to the building materials that allow the evaluation of how and in how much time the solar radiation enters within the building.

The dynamic behaviour of the opaque building envelope is calculated according to the EN ISO 13786 standard that defines the criterion for the calculation of three parameters:

- the decrement factor;
- the thermal lag or time shift (*h*);
- the periodic thermal transmittance (YIE) measured in W/m^2 K.

Unlike the calculation of the thermal transmittance, in which it is considered that the indoor and outdoor temperatures do not vary, the EN ISO 13786 standard presupposes that the boundary conditions vary in a sinusoidal manner, and it considers the solar radiation; therefore, there is a quantity of heat flow that goes from the outside towards the inside (i.e. gains) and from the inside towards the outside (i.e. dispersions).

The *decrement factor* is given by the ratio between the quantity of heat that traverses the wall and the ability of the same wall to conduct heat (transmittance). The higher the value of the decrement factor, the lower is the amount of heat flow, per time unit, that traverses the building element.

The *thermal lag* or *time shift*, easier to understand, is the time it takes the heat flow, due to solar radiation, to traverse the closure from the outside towards the inside; the greater the thermal lag, the lower the overheating risk. For example, a phase shift of 8 h of a vertical wall means that the amount of solar radiation that strikes the wall from 8:00 to 9:00 a.m. traverses the building envelope and is reradiated towards the inside, from 16:00 to 17:00.

The periodic thermal transmittance (YIE) is a parameter that expresses the quantity of heat flow that traverses, from the inside towards the outside, the opaque element throughout the arc of the day, with the sinusoidal boundary conditions established by legislation. In more simplified terms, this is a sort of economic balance, given by the difference between the incoming heat flow (solar radiation) and the outgoing heat flow (thermal dispersions). Theoretically, the value of zero occurs when the total incoming heat flow is equal to the outgoing heat flow, in actual behaviour, and as a result of the technical standard, the thermophysical parameter allows one to say that: the lower the value of the periodic thermal transmittance, the lower the heat flow that traverses.

The dynamic values depend on the characteristics of the individual materials that compose the building envelope, on their density (kg/m^3), thermal capacity (kJ/kg K), and on their arrangement and stratigraphy from the inside towards the outside.

6.2.8 Hygrometric Properties

The building envelope delimits the indoor environment from the outdoor one, and this demarcation is not a break, but it is traversed by some physical phenomena: the flow of heat (thermal energy) from the inside to the outside and vice versa due to solar radiation, the passage of air through the windows and air leakages, water impermeability (liquid state) and the passage of water vapour (gaseous state) through the opaque walls, foundation floor slabs and the roof. Water is a substance that is present in various physical states: solid, liquid and gaseous; all three can lead to situations of damage and deterioration of the building envelope and of the indoor environment.

The design of the building envelope must ensure that there are no water infiltrations, for example, that of rain or snow, from the outside towards the inside, through the use of waterproof layers, i.e. the use of materials which are impermeable to the passage of water, layers that are generally placed where there may be damaging atmospheric phenomena: in the roof, to protect it from rain, in the foundation and support structures to avoid rising dampness, the rising of the groundwater or the rain present in the soil.

On the other hand, the building envelope must ensure that the water vapour present in the air inside the building, and caused by the presence of people (respiration), of activities (kitchen, bath, shower) or other sources (detergents, appliances, etc.), traverses from the inside towards the outside to avoid phenomena of surface condensation, i.e. to prevent the water vapour from reaching concentrations and conditions of water vapour pressure and air temperature, such as to pass from the state of vapour to liquid, forming humidity stains where they can lead to the creation of bacterial cultures (moulds and mildew) or other damage.

Construction materials (brick, insulation, etc.) are permeable to water vapour, that is, they allow the passage of air and water vapour thanks to their porosity or permeability.

The ISO 13788 standard defines the hygrothermal performance of building components and building elements, and the calculation procedure to verify that there is no creation of superficial condensates, internal or external, or interstitial condensation inside the wall: both phenomena bring about damage to the indoor environment and to the materials, also altering the thermophysical properties. The calculation refers to the stratigraphy of the opaque vertical and horizontal closures (wall, floor, roof), while for more complex structures such as the thermal bridges, one refers to the ISO 10211 technical standards.

The main properties of the materials and information that would be useful to the designer in the choice of the building materials are provided, taking account of the moisture transfer through the building components; while for the calculation procedure, refer to the standard, to the specialised texts and to the calculation software.

The passage of the water vapour through the building envelope follows the same principle of the thermal flow, i.e. the quantity of water vapour that traverses the building envelope (g, density of water vapour flow rate, expressed in kg/m^2 s: kilograms of water vapour for every square metre of surface per second) depends on the difference of the water vapour pressure (measured in Pa, Pascal) between the indoor and the outdoor environments, and by the total water vapour diffusion (D_{tot}) of the entire wall.

The indoor and outdoor water vapour pressures are expressed in relation to the corresponding relative humidity of the air (expressed in percentage %), once one knows the ratio between the water vapour pressure and the water vapour pressure at saturation.

The density of water vapour (g) is directly proportional to the water vapour permeability of the materials (δ) and of the air (δ_0) expressed in kg/ms Pa, i.e. the quantity of water vapour (kg) that passes through a metre of the thickness of the element per second for each Pascal of pressure difference. As can be seen, it is a similar magnitude—conceptually—to the thermal transmittance, i.e. it expresses the ability of the material to allow the water vapour to traverse; the higher it is, the greater the quantity of water vapour that traverses it. The greater value is related to the water vapour permeability of the air (δ_0), where $\delta_0 = 2 \times 10^{-10}$ kg/ms Pa.

The water vapour can change state, passing from the vapour state to the liquid state by means of the phenomenon of condensation (liquefaction) in relation to the pressure of the water vapour and its temperature. In passing through the building envelope, each layer, internal, external and interstitial (intermediate) can have a different temperature, in relation to the thermal conductivity (λ) of the individual materials and the thermal resistance of the entire wall. Moreover, the water vapour may have a different pressure, for each layer, in relation to the difference between the indoor and outdoor water vapour pressures. The physical properties of the substances at each combination of temperature and pressure correspond to a physical state, and therefore there is a condition of temperature and water vapour pressure in which it passes from the vapour state to the liquid state and there is condensation; this value is called water vapour pressure at saturation: when the water vapour pressure (p_v) is equal to or greater than the water vapour pressure at saturation (p_{sat}), it creates condensation, and the calculation procedure serves to verify that this condition will not be created.

The calculation has as its objective to determine how much water vapour traverses the wall, and this value is expressed in relation to the resistance of the water vapour expressed on the basis of the parameter "water vapour resistance factor" (μ, *a*-dimensional parameter) that is given by the ratio between the water vapour permeability of the air (δ_0) and of the individual material (δ), and therefore, for a material $\mu = \delta_0/\delta$; so, if the value of $\mu = 1$, it means that the material has the same water vapour permeability as the air and therefore has a high permeability value, while the higher the water vapour μ value, the greater the resistance of the material to the passage of the water vapour. The unit of measurement of μ is *a*-dimensional.

Construction materials have the μ value between 10 and 20 (plaster) and 60–80 (insulating materials), while the materials that hinder the passage of the water vapour, such as aluminium, glass or water vapour barriers, have the μ value greater than 10,000 or 100,000. (This value is a calculation convention; since the materials are totally impermeable to vapour, it is not possible to show the value as "infinite".) When, according to the calculation, it appears that the stratigraphy designed involves the formation of condensation, one may act by inserting a water vapour barrier, a material that has a high μ value.

The μ value is given in the technical data sheets of the materials, and another parameter that can be found on these data sheets is the s_d water vapour diffusion equivalent layer thickness (m) that expresses how thick (m) the air layer should be in order to ensure the same permeability of the material. For example, the s_d value of 5 cm of air is equivalent to 5 cm, while in the case of a material of 5 cm with μ equivalent to 10, it has the same resistance to the passage of water vapour of a layer of air equivalent to 50 cm. The μ value is calculated according to the ISO 10456 and ISO 12572 standards.

The calculation, according to ISO 13788, and carried out with the thermo-technical software, provides a double verification:

- calculation of surface temperatures to avoid critical surface humidity;
- calculation of interstitial condensation.

The calculation is carried out, for each month, in relation to the external climatic conditions; in the case in which there is the formation of condensation, in one month, it is possible to evaluate whether or not this amount of condensed water has evaporated during the summer months.

Although this is possible according to the standard, the presence of condensation, even for only one month, and even if it evaporates, can cause problems, because the presence of a trace of water inside the structure may lead to damage of the materials, to rotting, or to transition from water to ice in some specific situations, a phenomenon that involves a mechanical action within the structure. In the case of the surface layers, such as the plasters, this phenomenon brings about leaching and/or the separation of the plaster.

The design of a new building, in particular if it is a high-performance one, must avoid, in all instances, the occurrence of the formation of condensation, acting on the properties of the materials (conductivity λ or water vapour resistance factor μ), on their thickness (m), on their positioning in the stratigraphy (preferring the most external insulating layer), or with the use of vapour barriers, or even by intervening on all of these parameters.

6.2.9 Transmission and Ventilation Heat Transfer Coefficients

The last parameter—before moving onto the next section—that characterises the physical behaviour of the building is the heat transfer coefficient, measured in W/K, which expresses the heat flow per unit of time (W, Watt = Joule/sec) exchanged by the building for every Kelvin (K) degree of temperature difference.

Please note: the parameter is referred to the building and not to the building envelope, because the heat transfer coefficient is given by the sum of:

transmission heat transfer coefficient: heat flow rate due to thermal transmission through the fabric of a building, divided by the difference between the environment temperatures on either side of the construction (ISO 13789);

ventilation heat transfer coefficient: heat flow rate due to air entering a conditioned space either by infiltration or ventilation, divided by the temperature difference between the internal air and the supply air temperature (ISO 13789).

The transmission heat transfer coefficient is the sum of the product from the transmittances of the opaque and transparent elements of the building envelope and their respective areas, and therefore dependant on the geometric and thermophysical characteristics; while the ventilation heat transfer coefficient depends on the net volume, the rate of air exchanges required by regulations for the intended use, and any possible mechanical ventilation systems.

While to reduce the heat transmission coefficient it is possible to intervene on the choice of materials, for the ventilation heat transfer coefficient, it is necessary to act on the other elements:

- the airtightness of the building envelope to reduce the air leakage;
- the ventilation, natural or artificial, i.e. the use of mechanical devices for the air exchange.

By intervening on these two factors, it is possible to reduce the value of the thermal exchanges due to ventilation. While as regards the ventilation, it is necessary to evaluate whether or not to equip the building with mechanical ventilation systems and to define what their characteristics should be. In case of reduction of the draughts, it is necessary to check both the design and the execution in the construction site for the realisation of the stratigraphy of the wall, of the windows, etc., and in particular the installation of the door and window frames should be checked, as well as each element of direct indoor and outdoor connections.

6.3 Building Energy Performance

The design and construction of a building with high-performance energy cannot neglect the calculation and evaluation, during the various phases of the design, of the Building Energy Performance (BEP). The BEP concerns both the evaluation of the energy behaviour of the building (understood as the building envelope) and the set-point of the indoor parameters based on the intended use, evaluated in dynamic or steady-state conditions (following ISO 13790).

This book does not intend to give detailed descriptions of the procedure for the calculation of the energy performance, a subject for which there is an extensive scientific literature and calculation software; the aim is to provide the main concepts that allow one to understand how the building energy performance is calculated, i.e. the final result of the architectural, technological and technical systems choices, as regards energy.

In the first place, it is necessary to clarify certain concepts: the Building Energy Performance can be referred to the calculation of the *Power* of the building, expressed in kW (kilowatt), or to the *Energy* expressed in MJ (Mega Joule) or kWh (kilowatt-hour).

The *Power* (kW) is defined as the amount of energy/work exchanged in the unit of time; the greater the power, the greater the amount of energy that is provided per second. In case of the design of the buildings, in general, the power refers to the devices and to the generators (boilers, heat pumps, etc.) of the heating and/or cooling systems. The calculation refers to the evaluation of the quantity of energy to be supplied to the building in the "worst case" (or more extreme) condition in which, on average, the building could find itself. For example, one evaluates how much energy is necessary to provide, to the building and to the technical system, when the indoor temperature is equivalent to 20 °C and the outside temperature is −5 °C (or 35 °C during the summer). This allows one to determine the maximum power that the generator must have in order to meet this critical-average condition, even though this condition is not frequent in normal operation.

The evaluation of the *Energy* expresses the amount of energy that is necessary to provide the building, to ensure the conditions of comfort, during a *specific period of time*, usually a year; it, therefore, takes account of the boundary conditions (temperature, radiation, etc.) that *vary over time*. The energy is expressed in MJ/yr (Mega Joule/year) or, in the case of buildings, in kWh/yr (kilowatt-hour/year). For example, if you keep a 100 W light bulb lit for 1 h, it will have consumed 100 Wh.

Given that the quantity of energy expressed in kWh/year may vary in relation to the dimensions of the building, this value is referred to the usable unit of surface area and expressed in kWh/m^2 year, which expresses the quantity of energy that is necessary to provide for every square metre for each year; in this way, it is possible to compare the building energy performance of various buildings, compared to the limits of the law or to the evaluation protocols.

The calculation of the quantity of energy to be supplied can be done with various levels of "sophistication", in relation to the availability of the boundary data and to the purpose of the calculation.

The *dynamic calculation*, through calculation software such as EnergyPlus, TRYNSIS, provides that the boundary conditions (outdoor temperature, radiation, internal loads, the presence of people, etc.) are the actual ones and therefore ones that vary continuously, instant by instant and second by second. This procedure allows one to obtain a result and a trend profile of the consumption and/or energy needs and/or temperatures, etc., during the entire period of the year that is similar or identical to the real one. The objective of this type of simulation is precisely that of obtaining a result that is coincident with the data and/or consumption measured in situ, and is generally used for energy diagnosis or for research and validation of other thermo-technical software.

The *steady-state calculation*, provided for the verification of the limits of the law, for the Energy Performance Certification and for other certification protocols, including Passive House, provides that the evaluation of the energy performance takes place considering that the variations of the boundary conditions vary rather slowly and are always in conditions of thermodynamic equilibrium. This principle helps simplify the complexity of the calculation by defining the indoor set-point conditions and the outdoor climatic variables in relation to the duration of the boundary conditions, which may be: on an hourly, monthly or annual basis. Generally, most of the steady-state calculation models and the ISO and EN standards consider a minimum period of one month, and therefore, the values of the outdoor temperature, radiation, etc., represent a monthly average.

The PHPP calculation model uses the steady-state calculation.

In the above paragraphs, we used the expression "*amount of energy to supply*", this terminology is generic, and the legislation stipulates that the calculation be referred to the "*energy demand*": the energy in which the building, understood as building and technical systems, needs to ensure the set-point indoor comfort conditions during the entire period of the year, in the winter and in summer, and for all the "*Energy Services*" or "*Energy use*".

We must now clarify which "type" of energy the *energy services* refer to.

Various activities take place in a building, each of which requires the use of a specific technical system which uses (consumes) energy. The energy services present in the building are: heating and cooling to ensure the set-point conditions of indoor comfort in the summer and in the winter, the production of domestic hot water, lighting, the various electrical domestic appliances, ventilation (if present) and the transport systems (lifts, etc.), and each of these can use electricity, natural gas, and other energy sources or energy carriers.

How is it possible to compare the various sources or energy carriers?

To be able to compare the energy consumption of the buildings, we must refer to the form of the energy itself, and specifically we have to refer to the "*Primary Energy*", which is defined as the quantity of energy of a source of energy or an energy carrier, before it is converted into other forms of energy. It is, therefore, possible to compare the primary energy of a device that uses natural gas with the one that uses electrical energy, given that they are converted into the same form of energy: *primary energy*. The conversion factors of the energy sources/carriers in primary energy are defined by the standards and/or by national, European or other legislation. The most common unit of measurement of the primary energy is the tons of oil equivalent (TOE), but this unit of measurement is too "large" for buildings, and therefore, we use the kWh of primary energy (kWh_{ep}).

The calculation of the Building Energy Performance takes into consideration:

– the thermal energy need for winter heating and summer cooling, defined by ISO 13790 as:

> energy need for heating or cooling: heat to be delivered to, or extracted from, a conditioned space to maintain the intended temperature conditions during a given period of time.
>
> The energy need can include additional heat transfer resulting from non-uniform temperature distribution and non-ideal temperature control, if they are taken into account by increasing (decreasing) the effective temperature for heating (cooling) and not included in the heat transfer due to the heating (cooling) system. (ISO 13790);

and according to the same criteria, one must consider the thermal energy need for the domestic hot water (DHW):

- the quantity of energy that the technical building system (heating and/or cooling system) has to provide including the auxiliary electricity (pump, fan, fan coils, etc.);

technical building system: technical equipment for heating, cooling, ventilation, domestic hot water, lighting and electricity production.

energy use for space heating or cooling: energy input to the heating or cooling system to satisfy the energy need for heating or cooling, respectively.

auxiliary energy: electrical energy used by technical building systems for heating, cooling, ventilation and/or domestic water to support energy transformation to satisfy energy needs (…) This includes energy for fans, pumps, electronics, etc. Electrical energy input to a ventilation system for air transport and heat recovery is not considered as auxiliary energy, but as energy use for ventilation (ISO 13790)

- the energy need that the generator (boiler, heat pump, solar thermal, etc.) must provide to the plant subsystems (distribution, regulation and emission);
- the quantity of energy that must be delivered to the generator;

delivered energy for space heating or cooling: energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (heating, cooling, ventilation, domestic hot water, lighting, appliances, etc.) or to produce electricity (ISO 13790).

- and the conversion of delivered energy in primary energy depending on the energy source/carrier used by the generator.

The calculation procedure consists in a flowchart, a sequence in which, starting from the building, one determines the energy needs to be met with the use of the technical systems, depending on the type of generator and energy source/carrier considered.

The designer, therefore, has various tools available for reducing the primary energy need, in particular the energy need coming from fossil fuel sources; he or she can act on the reduction of the thermal energy need of the building, to heat and/or cool it; on efficiency and the type of technical systems as well as on the type of energy source used, favouring renewable energy sources.

It is obvious that the preferable solution, in particular in the case of new buildings—without the constraints and difficulties that exist in the case of energy retrofitting of existing buildings—is to reduce the thermal energy need of the building; in this manner, one reduces the energy need that the technical systems must provide and it is thus possible to meet this demand, for the most part, by the use of technical devices with high efficiency and low temperature (floor radiation, heat recovery ventilation, etc.) and with extensive use of energy from renewable sources, until the point of using almost exclusively renewable sources, using energy from fossil fuels only as auxiliary system in the event of exceptional events (extremely hot summers or very cold winter days).

With regard to renewable energy sources, it is worth highlighting what is provided by the calculation standard and by the legislation in the European Union: Directive (2009/28/EC) defines as renewable sources (article 2):

(a) 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;
(b) 'aerothermal energy' means energy stored in the form of heat in the ambient air;
(c) 'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth;
(d) 'hydrothermal energy' means energy stored in the form of heat in surface water;
(e) 'biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste; (Directive 2009/28/EC).

As you can see, even the heat pumps, which use the aerothermal, geothermal or hydrothermal energy that is contained, respectively, in the air, in the ground or in water basins, can be considered—in part—as a renewable energy source.

Two aspects can be added to the above: the first, that the heat pumps have the greatest yield (COP = Coefficient of Performance) when they must provide little energy or energy at low temperatures (floor radiant heating/cooling), and thus it is to one's advantage to design a building that has a reduced thermal energy need; according to which the electrical heat pumps may be fed through the use of electric energy produced by photovoltaic panels.

The design of buildings with a high energy performance, Low Energy Buildings, Nearly Zero Energy Buildings (NZEB) and Passive Houses must take into consideration all three of the aspects, building, technical systems and renewable energy sources, by adopting solutions with greater efficiency and/or performance in relation to the specific case: in other words, it is good to evaluate, each time, if it is preferable to act on the building envelope, technical systems, generator and so forth, in a continued iteration and interaction between architectural, technological and systems design, and the calculation results, without adopting extremist approaches, instead of adopting pre-arranged technological solutions or those copied from other examples, not always suitable for all contexts.

Having clarified this aspect, it is evident that the main aspect on which we must concentrate in the design of a building is its conformation in an architectural and technological sense, as well as from the energy point of view on the *Energy need for heating and cooling*.

The calculation procedure, as stated, is defined by the ISO 13790 standard, which provides for the calculation of an energy balance at the building level; it is in fact a kind of balance between the quantity of outgoing and ingoing energy in the building, as if it were a family budget:

– on the one hand, there is the energy that "*exits*" from the building, i.e. the thermal exchanges for transmission and ventilation (*heat transfer coefficient*), calculated month by month: element that constitutes a negative aspect in the winter and positive one in the summer.
– on the other hand, there is the energy that "*enters*" into the building or the thermal gains due to the presence of internal sources (*internal heat gains*: people, appliances, activities, cooking, etc.) and to the solar radiation (*solar heat gains*), calculated month by month: element that constitutes a positive aspect in the winter and a negative one in the summer, given that the radiation can lead to the overheating of the indoor environments.

Specifically, ISO 13790 defines:

> – internal heat gains: heat provided within the building by occupants (sensible metabolic heat) and by appliances such as domestic appliances, office equipment, etc., other than energy intentionally provided for heating, cooling or hot water preparation;
> – solar heat gains: heat provided by solar radiation entering, directly or indirectly (after absorption in building elements), into the building through windows, opaque walls and roofs, or passive solar devices such as sunspaces, transparent insulation and solar walls (ISO 13790).

The calculation can be done on an hourly, monthly or seasonal basis; in most applications, it is on a monthly basis, and, as has been said, it is a steady-state calculation; therefore, it considers the boundary conditions that vary continuously on a monthly basis. In other words, the calculation method requires a "*correction*" that takes into account the dynamic behaviour due to, for example, the day/night variation of solar radiation, and the thermal capacity (see above) of the building envelope and indoor air of the environments. The ISO 13790 standard provides two corrective factors, *loss utilisation factor* (for the summer) and *gain utilisation factor* (for the winter) that allow one to obtain results which take account of the dynamic behaviour of the building, so as to render the results comparable with actual ones.

What use is this information for the designer?

In the first place, it gives a clear idea of the criteria and the methodology of calculation, without having to go into the detail of the algorithms and the individual formulas (although they are interesting and useful) allowing the designer to avoid relying exclusively on pre-constituted solutions, often corresponding to a "sustainable" architectural design rather than to the actual energy and environmental performance. In the second place, it prevents one from having to rely, blindly, on those who carry out the calculations, but allows control in every step of the design, as has been described in the other sections of this book. Lastly, it allows the designer to understand which elements can act in the energy balance of the building in relation to their own architectural, technological and economic requirements.

The designer may not be omniscient, but not even a "*Duckspeaker*" (Orwell 1949) would adopt unverified solutions, also because if it is true the certification system is what checks and validates a design and construction; it is, however, the architectural designer who is responsible for the result and the duration in time of the result.

The ISO 13790 standard contains a brief description of the *entire* procedure for the calculation of the energy balance at the building level:

> The energy (heat) balance at the building zone level includes the following terms (only sensible heat is considered):
>
> transmission heat transfer between the conditioned space and the external environment, governed by the difference between the temperature of the conditioned zone and the external temperature;
>
> ventilation heat transfer (by natural ventilation or by a mechanical ventilation system), governed by the difference between the temperature of the conditioned zone and the supply air temperature;
>
> transmission and ventilation heat transfer between adjacent zones, governed by the difference between the temperature of the conditioned zone and the internal temperature in the adjacent space;
>
> internal heat gains (including negative gains from heat sinks), for instance from persons, appliances, lighting and heat dissipated in, or absorbed by, heating, cooling, hot water or ventilation systems;
>
> solar heat gains (which can be direct, for example, through windows, or indirect, for example via absorption in opaque building elements);
>
> storage of heat in, or release of stored heat from, the mass of the building;
>
> energy need for heating: if the zone is heated, a heating system supplies heat in order to raise the internal temperature to the required minimum level (the set-point for heating);
>
> energy need for cooling: if the zone is cooled, a cooling system extracts heat in order to lower the internal temperature to the required maximum level (the set-point for cooling). (ISO 13790)

and of the *Energy balance at the level of the technical building systems*:

> The building energy need for heating and cooling is satisfied by the energy supply from the heating and cooling systems. At the system level, the energy balance for heating and cooling, if applicable, includes:
>
> energy need for heating and cooling of the building zone;
>
> energy from renewable energy systems;
>
> generation, storage, distribution, emission and control losses of the space heating and cooling systems;
>
> energy input to the space heating and cooling systems;
>
> energy input to central pre-heating and pre-cooling of ventilation air, including transport, thermal losses and control;
>
> special: energy output from the space heating or cooling systems (e.g. exported electricity from a combined heat and power installation). (ISO 13790)

Finally, to conclude this section on the calculation of the Building Energy Performance, the performance is expressed on the basis of a single indicator that has different names (primary energy index, etc.) and it expresses, as has been said, primary energy need (kWh) per square metre of surface (m^2) for the entire year

(year). In the case of low-energy and Passive House buildings, this index, expressed in kWh/m^2 per year, includes all the energy uses: heating, cooling ventilation, domestic hot water, lighting, auxiliary electric consumption and domestic appliances. Added to this is also a limit value referred to the energy use for space heating and cooling, which must be less than 15 kWh/m^2 per year; in fact, the Passive House protocol gives priority to interventions relative to the building.

6.3.1 Building Performance Simulation

The calculation of the Building Energy Performance, given the complexity of the input and output data, in addition to the quantity of algorithms, is carried out by means of modelling software with the use of the virtual model and in some cases of the Building Information Model (BIM).

Building Simulation consists in the use of the virtual model, processed by computerised simulation, that allows the evaluation of some specific aspects relating to the building; among these, concerning the study of the indoor microclimate, one uses the *Building Performance Simulation* (BPS), a generic term that means the virtual models that allow the study of the building performance: indoor microclimate, lighting, energy, human behaviour, acoustics, Indoor Air Quality and so forth. In particular, the software

- *Building Energy Performance* (BEP), a term which refers to the simulation of the thermal energy need for heating and cooling and primary energy need, for predicting the energy use of the building;
- *Virtual Environmental*, which concerns the study of the characteristics of the indoor microclimate;
- *Computer Fluid Dynamics* (CFD), which consists in the simulation of the fluid dynamics behaviour of the air inside and the outside of the building due to natural ventilation or controlled mechanical ventilation (CMV);
- HVAC systems performance prediction;
- indoor thermal quality performance prediction;
- daylight performance predictions, lighting and daylight simulation;
- other application software specific to architectonic acoustics and/or environmental acoustics (room acoustics performance prediction), to the modelling of the thermophysical characteristics (transmittance, phase displacement, etc.), sustainability software, energy labelling software, Building Simulation in building automation systems.

The scientific literature covers many of the journals and conferences which are concerned with the study of the buildings, with two specific Building Simulation journals by Springer, and journal of Building Simulation, official journal of the IBPSA (International Building Performance Simulation Association, a nonprofit international society of building performance simulation researchers, developers and practitioners, dedicated to improving the built environment), association that joins together the majority of the scholars and experts in Building Simulation. As for the IT and computer graphics sectors, the evolution is so fast that the technical manuals find it difficult to keep pace, and therefore, there are no manuals, atlases or books that summarise the entire universe of Building Simulation.

The steady-state calculation models consider the boundary condition (indoor and outdoor temperatures, internal load, human behaviour, ventilation, etc.) as constants and variables in continuity, that is, the model is considered as always in a condition of equilibrium. These calculation models are derived from the ISO 13790 standard and are mainly used to evaluate the energy performance of the building for the purposes of compliance with laws (minimum energy requirements) and with the energy labelling. These software programmes are not useful in the study of the indoor microclimate because they refer (almost exclusively) to the energy need and do not allow us to know the characteristics of the indoor microclimate that is being considered with conditions resulting from a given set-point during the design phase.

The dynamic calculation models take into consideration the boundary conditions (indoor and outdoor) that are continuously variable, and therefore take account of both the indoor and outdoor variations, in the presence and in the absence of HVAC; once the input data relevant to the building and to the outdoor climatic variables and to the indoor microclimate (Virtual Environmental) have been defined, one obtains the result of the simulation, making it possible to know the trend of the temperature and of the other indoor microclimatic variables.

The calculation of the Building Energy Performance for Passive House certification, as provided for by the Passive House protocol, must be done with the PHPP (Passive House Planning Package) software. PHPP is based on an MS Excel workbook in the xlsx/xlsm format. Microsoft Windows XP (or higher) and Microsoft Excel 2007 (or higher) are system requirements (Passive House Institute).

6.4 Indoor Comfort

The primary aim in the design of a building is to guarantee the best indoor wellness conditions, i.e. comfort; in particular in the case of low-energy buildings, NZEB, Passive Houses, etc., even if, as it may seem, the aspect linked to the energy need and its environmental impact seems to attract greater attention. This is because comfort is a given set-point, a point of departure of the entire process of designing, calculation and construction, as well as of the management, maintenance and use of the building.

Indoor comfort is, therefore, the result of the application of the design and technological choices, and, in the specific case of the *Fiorita Passive House*, it was also decided to monitor in order to verify if the expected results of the design are the actual results. This will confirm how secure a correct design is, or rather, a design that is thought out and reasoned will be able to ensure reliable results. The characteristics of the monitoring system and the results are described in the last chapter of this book.

In this segment, we want to illustrate some terms, concepts and criteria relating to how one evaluates indoor comfort, following the approach of the book: to navigate, it is necessary to know how to read the maps, understand the behaviour of the winds, properly read the compass and to then choose the right tools, also conceptual ones, to reach the destination.

The condition of the comfort of an environment depends on the interaction between multiple physical, physiological and psychological factors. The World Health Organization (WHO 1999) defines comfort as

> Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity

> condition in which satisfaction is expressed with regard to the thermal environment

and the ASHRAE 55 Standard (ASHRAE 55) defines comfort as

> that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

The term *comfort* includes at least four types of comfort:

– *thermal comfort* or thermohygrometric comfort, concerning the sensation of hot/cold and related discomfort;
– *acoustic comfort*, connected to the presence of noise coming from the outside or from other environments;
– *lighting comfort*, connected to the lack of natural light (daylight factor) within the ambients;
– and the *Indoor Air Quality (IAQ)* which expresses the purity of the air and the absence of chemical, biological and other substances which may have negative effects on health and that can be inhaled by breathing, through the mucous membranes or through other forms of contact.

In this section, we focus on thermal comfort and on Indoor Air Quality, most directly connected with the Building Energy Performance and the construction choices to obtain the Passive House certification, while the aspects related to acoustic comfort, linked to the design of the façades and the elements of the division between the apartments (airborne noise and trampling noise) and to lighting comfort and daylight factor, do not have any special design measures, because the Italian legislation already provides very stringent requirements.

6.4.1 Thermal Comfort

The human body can be modelled as an open system that exchanges energy through its contour to maintain an internal temperature of approximately 37 °C. The heat produced by the human body is due to basal metabolism, which is the base that allows the body to be kept alive, and by muscle metabolism or by mechanical exertion of the human body. The energetic balance of the human body consists in an open system, which exchanges energy and matter (food, respiration, evapotranspiration) with the outside through its contour (human body area, skin). Taking the example of a room located in a building that has been scarcely and poorly insulated, with an outside temperature of −5 °C and an indoor temperature of 20 °C, it could record surface temperatures of 16 °C on the window panes, 11 °C on the window frame, 15.5 °C on the internal wall, 8.7 °C in correspondence with the corner, 10.1 °C where the external wall meets the floor, 5.1 °C behind the cabinets. These temperature differences, in addition to discomfort, can generate moulds and condensation.

The energy exchanges through the contour of the human body, skin and clothes are due to the phenomena of heat exchange by convection and radiation between the surface of the body and the external environment, and in part by conductivity. The human body is modelled as a body that finds itself at a given temperature that exchanges heat with the environment by means of thermal radiation. Clothes are the main factor of climatic adaptation of man to the environment, followed by the use of fire for controlling the microclimatic conditions of the indoor environments.

Thermal comfort expresses the judgement of the person who occupies an environment in regard to his or her own sensation of thermal comfort; in general, for new buildings, thermal comfort must always be guaranteed as a condition of "neutrality", i.e. an environment must not be either very hot or very cold. The study of thermal comfort, by Fanger (1970), constitutes a discipline that has gone through a first experimental phase, but that, with the approval of the ISO 7730 and ASHRAE 55 standards, has consolidated evaluation criteria, to which reference is made, and that we will try to summarise in this section. If the condition of neutrality is the requirement for new buildings or those that are undergoing retrofitting, the same cannot be said for historical buildings, heritage buildings and buildings that are used as museums, since here the priority is given to the conservation of the artefacts and the building. Which of the two is a priority? The thermal comfort of the visitors or the conservation of the artefacts? Between these two extremes, there may be, on the part of visitors, different degrees of tolerance to the sensations of thermal discomfort, for the positive aspect of visiting the cultural asset. In other words, the visitor may be willing to bear with discomfort in order to remain for a short period of time in an environment that is slightly too warm or slightly chilly (or too hot or cold) while enjoying the cultural asset.

The ISO 7730 and the ASHRAE 55 standards define the criteria for measuring and calculating the indices of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD):

> **PMV**. The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (see Table 6.1), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment. In a moderated environment, the human thermoregulatory system will automatically attempt to modify skin temperature and sweat secretion to maintain heat balance. (ISO 7730)

Table 6.1 Factors and parameters for the quality of the indoor environment (Blyussen 2009)

	Thermal comfort	Indoor Air Quality
Parameter	Air temperature, Mean radiant temperature, Relative humidity, Air velocity Human metabolism, Clothes	Pollution sources and air concentration: (allergic, irritational, carcinogenic, etc.); Ventilation rate and efficiency
Control	Design of building (architecture, insulation, windows, etc.), Design of HVAC, IAQ	HVAC, Ventilation systems and Maintenance air cleaning, Activity control
Issues	Thermal adaptation, Energy Use, HVAC system (e.g. radiators, fan coils, etc.), Human behaviours	Secondary pollution: Indoor chemistry, Microorganisms, Dust; Energy use

> **PPD**. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. For the purposes of this International Standard, thermally dissatisfied people are those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale given in Table 6.1. (ISO 7730)

The Predicted Mean Vote (PMV) is the *Sensation* index most frequently used in the literature and in the international standards; it allows the evaluation of the opinion expressed by a healthy adult subject in a moderate environment. The PMV is expressed according to a 7-point scale from Cold (−3) to Hot (+3); each level of the scale is the result of an equation which takes account of the indoor microclimatic variables and of the metabolism and clothing of the subject, starting from the balance equation of the heat exchange between the human body and the environment.

The Predicted Percentage of Dissatisfied (PPD) is a *Statistical* index related to the PMV, but it can also express compliance with other indicators such as CO_2, the level of illumination or local situations of discomfort.

In the exchange of energy between the human body and the environment, once we have defined the physiological parameters (Human Body Heat balance) and the clothing, it is necessary to describe the parameters which act on the contour of the system, i.e. the parameters relating to Indoor (or Outdoor) Environment Microclimate.

The indoor parameters are:

– air temperature (t_a measured in °C), which has characterised the exchanges of thermal energy between the body (skin temperature or clothes temperature) and the environment;
– relative humidity (RH measure in %), which characterises the thermal exchanges of mass and energy due to heat loss by Skin Diffusion (Ed) and Latent Respiration Heat Loss (Ere), in the case of high values of RH (e.g. >75%) of the indoor environment, the quantity of energy and mass in which it is possible to exchange is lesser compared to lower RH values;

– air velocity (air, measured in m/s), which characterises the thermal exchanges by convection (heat loss by convection) between human body or clothes surface and the air of the environment;
– mean radiant temperature (MRT measured in °C), which characterises the thermal exchanges by radiation (heat loss by radiation) between the human body or clothes surface and the walls at a constant temperature, described in the following chapter.

The PMV and PPD indices of thermal comfort refer to the average conditions of the environment. In addition to these, factors of local thermal comfort must be considered, which may depend on:

– microclimatic situations that are particular and localised in a part of the space, for example, close to the windows or in the proximity of the terminals of the heating system;
– individual variables, floor temperature, vertical asymmetry, air draughts, etc.

Local discomfort has a negative effect on the perception of the quality of the indoor environments because it affects the individual persons directly. In environments for collective and continuous use, such as offices, schools and the like, in which different people occupy, often, the same seats, it can generate situations of chronic illness and, in addition to physiological discomfort, can also alter the relations of social microcosm that is created between the occupants.

Once it has been clarified what parameters should be used to evaluate the thermal comfort in the indoor environments, it is useful to provide some indications concerning design. In the first place, it should be stressed that there is a direct correlation between thermal comfort and energy performance, i.e. it is not said that buildings with high-performance energy always ensure thermal comfort: there could be situations of general discomfort or local discomfort, due to specific situations or design choices, for example, a large window, advantageous as regards the thermal gains in the winter, can be a factor of discomfort. There is a linear correlation, but, in general, low-energy buildings adopt solutions that favour the sensation of positive thermal comfort, such as the uniformity of the surface temperatures of all the surfaces within the environment, reducing the presence of radiating asymmetries and the possible convective phenomena with the generation of annoying air draughts. The use of radiant floors and/or air-conditioning systems (controlled mechanical ventilation) can increase the presence of "hot" floors (discomfort) and/or of draughts (another factor of discomfort).

6.4.2 Indoor Air Quality

The other comfort to guarantee in an environment is linked to the Indoor Air Quality (IAQ) and to the absence of pollutants or other phenomena that can "be bothersome" or damage the respiratory system. IAQ is a performance which is not related to the energy performance, i.e. it depends exclusively on the dilution of the pollutants (dusts, odours, etc.) present within the environment; this dilution occurs by means of the entrance of "*clean*" air (fresh air) from the outside by natural or mechanical ventilation. The only relationship with the energy performance is due to the fact that the introduction of a new volume of air for the dilution of the pollutants entails a reduction in the air temperature, with the relative heat loss.

In general terms the indoor environments refer to the discipline that investigates the "Indoor Air Quality", the subject of various standards: at the international level, we cite the ASHRAE Standard 62, the scientific literature, as well as research programmes and guidelines by the World Health Organization (WHO), WHO guidelines for IAQ: selected pollutants, (WHO 2010), Development of WHO Guidelines for Indoor Air Quality (WHO 2006).

Indoor pollutants may have various origins (physical, chemical, biological) and involve different types of damage to human health (diseases, chronic or acute illnesses and even death) and/or to the building (moulds, fungi, rot, biological attacks, detachment of the plaster, leaching, etc.); it defines acceptable IAQ as follows:

> acceptable Indoor Air Quality: air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction. (ASHRAE Standard 62)

The study of the IAQ concerns the architectural design of the natural ventilation systems, the design of the Heating, Ventilation and Air-Conditioning (HVAC) systems, as well as sources of pollutants present in the indoor environment or coming from the outdoor environment. The polluting factors that determine the IAQ can be removed thanks to ventilation, which in turn can be performed automatically by the HVAC, or carried out on the basis of the habit of periodically ventilating the environments by the occupants, and detected with the aid of the receptors of bad odours that are present in the human nose.

IAQ pollution is perceived by scent detection, thanks to the olfactory epithelium, present in the human nose.

The pollutants can be divided into two categories:

(a) pollutants *with odour*, which can be perceived *in a direct way* by the human nose, and for which the feeling of discomfort is evident, bad smell, dust, mud, acids, detergents, perfumes, benzene, etc.;
(b) pollutants *without odour*, which in turn:
    (i) can be perceived *in an indirect way*, because they cause allergic phenomena, irritation of the mucous membranes, such as carbon dioxide (CO_2) that alters the quantity of oxygen and thus causes a sensation of fatigue;
    (ii) they cannot be perceived by the human sense of smell and are the cause of chronic (e.g. radon) or acute (e.g. carbon monoxide) phenomena.

The evaluation of the IAQ by persons concerns:

- on one hand, the risk that the concentration of pollutants has effects on human health, as described above;
- on the other hand, the fact that the quality and the smells of the air have an effect on the perception of indoor comfort;
- alternatively, one can evaluate the IAQ, in an indirect manner, on the basis of the ventilation rate.

The criteria for designing the IAQ take account of health (risk factors for diseases and related symptoms, by the WHO) or comfort (perceived IAQ or acceptability), or they concern human performance (for learning, work, sport activities, etc.).

The perception of comfort as regards the IAQ depends on the sense organs and in particular on the nose, throat, eyes and skin, all parts of the body that are sensitive to temperature, humidity and to a wide range of pollutants present in the air. These are the senses that determine the judgement of persons on IAQ comfort, in particular the "olfactory sensory receptor" (nasal cavity) and the general chemical reception sensors situated all over the mucous membranes in the nose and the eyes; these senses determine the feeling of "acceptability" of comfort. The indoor environment where people have greater negative sensations or negative reactions from such senses is judged as "Not Acceptable", "Tolerable", up to "Not Tolerable".

To reduce the thermal exchanges related to the ventilation of the environments, in buildings with high performance and low energy, there is a trend of building "airtight" buildings, so as to reduce the thermal exchanges that might develop as a result of draughts (air leakage). This choice, which is positive from the energetic point of view, may not be positive from the IAQ point of view, since less ventilation involves a greater risk of concentration of water vapour (relative humidity) or of pollutants. The use of mechanical ventilation systems that guarantee the correct air exchange for reduction of the pollutants has the disadvantage of having to provide filters and of continuous maintenance, and therefore requires the "education" of the occupants regarding the cleaning of the filters. Airtight buildings have a "distinctive smell", one that is drier.

ASHRAE 62 standard on ventilation for Acceptable Indoor Air Quality defines the criteria to define the minimum ventilation rate able to reduce the concentrations of pollutants, according to intended use, amount of litres/second per person of the air to be exchanged. The same approach is used in the international, European and national technical regulations (e.g. EN 13799), both for the calculation of the energy performance and for the calculation of the mechanical devices and relative subsystems (filters, fan, etc.).

Other standards define the procedures in detail, such as EN 15242, which shows the method of calculation for determining the air flow rates, including also the infiltrations, i.e. the air leakages, for the purposes of calculation of the energy needs and of the Indoor Air Quality ventilation, and applies both to the mechanical ventilation and to the opening of the windows (natural ventilation).

What are the design indications for ensuring the IAQ?

As for every criteria described in the precedent parameters, one should not rely on standardised and compliant solutions: the most common technological solutions are not always the best ones, and it is important to avoid applications that are not reasoned through when dealing with any technological solution. The search for the total reduction of energy exchanges for ventilation, while on the one hand, is a benefit for the energy balance, and, on the other hand, it can lead to greater concentrations of indoor pollutants, a factor that can be accentuated if users continue to behave as if they are in "traditional" buildings.

The designer must know—as well as the end user—that the building runs a greater risk that the indoor pollutants remain within the environment and therefore, the ventilation must be guaranteed and controlled, either by opening the windows—which should be easy to open and accessible—or by mechanical ventilation systems, which should be easily accessible for maintenance activities; moreover, in buildings with airtightness, the most common sources of indoor pollutants, such as solvents, detergents, activities which produce water vapour (cooking), dusts or the concentration of people (CO_2), etc., have a greater risk of concentration.

6.4.3 Airtightness

In the previous segment, we talked about the relationship between the concentration of pollutants, the IAQ and the ventilation of the environments. In buildings with excellent energy performance, NZEB, low-energy buildings, or Passive House buildings, one of the objectives is to minimise the energy exchanges, including the exchange of energy due to the ventilation of the environments: caused by the ventilation of the environments or on account of draughts (air leakage). To reduce the air leakages, technological solutions are adopted—which are described in other segments of this book—for the execution of the construction of the vertical walls, horizontal slabs, installation of the door and window frames, the technical systems and so forth that have as their objective the reduction of the draughts or their total elimination.

In other words, the building envelope has to be "impermeable" to the passage of air, i.e. it must be "airtight". The design solution consists in the sealing of all possible elements of connection between the interior and exterior environments, for example, the connection between the window frame and the wall should not have any spaces (less than a millimetre) through which draughts can pass, and the same applies to other joining elements which, during construction, may bring about the formation of small fissures or spaces that connect the indoor air to the outdoor air. The technical solutions consist in sealing, i.e. in the adoption of panels, fabrics, etc., that are able to seal these draughts.

The measurement of airtightness is made by putting the air within the environment (room, apartment) in a condition of "overpressure and vacuum" with the use of fans, and the subsequent verification of the presence of draughts. A useful analogy is that of a balloon; when the air pressure is increased, such as when it is being inflated, the balloon expands, and the reverse happens when the air leaves the balloon, as it deflates. The EN 15242 Annex B "leakages characteristics" defines the minimum requirements expressed and levels of leakages (draughts) in *n*(vol.h), i.e. air volume replaced per hour, for a pressure difference equivalent to 50 Pa (Pascal). The verification is carried out during the design phases and/or when the building is completed, by means of the in situ execution of the blower door test according to ISO 9972. The blower door test is the most common method for the certification of Low Energy and Passive House buildings, because it can be used easily in the construction site. There are other systems with gas tracers that are even more precise, but they are also more complex and expensive.

The question remains whether it is better to use the traditional natural ventilation or controlled mechanical ventilation. In order to evaluate which of the two solutions is the most convenient, it is necessary to bear something in mind.

The ISO 13790 standard gives two different values of the air exchange rate: the air exchange rate n, for natural ventilation, expressed in h^{-1} and the air exchange rate n_{50} resulting from a pressure difference equivalent to 50 Pa between the inside and the outside, including the effects of the openings for the intake of the air, for mechanical ventilation, expressed in h^{-1}.

In mechanical ventilation systems, the value of n_{50} may vary or decrease, because the so-called draughts are reduced compared to the value of n_{50} that corresponds to the "airtightness" of a building with natural ventilation, whose n value (V/h, volumes/hours) is defined by the standards and takes account of both the ventilation attributable to the opening of the windows, and to part of the energy dispersed by the "draughts" (air leakage). In the case of buildings in which there is a system of CMV, the part of dispersed thermal energy attributable to "draughts" is determined on the basis of the value of n_{50}.

By performing a blower door test, which measures the airtightness of the building envelope and its capacity of airtightness and impermeability to wind, it is possible to use the value of the air exchange rate n_{50} measured through the test; otherwise, as in our case, the value n_{50} is measured and has different values depending on the permeability of the building envelope.

> The "*Blower Door Test*" (ISO 9972) or fan pressurisation method allows one to
>
> characterise the air permeability of the building envelope or parts thereof. It can be used
>
> (a) to measure the air permeability of a building or part thereof for compliance with an design airtightness specification;
> (b) to compare the relative air permeability of several similar buildings or parts of buildings;
> (c) to identify the leakage sources;
> (d) to determine the air leakage reduction resulting from individual retrofit measures applied incrementally to an existing building or part of a building. (ISO 9972)

The test consists in using an apparatus consisting of a fan and a sheet to be placed in a doorway of the environment to be measured. The fan (air-moving equipment) allows one to increase or decrease the air pressure within the environment; once installed, the device increases (overpressure) the air pressure of the environment, approximately 10–50–100 Pa (depending on the size of the environment), to verify the air that exits from the environment (remember that the standard atmospheric pressure is equal to 101,325 Pa; therefore, 10–50–100 Pa does not entail risks for the person who carries out the test). The test is repeated with the decrease (vacuum) of 10–50–100 Pa, to check the air that enters into the environment. Once the environment put in overpressure or vacuum has reached a constant air pressure, the fan is switched off and every 30 s the pressure difference is measured, until it arrives at the "*zero-flow pressure difference*". At the same time, one searches for the draughts with the "*pressure measuring devices*", and sometimes it is possible to feel the draught also by placing one's hand near a poorly installed window frame, that is, one that has not been installed to ensure airtightness.

The final evaluation of the test is expressed with the air flow coefficient (C_{env}), the air flow exponent (n) and the air leakage coefficient (C_L); a good result is when the value of n is less than 0.6 h^{-1} (Passive House standard).

6.4.4 Indoor Environmental Quality (IEQ) Assessment

Lastly, comfort also depends on other "physical" factors that characterise the environment in addition to thermal comfort and IAQ, such as lighting comfort and acoustic comfort. This topic is so vast that at this time, we shall limit ourselves to including a summary of the EN 15251 Standard[2] that defines the criteria for evaluating all the parameters that affect the perception of indoor comfort.

The Standard is part of the collection of regulations that calculate the Building Energy Performance and define the indoor environment parameters for energy calculation and the standard conditions (designed or measured) when they are not defined by national legislation or other regulations. The comfort parameters concern:

- *thermal comfort*, described in the previous paragraphs;
- *Indoor Air Quality*, described in the previous paragraphs;
- *humidity*, factor which affects thermal perception as well as bad odours and the formation of phenomena of irritation of the mucous membranes and diffusion of microbiological factors;
- *lighting comfort*, factor which affects the visual perception of the environment and the execution of the visual task of the environments, working and non-working;
- *noise (or acoustic comfort)*, due to the presence of sources of noise inside the indoor ambient, in the building or outside of it.

[2]EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing Indoor Air Quality, thermal environment, lighting and acoustics.

References

ASHRAE 55 (2004) Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta

ASHRAE 62 (2013) Ventilation for Acceptable Indoor Air Quality, ASHRAE

Blyussen PM (2009) The Indoor Environment Handbook, How to make buildings healthy and comfortable, Earthscan, London Butera FM (1998) Chapter 3—Principles

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

EN 13363-1 Solar protection devices combined with glazing. Calculation of solar and light transmittance. Part 1: Simplified method

EN 13363-2 Solar protection devices combined with glazing. Calculation of total solar energy transmittance and light transmittance. Part 2: Detailed calculation method

EN 13779:2007 Ventilation for non-residential buildings—performance requirements for ventilation and room-conditioning systems

EN 15232 Energy performance of buildings. Impact of building automation, controls and building management

EN 15242 Ventilation for buildings. Calculation methods for the determination of air flow rates in buildings including infiltration

EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

EN 410 Glass in building—determination of luminous and solar characteristics of glazing

EN 13790 Energy performance of buildings. Calculation of energy use for space heating and cooling

EN ISO 10077 Thermal performance of windows, doors and shutters. Calculation of thermal transmittance

EN ISO 6946 Building components and building elements. Thermal resistance and thermal transmittance. Calculation method

EN ISO 7345 Thermal insulation. Physical quantities and definitions

EN ISO 10211 Thermal bridges in building construction—heat flows and surface temperatures—detailed calculations

EN ISO 13788 Hygrothermal performance of building components and building elements—internal surface temperature to avoid critical surface humidity and interstitial condensation—calculation methods

Fanger PO (1970) Thermal comfort-analysis and applications in environmental engineering. Danish Technical Press, Copenhagen

ISO 10456 Building materials and products—hygrothermal properties—tabulated design values and procedures for determining declared and design thermal values

ISO 12572 Hygrothermal performance of building materials and products. Determination of water vapour transmission properties

ISO 13786 Thermal performance of building components—dynamic thermal characteristics—calculation methods

ISO 13789 Thermal performance of buildings—transmission heat loss coefficient—calculation method

ISO 9972 Thermal performance of buildings—determination of air permeability of buildings Fan Pressurisation Method

Orwell G (1949) Nineteen Eighty-Four, Secker and Warburg

Passivehouse: by website http://passivehouse.com/04_phpp/04_phpp.htm (last visit 28 March 2017)

WHO (2006) Development of WHO Guidelines for Indoor Air Quality

WHO (2010) Guidelines for Indoor Air Quality: selected pollutants

WHO World Health Organization (1999) Basic documents, 42nd edn. World Health Organization, Geneva

Chapter 7
Designing the Thermal Bridges

What are thermal bridges? Where are they found? What construction solutions have to be adopted to reduce them? Do the thermal bridges have to be eliminated in a Passive House?

My mother is a good cook; well actually, she hasn't always been one, but over the years she has become a good cook. When she cooks *ragù alla bolognese*, she uses a rather tall metal pot, mixing, now and then, the boiling content with a wooden spoon which remains immersed in it during most of the preparation. When I went to live on my own, to celebrate my new independence, I decided to cook the same dish for myself. I had no experience in this regard, but the instinct of emulation was my inspiration. Unfortunately, my new kitchen had very limited means, so I had to cook the ragù using a metal spoon.

All it took was a few seconds; I grabbed the handle of the spoon that had been immersed in the boiling ragù for a few minutes and burnt my hand: Eureka! I understood what a thermal bridge was. The steel of the spoon "*subtracted*" heat from the ragù, and my hand was going to do the same thing. While steel, in relation to the percentage of nickel, has a conductivity which varies between 29 and 105 W/mK, the conductivity of wood varies between 0.10 and 0.12 W/mK; for this reason, my mother's cooking never included her hand getting burned.

Moreover, if you decide to follow my example, using a metal spoon, you will notice that the thicker the spoon, the more heat will be able to pass through it, causing a directly proportional burn.

Now imagine that our Passive House is a small, covered, well-insulated saucepan, and the ragù represents the internal thermal loads: to avoid thermal bridges, we must prevent any element having an elevated heat resistance from interrupting or reducing the thermal insulation of the saucepan so as to not increase the flow of heat towards the outside. If it is necessary to interrupt the continuity of the insulation, we must do as my mother did: we have to use a wooden spoon or, at the very least, an oven mitt. The oven mitt, if you think about it, is nothing more than an insulator.

In case the example of the saucepan is not satisfactory, the EN ISO 10211 standard defines the thermal bridge as follows:

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_7

> **thermal bridge**: part of the building envelope where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions. (EN ISO 10211)

This book is a practical manual for the construction of a Passive House; therefore, I will try to go more fully into the construction technologies adopted to solve the thermal bridges, while I will give a general framework on aspects relating to their calculation. Anyone who is curious about the argument can extend their knowledge by reading the EN ISO 10211 standard, or through the bibliography of the sector (Fabbri and Marinosci 2015).

The EN ISO 10211 standard, in addition to defining thermal bridges, illustrates their calculation procedures; you must first carry out a geometrical model of the node where the thermal bridge is present.

Up to where is it necessary to model the node?

The standard indicates describing the node with an extension such that beyond it, the flow is definitely orthogonal to the structure. To simplify, it suffices to know that the modelling must be carried out through cut planes placed at a distance from the node equal to 1 m, or 3 times the thickness of the element considered. Once you have defined the model, it is necessary to assign conductivity to each material as well as the temperature conditions at its outlines.

Essentially, it is like extrapolating a node of the building, putting it on a laboratory table and examining it under a "*microscope*". The "*microscope*" allows us to observe:

- the heat flows that traverse the node, so as to calculate the losses and obtain the line-based transmission coefficient Ψ (W/mK);
- the distribution of the temperature in any point of the node;
- the minimum surface temperatures to analyse the occurrence or otherwise of mould, mildew or surface condensation.

While the heat losses are calculated through EN ISO 10211, it is EN ISO 13788 that defines the calculation methods for the minimum surface temperatures and the consequent risk of condensation; therefore, in the analysis of a thermal bridge, the following factors are important:

1. containment of the dispersions of the envelope;
2. verification of the internal surface temperatures;
3. verification of the phenomena of mould, mildew and condensation, superficial and interstitial.

How have we calculated the thermal bridges of the Fiorita Passive House?

The calculation can be carried out by modelling the thermal bridge with special software. We have used *Dartwin mold simulator 2 pro* (Dartwin Mold) for the thermal bridges of the opaque envelope and *Dartwin frame simulator* (Dartwin

Frame) to determine the thermal bridge of the installation between the frame and the external walls.

With the aid of software, a model of the node is developed that includes the concerned functional layers, to which is associated the thermal conductivity of the material (λ). In the modelling of the nodes, we have excluded the functional layers of negligible thickness, irrelevant in terms of transmittance, as for example water vapour barriers, waterproofing sheaths, membranes.

Both software programmes are able to calculate the linear transmission coefficient Ψ, which must be inserted in the PHPP, the surface temperatures and the possible formation of surface condensation that over time can generate the formation of mould and mildew.

The linear coefficient is the parameter that describes the energy behaviour of the node in which the thermal bridge is present; when the linear coefficient is positive, a dispersion is present in the node that is directly proportional to the Ψ value and to the linear extension of the node. In the case in which the Ψ value is negative, we can consider ourselves to be lucky because the dispersions of the node are lesser than those of the envelope. Negative thermal bridges can occur, for example, in the corners of the building where, linearly to the edge, the thickness of the insulation is greater.

The thermal bridge can be linear or in a localised point. In the first case, we have a dispersion distributed along an axis, for example in the presence of the projection of a balcony; in the second case, the dispersion will be concentrated in a single point, for example in the presence of a beam that emerges from the envelope.

We may also have thermal bridges towards the outside air, towards the ground or towards unheated spaces.

In the design of a Passive House, all thermal bridges must be identified and analysed (whether they are positive or negative and whether they are in the form of a point or linear) to allow the PHPP to perform a calculation of the dispersions of the building that is as close as possible to reality. In the PHPP, it is necessary to enter the type of thermal bridge on the basis of a classification in the software, indicating its extension and its linear transmission coefficient.

In the final construction project of the *Fiorita Passive House*, we have identified the nodes where there was a discontinuity of the thermal insulation with respect to the envelope. To protect the thermal bridge, we examined several design solutions until we identified the one able to guarantee a satisfactory linear coefficient. In the design of a Passive House, it is not necessary to eliminate all the thermal bridges; it is sufficient to assess, through the PHPP, if the amount of relative dispersions is compatible with the energy balance for the climate control of the building. In the sheet "annual heating demands", the PHPP expressed the dispersions of the building in terms of percentage: the thermal bridges of *Fiorita Passive House*, as they have been designed, involve 0.9% of the overall dispersions.

The linear coefficients of the thermal bridges of the *Fiorita Passive House* are shown in Table 7.1 (Fig. 7.1).

In addition to those indicated in the previous table, the thermal bridges relative to the nodes between the frame and the envelope were calculated. The calculation of

Table 7.1 Thermal bridges of the envelope

Description	Extension (m)	Ψ (W/mK)
Node between the external wall clad in ceramic slab and the ground floor slab	23.23	−0.023
Node between the external wall clad with wood and the terrace	85.20	0.022
Node between the external wall clad in ceramic slab, terrace and the external wall	23.23	0.030
Node between the external wall clad with wood and the roof with overhang	36.36	−0.056
Node between the external wall clad with wood and the roof without overhang	6.30	−0.066
Node between the internal wall and the foundation's kerb	17.90	0.458
Corner node of the external wall	48.00	−0.067
Interference of the wood studs within the wall clad in wood	774.90	0.002
Interference of the sheet metal studs within the wall clad in ceramic slab	386.10	0.004
IPE profile installed in the roof to support the overhangs of the terraces (body)	7.78	0.040
IPE profile installed in the roof to support the overhangs of the terraces (wings)	7.78	0.002
Anchor pin of the life line in the roof	0.13	0.005
Crossbar in sheet metal placed on the foundation's kerb	0.70	0.030

the linear coefficient Ψ was carried out on every side of the frame (top, left, right, bottom). The PHPP calls this value $\Psi_{installation}$, the linear coefficient relative to the thermal bridge of installation of the window, due to the thermal exchange between the point of contact between the frame and the opaque envelope.

This operation was carried out for each type of door or window frame, so as to determine the *s* $\Psi_{installation}$ value of windows, doors and entrance doors.

All these operations are simplified using Passive House certified windows: in this case, it is possible to select the $\Psi_{installation}$ values available within the PHPP or in the certification reports, saving yourself a significant amount of work. Table 7.2 shows the $\Psi_{installation}$ values of the door and window frames used for the *Fiorita Passive House.*

Despite a detailed design having allowed us to avoid the formation of thermal bridges as much as possible, the design has a significant number of them, so many that an ad hoc book would would be necessary to describe them all. This does not mean that we have made any errors in the design—*certainly, it is always possible to do better*—but thermal bridges are also present in a Passive House. In contrast to traditional buildings, where their impact can be defined through rough parameters, or even neglected, in the Passive House, the certification protocol requires one to design them through the computation of the finished elements.

Fig. 7.1 Protection of the thermal bridge caused by a metal beam placed in the roof: the beam was insulated and coated with panels in fibre cement

Table 7.2 Thermal bridges of the installation between envelope and frame

Type of frame	$\Psi_{installation}$ left (W/mK)	$\Psi_{installation}$ right (W/mK)	$\Psi_{installation}$ bottom (W/mK)	$\Psi_{installation}$ top (W/mK)
Window	0.021	0.021	0.030	0.021
French doors	0.021	0.021	0.110	0.021
Entrance door	0.030	0.030	0.139	0.030
French door with integrated entrance	0.021	0.021	0.110	0.021
Window with integrated entrance	0.021	0.021	0.029	0.021
Entrance door	0.030	0.030	0.139	0.030

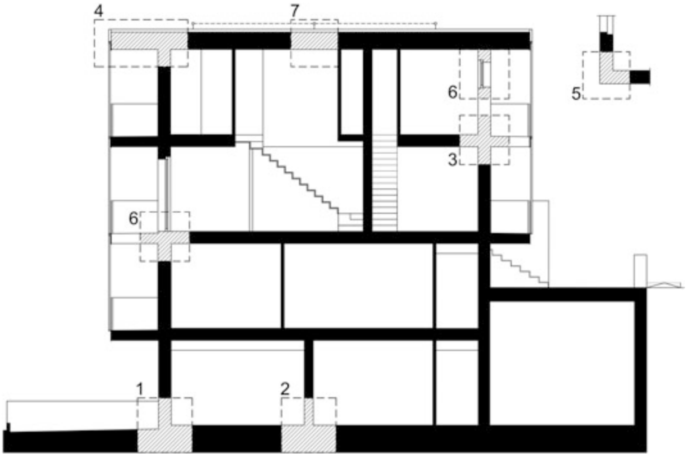


Fig. 7.2 Section of the building with identification of the thermal bridges analysed in the chapter

In the following paragraphs, the following thermal bridges are described:

1. thermal bridge towards the ground (external wall);
2. thermal bridge towards the terrace (internal wall);
3. thermal bridge of the terrace;
4. thermal bridge in the roof;
5. thermal bridge at the corner;
6. thermal bridge at the window and French door installation;
7. thermal bridge in the life line anchor pin (Fig. 7.2).

To close with another metaphor concerning the thermophysical capacity of materials and food (obviously, it is getting close to dinner time for me), listen to what Jun'ichirò Tanizaki writes in In ei raisan (In Praise of Shadows):

> Ceramics are by no means inadequate as tableware, but they lack the shadows, the depth of lacquerware. Ceramics are heavy and cold to the touch; they clatter and clink, and being efficient conductors of heat are not the best containers for hot foods. (…) I know few greater pleasures than holding a lacquer soup bowl in my hands, feeling upon my palms the weight of the liquid and its mild warmth. The sensation is something like that of holding a plump newborn baby. (…) vapour rises from within, forming droplets on the rim, and the fragrance carried upon the vapour brings a delicate anticipation. What a world of difference there is between this moment and the moment when soup is served Western style, in a pale, shallow bowl. A moment of mystery, it might also be called, a moment of trance. (Tanizaki 1962, pp. 14–15)

7.1 Thermal Bridge Towards the Ground (External Wall)

The thermal bridge towards the ground relates to the node between the wall clad in ceramic slab and the ground slab; in their intersection, one finds the foundation's kerb for the cement bed. Three different temperatures come into play in the calculation: the internal one, the external one and that of the ground. The technical solution adopted for designing the node allows a Ψ value = −0.0232 W/mK, for a length of 23.23 m; we managed to resolve the thermal bridge, making it negative. The negative value is due to the conventional criterion for the determination of the linear dimensions of the thermal bridge for the calculation according to what is defined by UNI EN ISO 10211.

To achieve such performance, we covered the kerb on the external side with panels in XPS (extruded polystyrene foam) with variable thickness between 20 and 12 cm. XPS is a material with $\lambda = 0.036$ W/mK, resistant to moisture and to loads (500 kg/m^2); therefore, it can be used in external environments in contact with the ground because it resists the load of the concrete flooring used for the outdoor spaces.

Furthermore, the panels in XPS were used in a vertical position for distancing from the ground the panels made of glass wool and wood, both perishable on contact with water. On the extrados of the foundation, in correspondence with the wall insulation, there is a profile made of galvanised sheet metal with a C-section: a horizontal profile that accommodates the vertical studs of the same material, used as support of the external cladding system composed of a panel of fibre cement onto which the ceramic slab is glued. The profiles have been excluded from the modelling of the thermal bridge towards the ground and calculated separately.

The panel in XPS was interrupted in correspondence with the studs, to allow the anchoring to the transverse profile applied to the extrados of the foundation. The holes caused by the interpenetration of the studs in the panel in XPS were subsequently filled with polyurethane foam.

The vertical portion of the panels in XPS was protected by a panel of phenolic multi-layer, used for the subsequent application of a bitumen-based sheath that contributes to the water seal of the node. The sheath is applied using a flame; therefore, it is not possible to apply it directly on the panel in XPS. Always to improve the water seal, on the side of the node in contact with the ground, a membrane made of high-density polyethylene has been applied.

To improve the performance of the node, on the internal side of the perimeter kerb, a panel in polyurethane foam with a thickness of 5 cm was applied. This is a material resistant to loads and moisture and with elevated insulating capacity, having $\lambda = 0.028$ W/mK. It costs more than XPS but it is particularly useful in situations where it is necessary to keep the thickness of the material to a minimum (Figs. 7.3, 7.4, 7.5, 7.6, 7.7 and 7.8).

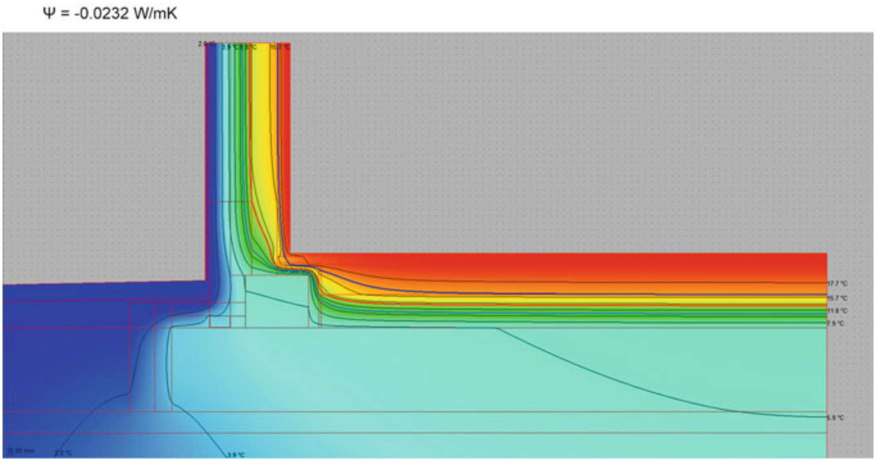


Fig. 7.3 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The internal surface temperatures are almost constant, and the formation of condensation is not verified

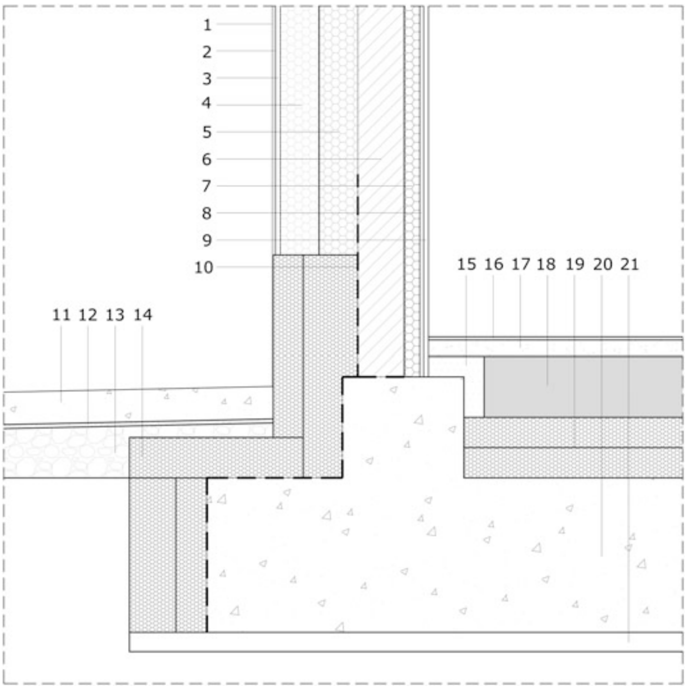


Fig. 7.4 Section of the node: (1) ceramic slab; (2) adhesive; (3) air; (4) fibreglass; (5) wood fibre; (6) CLT; (7) mineral wool; (8) air; (9) plasterboard; (10) bitumen-based sheathing; (11) reinforced concrete; (12) sand; (13) stabilised hardcore; (14) XPS; (15) polyurethane; (16) resin flooring; (17) cement screed; (18) lightened screed; (19) XPS; (20) foundation in reinforced concrete; (21) lean concrete

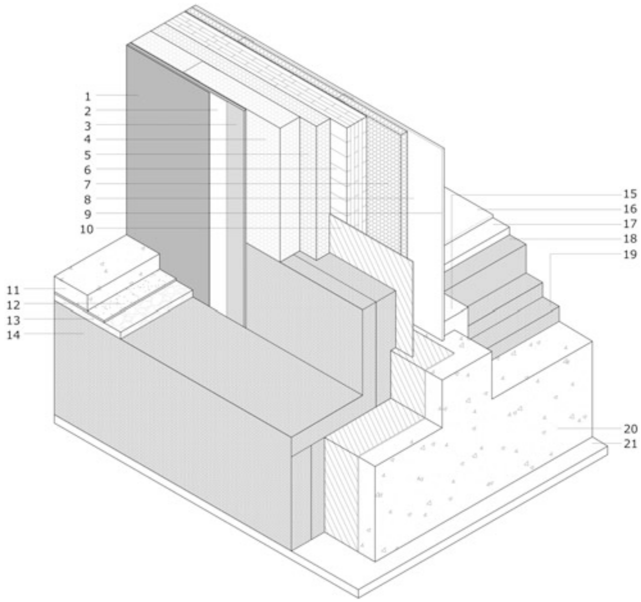


Fig. 7.5 Axonometric view of the node: (1) ceramic slab; (2) adhesive; (3) air; (4) fibreglass; (5) wood fibre; (6) CLT; (7) mineral wool; (8) air; (9) plasterboard; (10) bitumen-based sheathing; (11) reinforced concrete; (12) sand; (13) stabilised hardcore; (14) XPS; (15) polyurethane; (16) resin flooring; (17) cement screed; (18) lightened screed; (19) XPS; (20) foundation in reinforced concrete; (21) lean concrete

Fig. 7.6 Protection of the thermal bridge on the external side using panels in XPS. The interferences with the sheet metal structure are protected with injections of polyurethane foam

Fig. 7.7 Protection of the thermal bridge on the internal side using panels in polyurethane with impermeable surface (black)

Fig. 7.8 Lightened screed reaches the height of the polyurethane insulation

7.2 Thermal Bridge Towards the Ground (Internal Wall)

Thermal bridges do not relate exclusively to the discontinuities of the envelope towards the outside air, but also to those towards the ground. In the *Fiorita Passive House*, there is a thermal bridge in the node between the internal wall and the ground slab: in their intersection is the kerb of the foundation for the cement bed.

The internal wall divides the various apartments: composed of a 12-cm-thick panel in CLT, covered on both sides with a plasterboard false wall, insulated by a 4-cm-thick panel in mineral wool. The mineral wool performs the dual function of acoustic insulation, to reduce the transmission of sound between neighbouring apartments, and of thermal insulation in correspondence with the node. The inner wall rests on the foundation's kerb that interrupts the 16 cm of XPS of the ground slab. This discontinuity is protected by two 5-cm-thick panels in polyurethane foam, applied to the sides of the foundation's kerb for a height of 28 cm, being interrupted below the cement screed.

Two different temperatures come into play in the calculation: the internal one and that of the ground. The technical solution adopted for designing the node allows a Ψ value of 0.4576 W/mK, for a length of 17.90 m. It is a thermal bridge with a very high linear thermal transmittance Ψ value compared to the other thermal bridges of the building. However, such a high value was maintained for a reason. On the ground floor of the *Fiorita Passive House*, there are three studio apartments. They are apartments with a surface area of about 30 m^2 habitable by two people and equipped with all household appliances: oven, washing machine, dryer, refrigerator, and so forth.

People and appliances are producers of internal thermal contributions which, given the small size of a studio apartment, are significantly higher than those of the dispersions. Therefore, the introduction of a large dispersion towards the ground is not very significant in the winter, while in the summer, it is useful to have the disposal of the internal loads that, if in excess, could generate overheating.

The problem of the relationship between the surface and internal loads emerged in the design phase; unfortunately, we have not found any examples of Passive House studio apartments or good practices that could help us. After a discussion with the certification body, Margherita, Passive House Designer of the intervention, considered it appropriate to proceed in this direction because, even if relevant, the thermal bridge is compatible with the energy balance of the PHPP (Figs. 7.9, 7.10, 7.11 and 7.12).

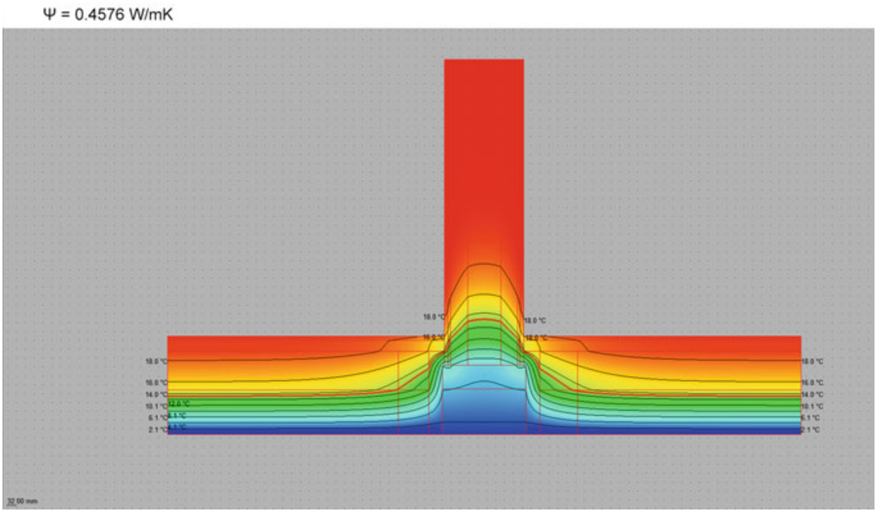


Fig. 7.9 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The internal surface temperatures are almost constant, and the formation of condensation is not verified

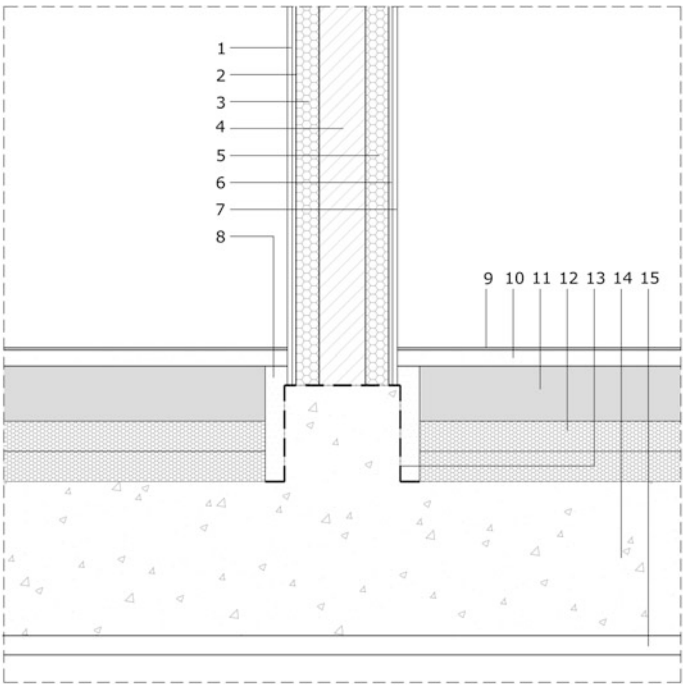


Fig. 7.10 Section of the node: (1) plasterboard; (2) air; (3) mineral wool; (4) CLT; (5) mineral wool; (6) air; (7) plasterboard; (8) polyurethane; (9) resin flooring; (10) cement screed; (11) lightened screed; (12) XPS; (13) bitumen-based sheath; (14) foundation in reinforced concrete; (15) lean concrete

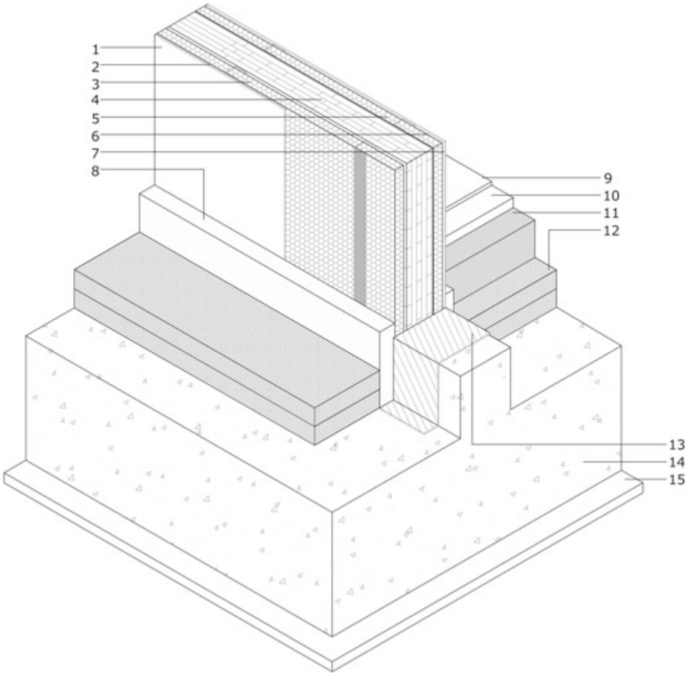


Fig. 7.11 Axonometric view of the node: (1) plasterboard; (2) air; (3) mineral wool; (4) CLT; (5) mineral wool; (6) air; (7) plasterboard; (8) polyurethane; (9) resin flooring; (10) cement screed; (11) lightened screed; (12) XPS; (13) bitumen-based sheath; (14) foundation in reinforced concrete; (15) lean concrete

7.3 Thermal Bridge of the Terrace

The thermal bridge of the terrace relates to the node between the wall clad in wood, the interfloor slab and the terrace, where the panel in CLT, which constitutes the horizontal load-bearing structure of the building, protrudes externally, creating the terraces.

The thermal bridge in the design phase has undergone several changes. Initially, we planned to insulate the intrados of all the terraces (the underside), following an established practice for high-energy efficiency buildings that involves the insulation of the entire surface of the overhanging structural element so as to avoid disastrous thermal bridges.

However, the introduction of insulating material in the intrados of the terraces requires a subsequent cladding to hide it from view. In coherence with the aesthetics of the building, we have envisaged the use of wood cladding, in continuity with that of the façades. However, given the extensive surface of the terraces, such processing would substantially increase the cost of the entire construction. On the other hand,

Fig. 7.12 Protection of the node with polyurethane panels having an impermeable surface (black)

again as a result of the extension of the terraces, the thermal bridge would have increased the dispersions of the building, considering that it extends for 108.43 m.

What should be done?

By introducing insulation on the upper surface and lower surface of the panel in CLT and applying a wood cladding on the lower one, it reaches a value of Ψ 0.0218 W/mK, while using insulating material only on the upper surface of the panel, leaving the bottom one in view, the value stabilises at Ψ 0.022 W/mK.

Even if the absolute value of the thermal bridge does not appear to be so significant, its extension to all the floors is such as to cause the project to depart from the certification parameters. Otherwise, introducing insulation and wood cladding on the lower surface of the panel in CLT, we would depart from another important parameter: the budget.

The only way to escape from this impasse was to reduce the building's losses by intervening on the other components (opaque envelope, transparent envelope, other thermal bridges, etc.) so as to fall within the certification parameters.

Unfortunately, for problems due to local urban regulations, it was not possible to increase the insulation of the opaque housing; therefore, we have enhanced the transparent envelope by adopting more efficient frames. This choice, with a truly minimum economic investment, allowed us to fall within the certification parameters without having to insulate the intrados of the terraces.

The thermal bridge is present on each overhang and varies, although with minor differences, in relation to the functional layers of the components in play. As regards the node in correspondence with the wall clad in wood, analysed in this paragraph, it develops for a length equal to 85.20 m, with a Ψ value equal to 0.022 W/mK. In correspondence with the wall clad in ceramic slab, the Ψ value is equal to 0.030 W/mK.

In addition to the insulating layers present within the wall clad in wood, we inserted within the stratigraphy of the balcony a 5-cm-thick panel of XPS on which is a cement screed and a flooring in epoxy-cement resin is laid. With this solution, the panel in CLT in the intrados of the floor slab can remain in view, however, achieving the objective of giving material continuity to the cladding of the façade (Figs. 7.13, 7.14, 7.15, 7.16 and 7.17).

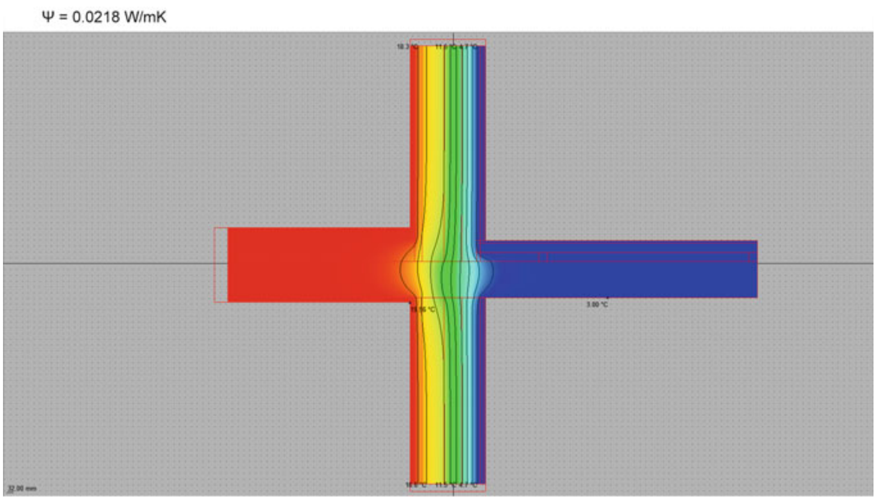


Fig. 7.13 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The internal surface temperatures are almost constant, and the formation of condensation is not verified

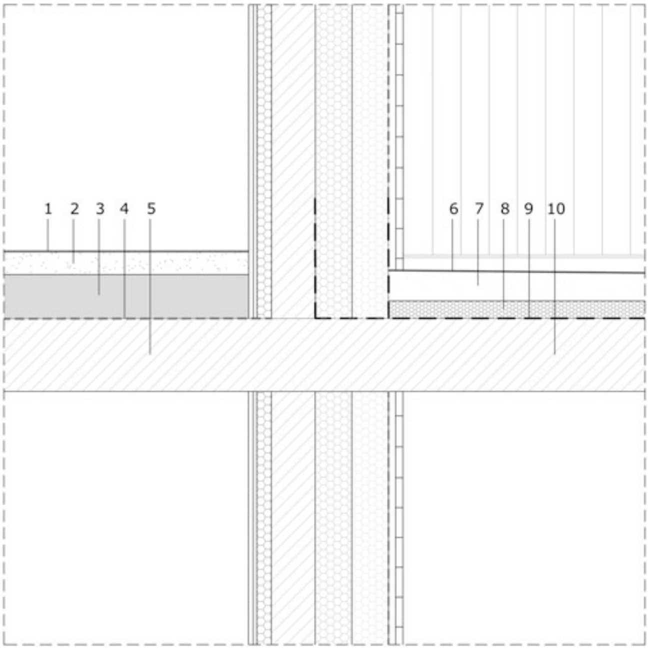


Fig. 7.14 Section of the node: (1) resin flooring; (2) cement screed; (3) lightened screed; (4) PVC; (5) CLT; (6) resin flooring; (7) cement screed; (8) XPS; (9) bitumen-based sheath; (10) CLT

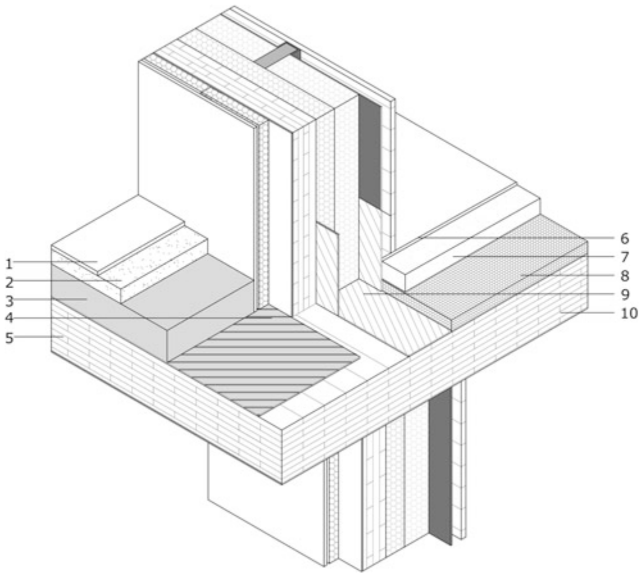


Fig. 7.15 Axonometric view of the node: (1) resin flooring; (2) cement screed; (3) lightened screed; (4) PVC; (5) CLT; (6) resin flooring; (7) cement screed; (8) XPS; (9) bitumen-based sheath; (10) CLT

Fig. 7.16 XPS panel ready to receive the laying of the cement screed in which a metal mesh is inserted

7.4 Thermal Bridge in the Roof

The thermal bridge in the roof slab relates to the node between the wall clad in wood and the roof slab, where the panel in CLT, which constitutes the horizontal load-bearing structure of the building, protrudes externally, creating a cornice of the same extension of the terraces.

To resolve the thermal bridge, it was sufficient to maintain unchanged the amount of insulating material present in the roof, equal to 32 cm in XPS. The thermal bridge has an extension equal to 36.36 m and reaches a Ψ value equal to −0.0561 W/mK, if we had used a reinforced concrete slab in place of the CLT we certainly would have a positive thermal bridge to worry about.

Fig. 7.17 Cement screed laid on the insulation in XPS, ready to receive the application of the resin flooring. The intrados of the upper terrace remains devoid of insulating, leaving the panel in CLT in view

In our case, the wall clad in wood meets the roof slab, and the functional layers present within the two components are sufficient to resolve the thermal bridge without requiring the integration of further layers of insulating material (Figs. 7.18, 7.19, 7.20, 7.21 and 7.22).

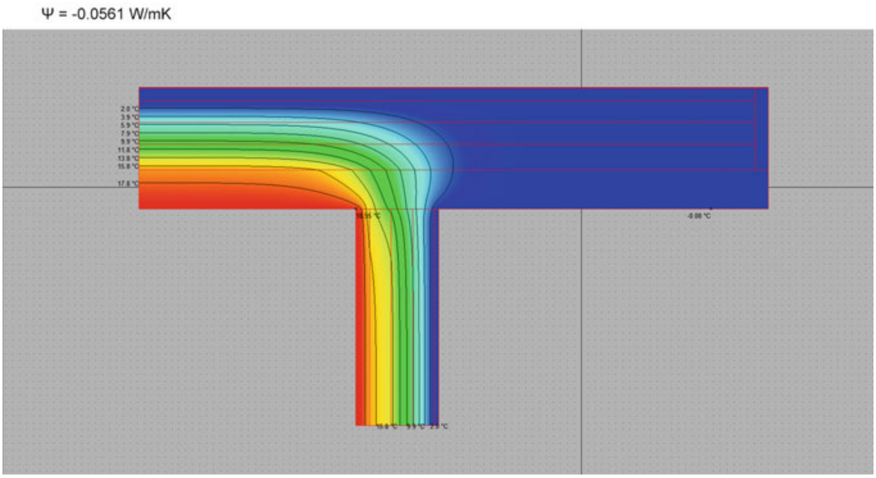


Fig. 7.18 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The internal surface temperatures are almost constant, and the formation of condensation is not verified

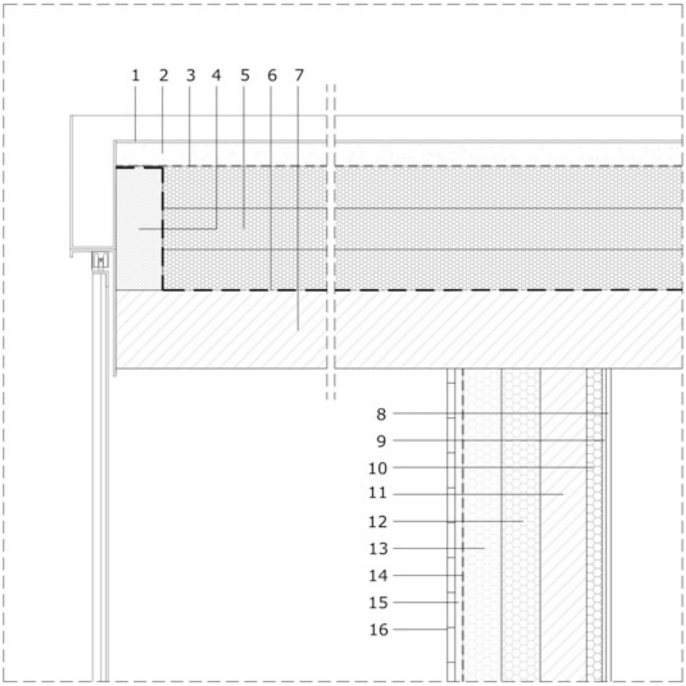


Fig. 7.19 Section of the node: (1) bitumen roof cladding; (2) cement screed; (3) PVC; (4) element in fir wood; (5) XPS; (6) bitumen-based sheath; (7) CLT; (8) plasterboard; (9) air; (10) mineral wool; (11) CLT; (12) wood fibre; (13) fibreglass; (14) wind barrier; (15) air; (16) planks of larch wood

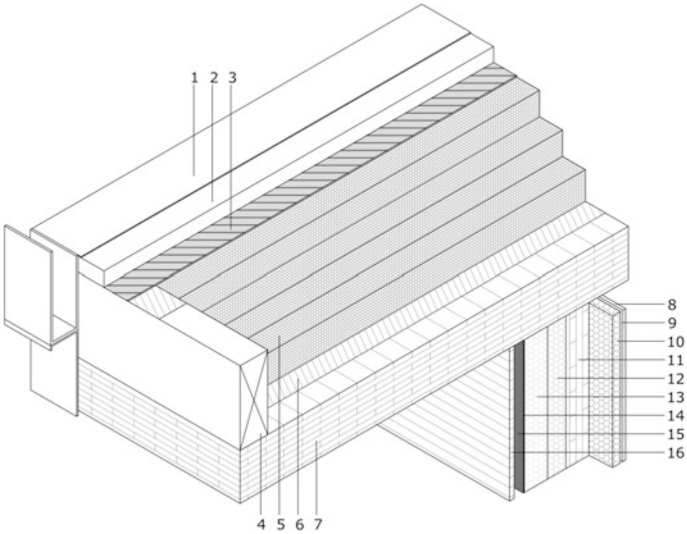


Fig. 7.20 Axonometric view of the node: (1) bitumen roof cladding; (2) cement screed; (3) PVC; (4) element in fir wood; (5) XPS; (6) bitumen-based sheath; (7) CLT; (8) plasterboard; (9) air; (10) mineral wool; (11) CLT; (12) wood fibre; (13) fibreglass; (14) wind barrier; (15) air; (16) planks of larch wood

Fig. 7.21 Insulating panels in XPS laid in a uniform manner over the entire surface area of the roof for a total thickness of 32 cm

Fig. 7.22 Processing of the finished roof, highlighted are the weights in cement for the laying of the photovoltaic panels

7.5 Thermal Bridge at the Corner

The thermal bridge at the corner is a "*negative*" thermal bridge, present in the majority of buildings; it is located at the corner of the building. In this particular situation, the functional layers present within the external wall form a 90° angle, increasing their thickness by $\sqrt{2}$, linearly at the corner of the building.

Along the edges of the external wall, the thickness of the insulation is greater; therefore, we will have a linear reduction of its transmittance. The node has a total extension of 48 m and a Ψ value equal to −0.0672 W/mK.

To increase the resistance at the outer edge of the wall where the planks clad in wood are cut at 45°, a vertical element in aluminium sheet metal was introduced which acts as an abutment for the planks. The function of this element, with its linearity, is also that of correcting any imperfections produced by any slight dimensional deformations that the planks of natural larch wood can undergo over time. The introduction of a metal element within the node has no influence on the final value of the thermal bridge (Figs. 7.23, 7.24, 7.25, 7.26, 7.27 and 7.28).

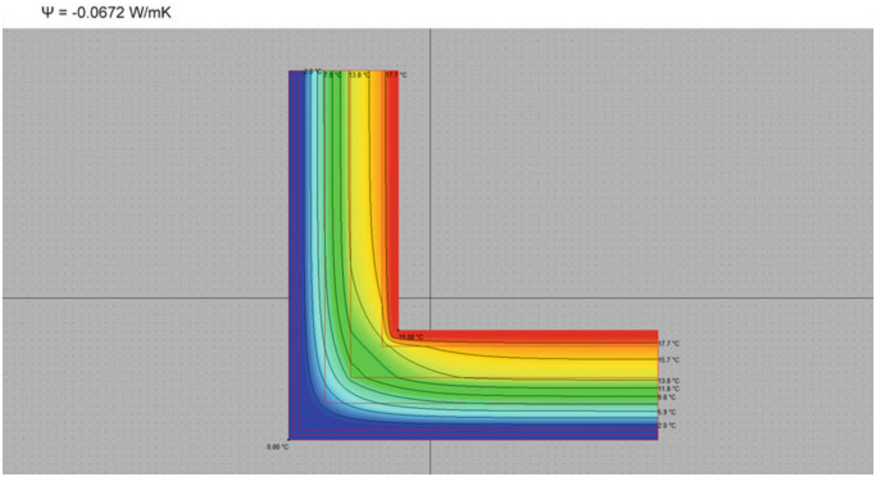


Fig. 7.23 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The internal surface temperatures are almost constant, and the formation of condensation is not verified

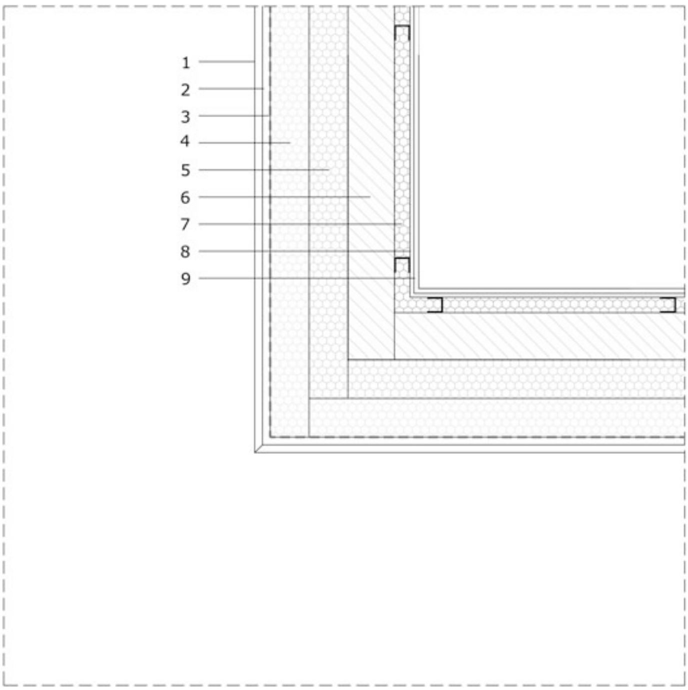


Fig. 7.24 Section of the node: (1) planks of larch wood; (2) air; (3) wind barrier; (4) fibreglass; (5) wood fibre; (6) CLT; (7) mineral fibre; (8) air; (9) plasterboard

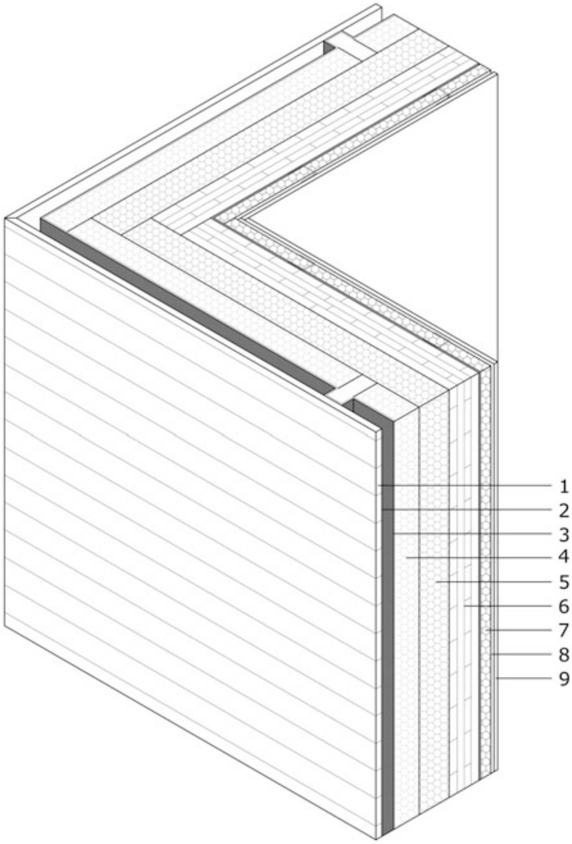


Fig. 7.25 Axonometric view of the node: (1) planks of larch wood; (2) air; (3) wind barrier; (4) fibreglass; (5) wood fibre; (6) CLT; (7) mineral fibre; (8) air; (9) plasterboard

7.6 Thermal Bridge at the Window and French Door Installation

The thermal bridge of the window is due to the different geometries and thermo-physical properties of the window frame compared to that of the perimeter wall. The calculation of this thermal bridge is necessary for determining the $\Psi_{\text{installation}}$ parameter. This parameter can vary on each side of the frame in relation to the type of wall or installation. In our case, the parameter remains constant on the left and right sides and on the top, while it varies on the lower side, where it presents a platform in painted aluminium sheet metal. The windows, like the French doors, consist of:

- glass, in our case we have a triple low emissivity glass with solar factor g of 0.62 and U_g 0.60 W/m^{2}K;
- frame, which is composed of a fixed part and a mobile one, we used a PVC frame with U_f 1.00 W/m^{2}K;

Fig. 7.26 Solution of the corner in the installation of the wood fibre

- subframe, or shutter box, useful for anchoring the frame to the wall, which can be normally made of wood, wood-metal, wood-PVC, PVC. We didn't use them.

In the *Fiorita Passive House*, the subframe was not used because the panel in CLT, on which the frame is installed, allows the execution of holes with pinpoint accuracy. With this solution, we not only achieved cost savings, but there is one less element to secure for airtightness.

The windows were installed immediately after the assembly of the panels in CLT. In this way, during the subsequent installation of the insulating layers, it has been possible to extend the insulation over the entire external surface of the fixed part of the frame, thus reducing the thermal bridge. Once the insulating panels were installed, the window sill was coated with a sheet of painted aluminium.

Fig. 7.27 Solution of the corner with the profile in aluminium sheet that accommodates the planks of larch wood with head cut at 45°

In the lower part of the frame is a platform in sheet metal. In the lower side of the window frame, there are small holes for the disposal of any condensation. The platform is positioned at an inferior height than these small holes, so as to permit the disposal of the condensation.

The use of sheet metal has proved to be a good strategy for reducing the thermal bridge; other traditional materials, such as stone, would have required a thickness of a few centimetres; on the contrary, the thickness of the sheet metal is measured in tenths of a millimetre. On the inner side of the window, a wooden frame has been installed.

For the calculation of the linear transmission coefficient of the installation ($\Psi_{installation}$), each element was modelled within the software by associating conductivity to each material, as was done for the thermal bridges described previously.

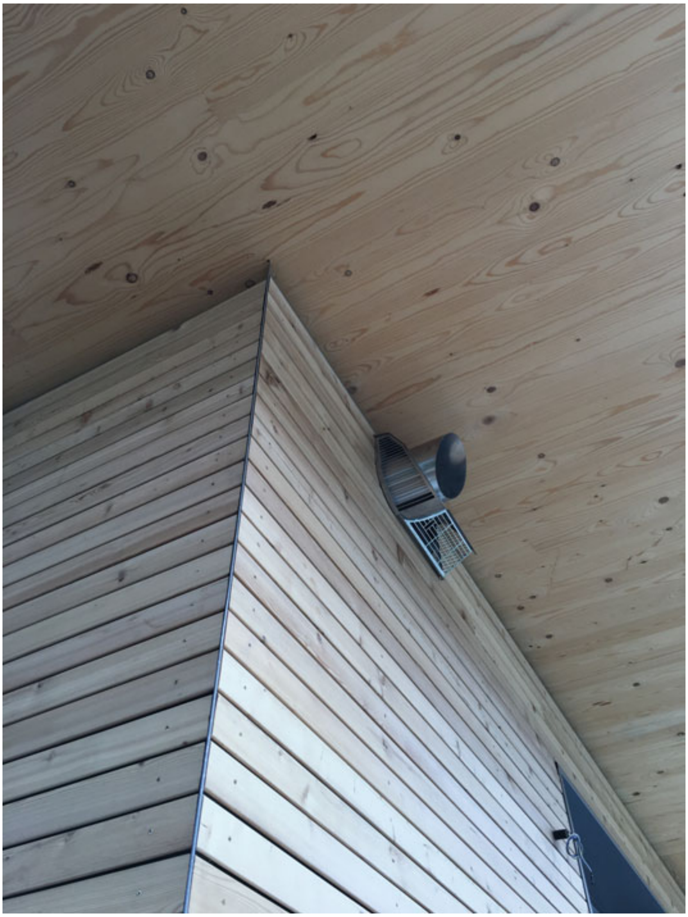


Fig. 7.28 Solution of the corner with planks of larch wood

The calculation reveals that the surface temperatures are almost constant and that there is no formation of condensation. The $\Psi_{installation}$ value is equal to 0.021 W/mK on the left, right and upper sides, while it is equal to 0.03 W/mK on the lower side.

Compared to the window, the French door differs for only the lower installation, where the door's threshold is located. Let us take, for example, one of the French doors located in the terraces; the threshold was made in extra hard sandstone, a frost-resistant type of stone. The threshold, of a 4 cm thickness, is glued on the panel in high-density XPS having a 14 cm thickness and a width of 26 cm.

The lower side of the frame is fixed to an element in larch wood, anchored to the panels in CLT, useful both for the anchoring of the frame and as a formwork to contain the pouring of the screeds of the interfloor slab. To improve the thermal bridge, a 6-cm-thick panel of XPS was inserted in the 12 cm thickness of the screed.

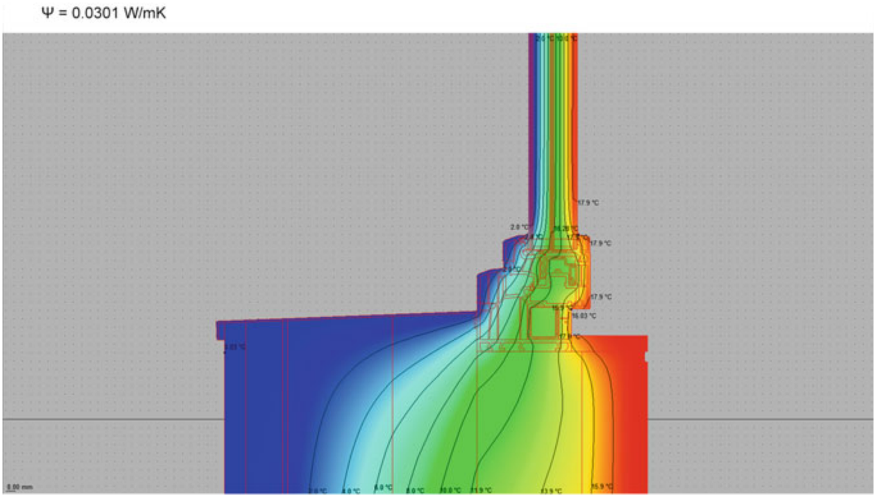


Fig. 7.29 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The node affects the lower attachment of the window inserted in the wall clad in wood. The internal surface temperatures are between 16.03 and 17.09 °C, and the formation of condensation is not verified

Stone ensures good durability but it must be used in consistent thicknesses, on the contrary, sheet metal used for the platform that has a thickness of a few tenths of a millimetre. The use of a painted aluminium sheet as a threshold is not recommended given the scarce durability of the paint: just a small pebble stuck in the sole of a shoe would be enough to scratch it. Using stone, the $\Psi_{installation}$ value is equal to 0.110 W/mK. Even if it has less performance than the prior solution, we only made a slight sacrifice of efficiency in favour of the greater durability of the technological solution we have chosen (Figs. 7.29, 7.30, 7.31, 7.32, 7.33, 7.34, 7.35, 7.36, 7.37, 7.38, 7.39, 7.40 and 7.41).

7.7 Thermal Bridge of the “Life Line” Anchor Device

The “life line” anchor device (*Anchor devices. Protection against falls from a height*[1]) is a fixed protection system that prevents the risk of falling from heights, safeguarding workers who access the roof for maintenance work. It consists of a steel cable that slides within pins surmounted by an eyebolt. The pin, also in steel, must be anchored to a resistant layer of the slab. The operator that accesses the roof, as if he were a climber, anchors his harness to the steel cable, thereby operating in safety (Figs. 7.42 and 7.43).

[1]Definition taken from UNI EN 795.

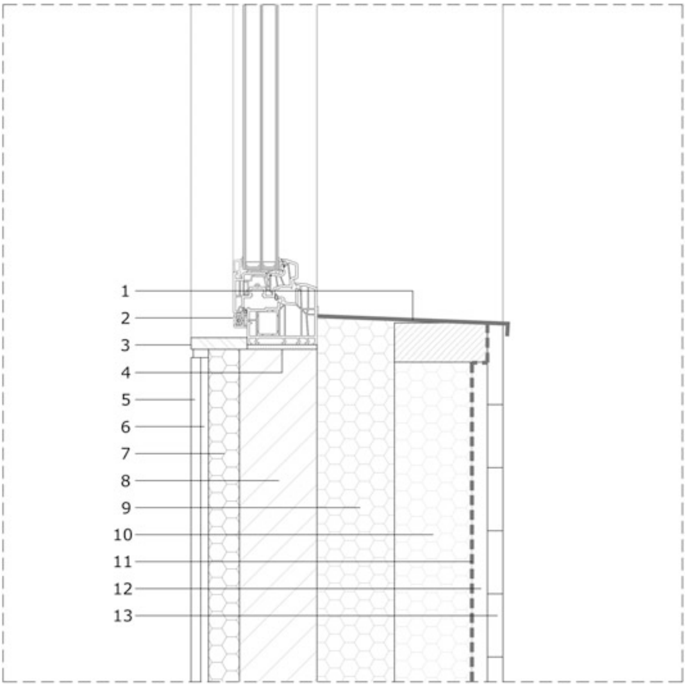


Fig. 7.30 Section of the lower anchoring of the window: (1) aluminium sheet; (2) fixture in PVC; (3) wooden frame; (4) expanding butyl tape; (5) plasterboard; (6) air; (7) mineral wool; (8) CLT; (9) wood fibre; (10) fibreglass; (11) wind barrier; (12) air; (13) planks of larch wood

In our case, the pin has been anchored to the panel in CLT. In the specific point, an additional element was added to the CLT to make the anchor more effective, all of it protected by a waterproof sheath.

It is a point element and quite slender: *Can it be possible that it too is a thermal bridge*?

Yes, in the design of a Passive House nothing can be left to chance (!), the pin passes through all the functional layers of the roof, where one finds 32 cm of thermal insulation, generating a flow of heat that cannot be neglected.

The anchor is a point thermal bridge that is rather simple to calculate using the UNI EN ISO 10211, even without the modelling of the finished elements. Its extension of 0.13 m is equal to 5 times the diameter of the insert (5 inserts were used in all) and has a Ψ value equal to 0.005 W/mK.

Coming back to the first lines of this chapter: we are dealing precisely with that metal spoon sitting in a pot of boiling ragù (Figs. 7.44 and 7.45).

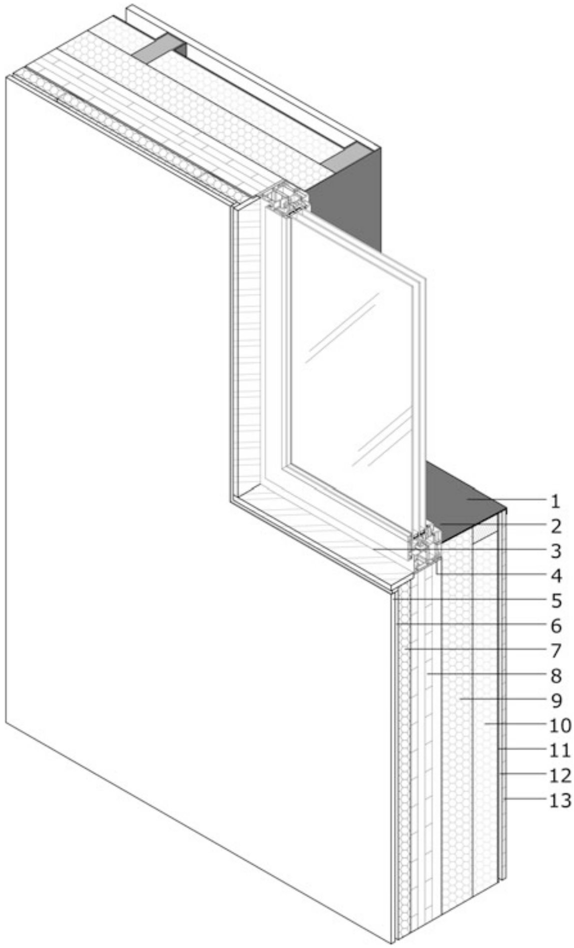


Fig. 7.31 Axonometric view of the lower anchoring of the window: (1) aluminium sheet; (2) fixture in PVC; (3) wooden frame; (4) expanding butyl tape; (5) plasterboard; (6) air; (7) mineral wool; (8) CLT; (9) wood fibre; (10) fibreglass; (11) wind barrier; (12) air; (13) planks of larch wood

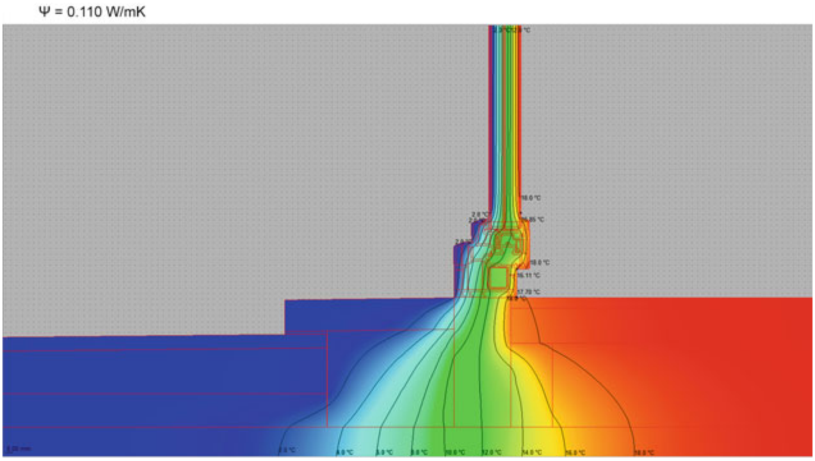


Fig. 7.32 Modelling of the thermal bridge of the finished elements: graph of the isotherms. The node affects the lower connection of the French doors at the terrace. The internal surface temperatures are between 16.11 and 18.0 °C, and the formation of condensation is not verified

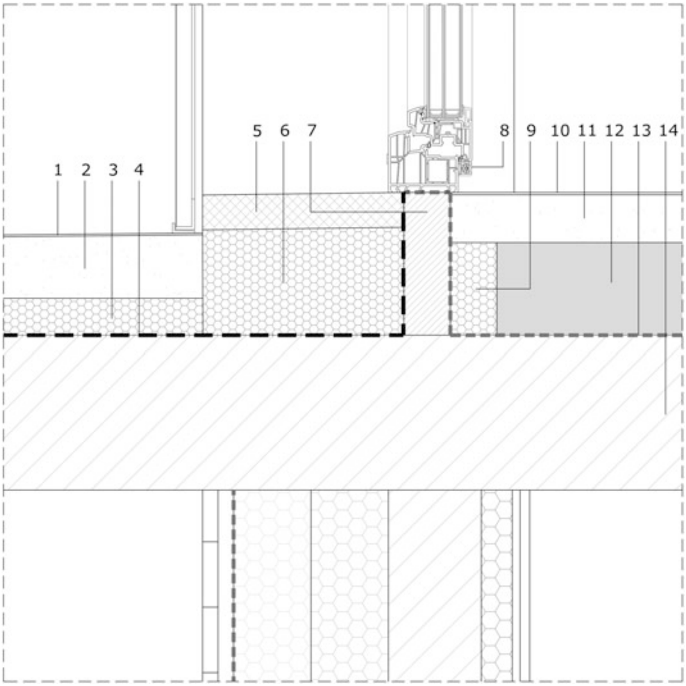


Fig. 7.33 Section of the bottom anchoring of the French doors at the terrace: (1) resin flooring; (2) cement screed; (3) XPS; (4) bitumen-based sheath; (5) element in stone; (6) XPS; (7) element in wood for the anchoring of the frame; (8) PVC frame; (9) XPS; (10) resin flooring; (11) cement screed; (12), lightened screed; (13) PVC; (14) CLT

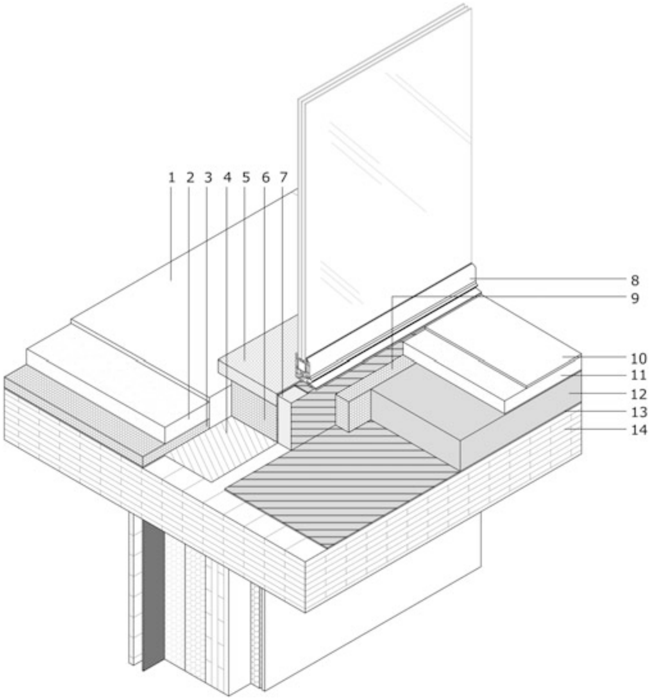


Fig. 7.34 Axonometric view of the bottom anchoring of the French doors at the terrace: (1) resin flooring; (2) cement screed; (3) XPS; (4) bitumen-based sheath; (5) threshold in stone; (6) XPS; (7) element in wood for the anchoring of the frame; (8) PVC frame; (9) XPS; (10) resin flooring; (11) cement screed; (12), lightened screed; (13) PVC; (14) CLT

Fig. 7.35 Installation of the window directly in the panel in CLT without the use of the subframe

Fig. 7.36 Installation of the window sills in painted aluminium sheet

Fig. 7.37 Lower installation of the French windows onto an element in larch wood, protected by a waterproof membrane

Fig. 7.38 Lower installation of the French door seen from the internal side, where a 12-cm-high panel in XPS, with the same thickness of the screed, has been inserted

Fig. 7.39 Lower installation of the French door where insulation in XPS was installed for the protection of the thermal bridge of the stone threshold

Fig. 7.40 Lower installation of the French door after the pouring of the cement screed on the terrace

Fig. 7.41 Lower installation of the French door after the installation of the stone threshold

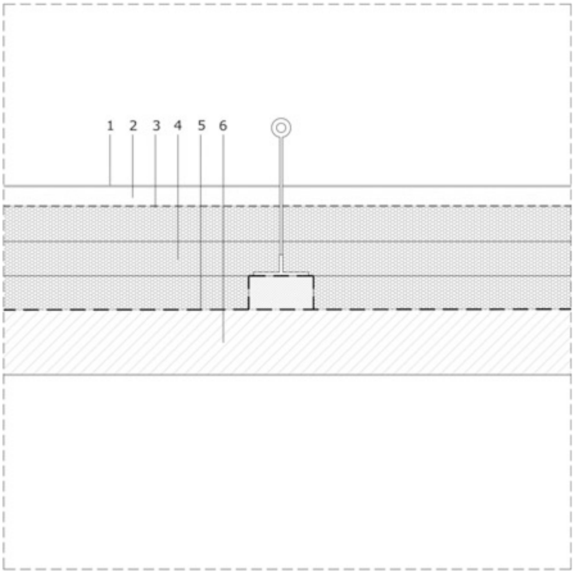


Fig. 7.42 Section in correspondence with the anchor insert of the life line: (1) bitumen roof cladding; (2) cement screed; (3) PVC; (4) XPS; (5) bitumen-based sheath; (6) CLT

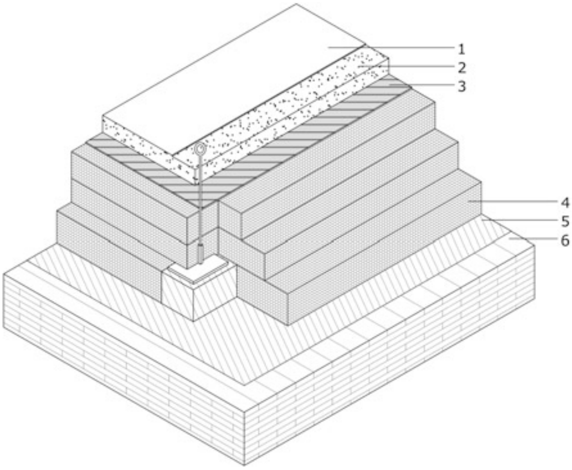


Fig. 7.43 Axonometric view in correspondence with the anchor insert of the life line: (1) bitumen roof cladding; (2) cement screed; (3) PVC; (4) XPS; (5) bitumen-based sheath; (6) CLT

Fig. 7.44 Steel pin for the fixing of the line life anchored to the CLT

Fig. 7.45 Steel pin for the fixing of the line life at completion

References

EN ISO 10211:2008. Thermal bridges in building construction—heat flows and surface temperatures—detailed calculations

Fabbri K, Marinosci C (2015) Ponti termici negli edifici, Wolters Kluwer Italia. ISBN 9788867500994

Hygrothermal Performance of Building Components and EN ISO 13788:2013. Building elements —internal surface temperature to avoid critical surface humidity and interstitial condensation— calculation methods

Tanizaki J (1962) In ei raisan, Chunokoron-Sha, Tokyo, Japan. Italian version: Tanizaki J (1995/2016) Libro d'Ombra, Bompiani/Rizzoli Libri S.p.a., Milan, Italy

Website

Dartwin Frame. https://www.dartwin.it/it/software/frame-simulator/. Last visit 07 Apr 2017

Dartwin Mold. https://www.dartwin.it/it/prodotto/mold_simulator_pro/. Last visit 07 Apr 2017

Chapter 8
Designing Airtightness

What is airtightness? What does it depend on? Where can it be checked? What construction solutions have to be adopted to ensure airtightness?

Imagine three small houses made of cardboard.

The first has the form of a perfect cube. The plants (an electrical cable and a small tube) that protrude from its envelope are protected by a polyethylene tape that has a mesh reinforcement coated with acrylic adhesive; the same tape can be found along the edges of each façade. The windows are holes in the cardboard, protected by a sheet of acetate whose joints are protected by the same tape. Wear has produced four small holes with a diameter of a pinhole, on the four corners of the cube.

The second has a prismatic form, with a square base and sloping roof in a single gable. The plants protrude from the envelope through small holes in the cardboard. Both the windows and the edges of the façades are held together by common adhesive tape, which in segments appears damaged.

The third has a square plan and two-gable roof. It is of greater volume than the previous examples. The edges, windows and plant installations are protected by polyethylene tape (Fig. 8.1).

The three houses are equipped with a cardboard cylinder placed on the roof to represent the chimney; each chimney is properly sealed and wrapped in a colourful balloon.

With adequate airtightness, all it takes is a little pressure from the fingers of one hand on the cardboard envelope to inflate, cheerfully, the balloon; but only one of the three houses is able to inflate the balloon: *which one?*

The first, in spite of its reduced volume compared to the subsequent ones, suggesting some advantage, it does not have good airtightness. With some pressure from the fingers, the balloon moves timidly but remains deflated; despite the taping, just four tiny holes present in the corners thwart the efforts made to ensure its airtightness.

The second, despite abundant use of adhesive tape, at pressure of the fingers on the envelope, the balloon remains motionless. I personally tried to press firmly and

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_8

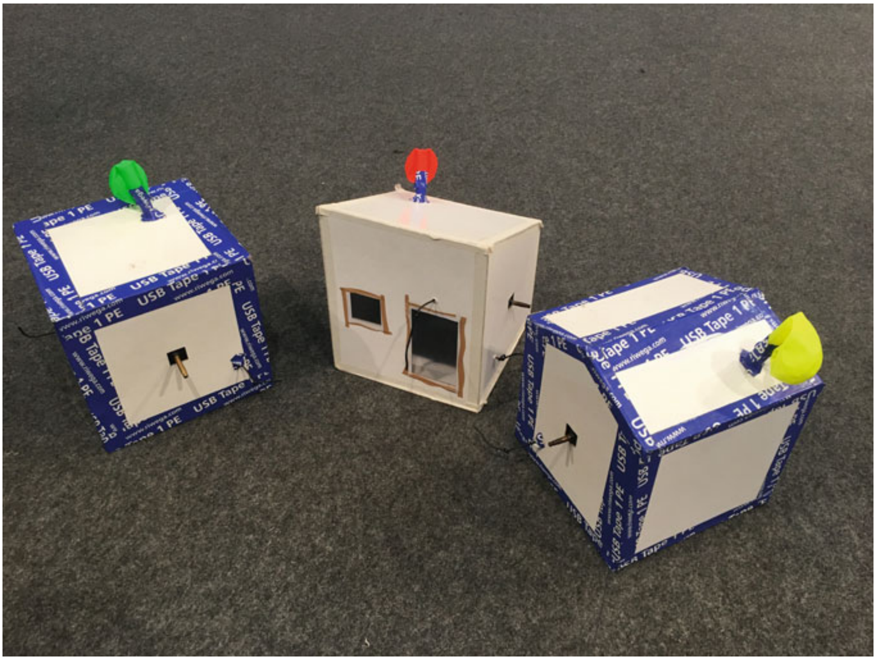


Fig. 8.1 Verification of the airtightness on the three different cardboard models

forcefully without getting any result, the sealing of normal adhesive tape is not effective. Moreover, many of the air leaks occur at the holes required for the passage of the plants and at the windows.

The third, despite the fact that it seems disadvantageous to have a larger volume than its predecessors, has perfect airtightness (!) and just the slightest pressure on the envelope and the balloon fills completely with air, the polyethylene tape applied correctly on each disconnection of the envelope ensures optimum airtightness.

I found this cute little game at the booth of *Zephir passivhaus Italy,* accredited IPHA certification (International Passive House Association) Institute, during the 2017 edition of the Klimahouse trade fair of Bolzano (IT). The example effectively describes the problems related to the airtightness in buildings. Fundamentally, good airtightness is unrelated to the volume or form of the building, but it essentially concerns the presence of holes or disconnections in the building envelope.

These issues typically occur in three situations:

1. in the assembly of the elements that constitute the envelope;
2. in the installation and in the choice of the door and window frames;
3. whenever a plant traverses the envelope.

A Passive House must guarantee an airtightness of $n_{50} < 0.6$ 1/h, value that must be tested and certified using the blower door test on the finished building (for the meaning of n_{50} and of the blower door tests, please refer also to Chap. 6). The test allows one to detect the amount of air leakage of the building envelope, and it must be carried out in accordance with ISO 9972 which has replaced the EN 13829 standard (withdrawn) in force at the time of construction of the *Fiorita Passive House*.

The blower door test has the purpose of determining the n_{50} value, i.e. the hourly number of air exchanges with a pressure difference between the outside and inside of 50 Pa. The value obtained is directly proportional to the quantity of air infiltrations into the building.

It is carried out by an operator who applies on the building's door a device composed of a fan inserted in an airtight sheet. The device is equipped with pressure sensors to evaluate the difference between the internal and external pressure, all connected to a computer which processes the measured data. The sheet must be hermetically installed, adhering to the fixed door frame. Careful attention should be paid to the correct installation of the instrument: during the blower door tests carried out in the *Fiorita Passive House*, we verified losses due to adherence that was not hermetic between the sheet and the frame.

When the fan is turned on, all communication with the external environment must be interrupted, while communication must be made with all the internal environments. The fan generates a pressure difference within the building envelope compared to the external environment which is adjusted by means of the number of revolutions of the fan and, through a specific reducer, through the cross section of the same.

The process is constantly monitored by specific software which receives data from the sensors in the device. The air flow generated by the pressure difference is defined as the *volumetric flow rate of air permeability*. By dividing the *volumetric flow rate of air permeability* V50 for the internal volume V subjected to the test, one obtains the air permeability n_{50} on the basis of the volume, parameter that measures the air permeability of the building envelope.

The test consists of two modes:

1. *cruise mode:* a first test that is run with constant vacuum, where the fan creates a pressure difference between the inside and the outside equal to 50 Pa. The pressure difference compared to the external environment forces the air to find every possible access route through the envelope, taking advantage of every discontinuity to make headway. This mode is used during the construction phase of the building to test the quality of the technical solutions adopted and to identify and correct possible air infiltrations.
2. *test mode:* in this phase, a decreasing vacuum is generated, measuring values every 5 Pa, starting from 70 Pa and arriving at 25 Pa. Other values are measured with the machine switched off before and after the test. The test is repeated by reversing the fan flow and creating pressure within the envelope. From the interpolation of the data obtained during the two phases of vacuum and pressure, one obtains the number of air changes at the reference pressure of 50 Pa.

But why are these air leaks are so important?

Every loss of air transforms itself into a dispersion of climate controlled air, and therefore, of energy. Due to the effect of the phenomena of pressure and vacuum, the hot air that exits from a hole of the envelope can draw cold in air through a second hole. The same phenomenon, on the contrary, may occur in the summer.

Moreover, the water vapour present in the air can condense in the presence of sudden changes in temperature. The surface and interstitial condensation can create serious pathologies related to the formation of mould and mildew and bring about the disintegration of the materials used. Good airtightness improves the acoustic insulation of the building, avoiding, with the passage of the air, external noise as well.

Therefore, effective airtightness is a guarantee of: energy efficiency, absence of moulds or condensates and a greater duration of the life cycle of the building.

In the event of a negative result of the blower door test, it is possible to identify the air leaks using anemometers, thermal imaging or smoke generators that make the passage of air between the interior and the exterior visible to the naked eye.

Once you have identified the air leaks, it is possible to correct them through restoration interventions; however, the methods of intervention will become destructive when the test is only carried out when the building is finished.

Therefore, my advice is to run the blower door test not only when construction has ended, but also during the most significant phases (installing windows and doors, installation of the plants) of the construction process, especially if, as in my case, it was the first experience in the construction of a certified Passive House and you do not want to risk making a fool of yourself. Through this methodology, the blower door test becomes an effective instrument for testing the solutions adopted, improving efficiency and correcting any errors in the course of the work without recourse to destructive intervention.

On the market, there are several useful products to ensure the airtightness of a building; there are also many technical solutions and shortcuts that vary in relation to the type of construction technology used.

In the following paragraphs, I will limit myself to illustrating the solutions used to ensure the airtightness of the *Fiorita Passive House*. Creating a seal of $n_{50} < 0.6$ 1/h means ensuring energy efficiency, health and indoor comfort, in short, the opposite of what you can find concerning houses, in the fiction of H. P. Lovecraft, as he writes in the story The Shunned House:

> What I heard in my youth about the shunned house was merely that people died there in alarmingly great numbers. That, I was told, was why the original owners had moved out some twenty years after building the place. It was plainly unhealthy, perhaps because of the dampness and fungous growth in the cellar, the general sickish smell, the draughts of the hallways (…). (Lovecraft 1924, p. 51)

The *shunned house* really exists; it is located in Providence, Rhode Island, on Benefit Street. I hope that nobody ever thinks about correcting its airtightness, otherwise we can say, "goodbye mystery"! (Fig. 8.2).

Fig. 8.2 Various types of sealing tape

8.1 Airtightness of the Building's Structure

Based on my experience, the weak points which concern the airtightness of a structure in CLT (cross-laminated timber) are as follows: the joints between the panels, the joints with the foundations, the anchoring plates and every element that intersects the CLT.

In the joints between the panels, in correspondence with their thickness, we applied two strips of butyl tape (Butyl Band produced by Rothoblaas®) composed of black butyl adhesive with the interposing of a mesh in polypropylene filament that limits the over-extension of the product. The tape, once subjected to the pressure of the two fixed panels with mechanical anchorage, seals the vertical joints, ensuring thermal and acoustic insulation, water sealing and airtightness. The requirement is further enhanced by the application of an airtight tape (Flecto produced by Klober®) both on the internal and external sides of the panel. The tape is composed of acrylic adhesive with filamentous reinforcement free of chlorine, solvents, formaldehyde or emollients. This is a flexible product that can be used in any situation where it is necessary to seal the disconnections that can generate air infiltration (structure, frames, plants, etc.).

The same tape was applied to protect each disconnection of the structure, whether they are joints, metal plates or other elements capable of generating interferences.

Before installation of the horizontal panels in CLT constituting the structure of the floor slabs, a sound insulating joint is applied (Track produced by Rothoblaas) on top of the vertical panels. This is a product made of EPDM (Ethylene-Propylene Diene Monome) which restricts the transmission of vibrations between wood and wood due to trampling and at the same time increases airtightness. The same product is applied both under the vertical panels that rest on the foundation kerbs and at the base of the vertical panels that constitute the different floors of the building. To improve the airtightness of the joint in EPDM, whenever it is interrupted, the new application is saturated with silicone, so as to ensure its continuity.

In the joints of the horizontal panels, those that constitute the floor slab, a hole is applied in correspondence with their intersection with the vertical panels, exactly in the place in which the horizontal panels protrude, constituting the structure of the terraces. An injection of silicone is applied in the hole to stop the flow of air which could connect the outside with the inside of the building. For greater protection, the joint is further protected by the application of the sealing tape. The sealing tape is also applied to coat the anchoring plates where there are holes that pass through (Figs. 8.3, 8.4, 8.5, 8.6, 8.7, 8.8).

8.2 Airtightness of the Frames

Before choosing the door and window frames to be used in a Passive House, one should verify that they have an adequate air permeability class. EN 12207 defines five classes from 0 to 4, the best being Class 4, which identifies a window frame with outstanding airtightness. In the market for construction products, usually, only two types of door and window frames manage to reach Class 4: leaf door and window frames and side-shifting sliding frames. For the design of the *Fiorita Passive House,* we used frames with a leaf in PVC (Top90 produced by Finstrall), all belonging to Class 4.

The fixtures are composed of three elements:

– mobile frame, the opening frame of the window where the glass is placed;
– fixed frame, the fixed part of the window where the hinges are located;
– subframe, also called shutter box or counter-frame, required to connect the fixed frame to the wall of the building.

In the *Fiorita Passive House,* we have avoided the use of the subframe applying the fixed frame directly on the panel in CLT. On the panels in CLT, the holes for the entrance doors, windows and French doors were cut with pinpoint accuracy, through the use of numerically controlled cutting tools. With this solution, we obtained two advantages: cost savings and one less element to secure for airtightness.

To allow an airtight installation, expanded butyl sealing tape has been applied on the outer perimeter of each frame, both in contact with the panel in CLT and in contact with the other frames. The latter solution was used in systems composed of

Fig. 8.3 Sealing of the joints on the internal side with sealing tape

French doors and the entrance door. The expanded butyl tape is pressed during the anchorage of the frame, contributing to efficient airtightness.

As a supplement to the butyl tape, a sealing tape has been applied along the internal and external edge of the frame, so as to guarantee the achievement of the requirement and its duration over time. In fact, the mechanical fastening of the

Fig. 8.4 Sealing of the joints on the external side with sealing tape and silicone sealing on the anchorage plate

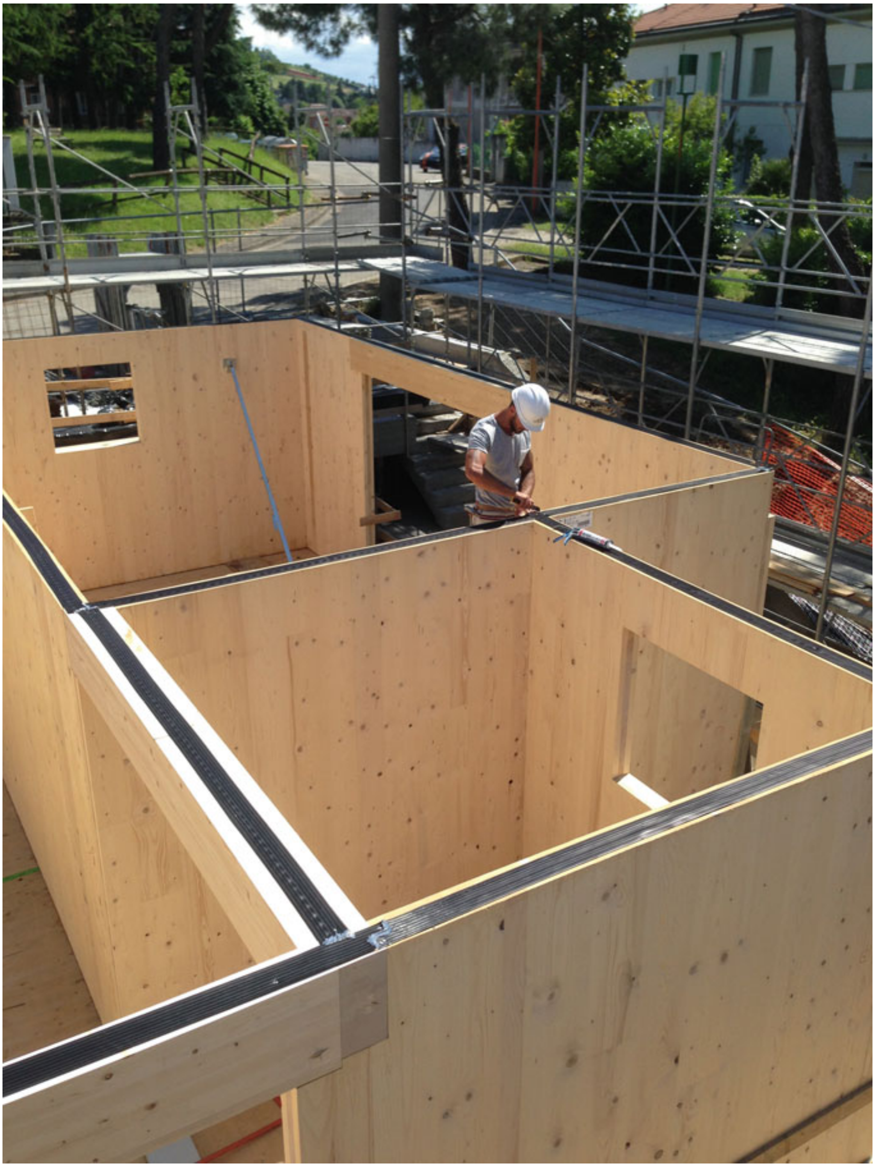


Fig. 8.5 Application of the sound insulating joint and suture with silicone to ensure the continuity of the element and improve the airtightness

Fig. 8.6 Taping in the presence of the anchoring plate with holes that pass through and protruding wooden beam

Fig. 8.7 Taping in the presence of the architrave of the windows

Fig. 8.8 Silicone injection in the presence of the joints of the horizontal panels of the floor slabs, carried out before the application of the sealing tape

frames could over time loosen, limiting the effectiveness of the expanded tape. In this context, the sealing strip located on the internal and external sides of the frame is able to absorb the dilations, ensuring continuity in the requirement of airtightness.

However, it is advisable to carry out a review of the mechanical fastening systems after a year from the installation of the window and door frames to check if any deformation phenomena of the wooden structure have caused the loosening of the connections (Figs. 8.9, 8.10, 8.11).

8.3 Airtightness of the HVAC and Plant Systems

In the *Fiorita Passive House,* we have 7 HVAC and plant system types:

- wiring system;
- photovoltaic system;
- domestic hot water system;
- rainwater harvesting;
- wastewater discharge system (washbasins, washing machines, dishwashers, WC);
- controlled mechanical ventilation heat recovery system with heat exchanger and post treatment battery;
- plant for the recovery of the condensation produced by the ventilation machines.

Every time that any one of these plants traverses the envelope, problems may occur in regard to airtightness. The tools to avoid them are mainly: airtight sealing caps, sealing tapes, silicone glues and polyurethane foams.

The airtight sealing caps are used mainly to prevent the infiltrations of air into the electrical system, whenever it traverses the envelope. On the market, there are numerous types, composed mostly of adhesive patches that house in their centre a sheath made of EPDM (Ethylene-Propylene Diene Monomer) on which there is a small hole through which the electrical wire is inserted by means of pressure. In this way, the sheath seals the wiring against the passage of air. These products, designed ad hoc for buildings that guarantee airtightness, are quite expensive. In order to keep the costs lower, in the *Fiorita Passive House* we used watertight sealing caps. They are plugs in stainless steel which have a rubber-coated hole, within which the electrical wiring is introduced. By rotating the head of the cap, the diameter of the hole shrinks, sealing the passage of water, and consequently, also that of air.

The distribution tubes of the domestic hot water system are protected by silicone glues injected inside the hole that is made to allow the tube to traverse the building envelope. For greater safety, sealing tape is applied on the external side and polyurethane foam is applied on the internal side.

The outlet pipes of the MVHR have a large diameter. The edges of the tubes are protected with airtight tape both on their exterior sides and on the exterior side of the panel in CLT. In the *Fiorita Passive House*, the taping of each plant was

Fig. 8.9 Taping of the system of door and window frames with coupled window and entrance door

Fig. 8.10 Installation of the frame with expanded butyl tape

Fig. 8.11 Application of the sealing tape

repeated in the intersection with the windproof sheet on the back of the wood cladding, to ensure greater efficiency of the system.

Wastewater discharges usually leave from the envelope through the ground; in this context, the airtightness is immediately effective. However, whenever a discharge tube traverses the envelope the procedure to ensure airtightness still goes through the use of sealing tapes and polyurethane foams.

In the *Fiorita Passive House*, being a building composed of several apartments, it was necessary to ensure good levels of airtightness also between adjoining apartments. In this context, there are no verified energy losses, but it is possible to prevent infiltrations of odours and acoustic bridges; to solve the problem, the passage points of the plants between the different apartments were protected with the injection of polyurethane foams (Figs. 8.12, 8.13, 8.14, 8.15, 8.16).

Fig. 8.12 Injection of silicone glues in the hole of the traversing of a water tube (external side)

Fig. 8.13 Injection of polyurethane foams in the holes of the traversing of water tubes (internal side)

Fig. 8.14 Sealing tape applied on the output channels of the controlled mechanical ventilation system (internal side)

8.4 The Blower Door Test in the Fiorita Passive House

The products described in the preceding paragraphs and used in the *Fiorita Passive House* represent only a small part of those present on the market. Specialised retailers offer various types of adhesive tapes suitable for every type of building technology, the same diversity we find in expanded tapes, sealing plugs for electrical installations, adhesive patches for the mechanical plants, airtight sheaths and so forth.

The knowledge of these products is crucial, especially if one intends to build a Passive House with dry construction technologies, as in our case. On the contrary, the requirement of airtightness is usually easier to reach in buildings made with wet construction technologies. Envelopes of reinforced concrete or plastered masonry are so uniform and compact as to create effective airtightness by their very nature. In these cases, the use of tapes is normally restricted to the installation of the frames and in correspondence with the installations which traverse the envelope.

Compared to the previous technology, in dry construction the disconnection between the elements increases, so the requirement is harder to achieve. For this reason, during the construction of the *Fiorita Passive House*, as a greater guarantee for achieving the result, we carried out ***three sessions of the blower door test***:

Fig. 8.15 Sealing tapes and polyurethane foams applied on the different types of plants (internal side)

1. *first test*: when the load-bearing structure was finished, to verify the connections between the load-bearing elements;
2. *second test*: after installing the windows and doors, to verify the correct installation of the frames;
3. *final test*: when the building was finished, to verify the achievement of the Passive House standard (Figs. 8.17, 8.18, 8.19, 8.20).

8.4.1 First Test on the Finished Load-Bearing Structure

In buildings with a wooden structure, in addition to the application of sealing tapes in the joints of the panels or between different elements, the use of airtight sheets is recommended. The sheets cover the entire surface of the external envelope, guaranteeing the result. This construction technique had been recommended to me by the Passive House certification body; moreover, I found confirmation about the technical solutions proposed by various companies that build wooden houses. However, the solution had not convinced me for three reasons:

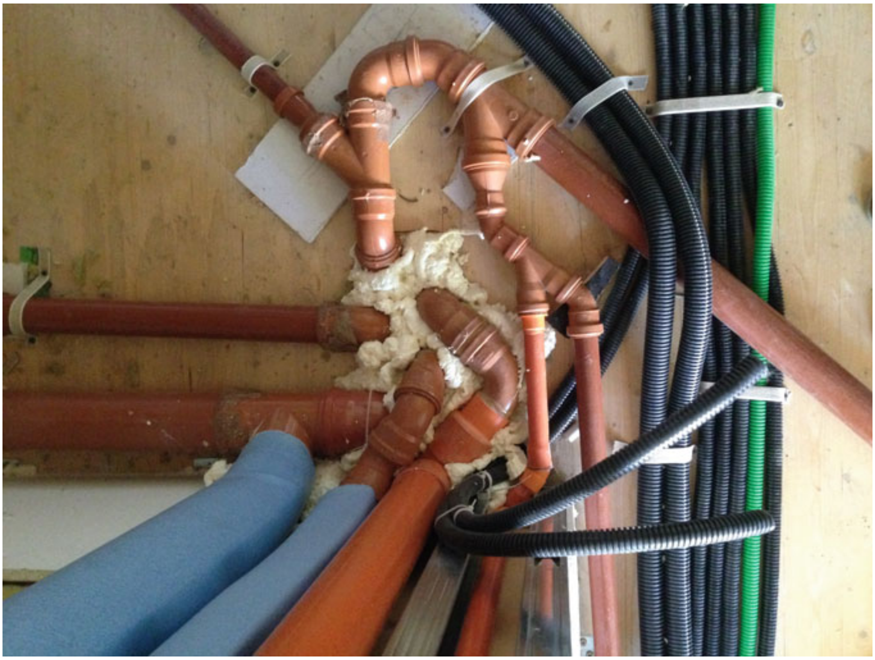


Fig. 8.16 Polyurethane foams applied in the hole of the traversing of the panel in CLT of the interfloor slab to ensure good airtightness between the different apartments. The requirement will be further enhanced by the subsequent laying of the lightened screed and the cement screed that will integrally cover the plants

- the considerable cost of the "*airtight sheets*" would have a significant impact on the budget;
- I had not found sufficient bibliographic sources and scientific literature so as to bring more clarity to the subject;
- the technical data sheet of the panels in CLT used indicated elevated airtightness in compliance with the European standard ONORM EN 12114, where the panels were subjected to differential pressures both positive and negative, with measurement for each degree of pressure from 10 to 400 Pa.

Why would such a high-performance panel, once its junctions are taped, not pass the blower door test?

On the one hand, I thought the use of airtight sheets was superfluous; on the other hand, I feared the negative result of the test, which would be a disastrous outcome: I would not have been able to have achieved the Passive House certification standard (Fig. 8.21).

Confident of my intuition, and after having consulted with my colleagues, Margherita in primis, we decided to carry out a blower door test when the structure was completed in order to verify the airtightness of the panels. My client would

Fig. 8.17 Installation of the fan for the blower door test (external view)

have paid for an extra test, but if the results were positive, he would be spared paying for a quantity of airtight sheeting. *It was a risk worth taking*!

Once the structure was finished and the holes of the windows were sealed with PVC sheets, we performed the tests on two apartments, which fortunately had positive results. In this way, we have demonstrated that a double taping, carried out

Fig. 8.18 Values detected during the blower door test in vacuum

on the internal and external side of the panels in CLT, is sufficient to ensure airtightness. The positive result of the test has allowed us to proceed without the use of the airtight sheets, allowing us to save on construction costs.

8.4.2 Second Test with Installed Door and Window Frames

The second test was carried out during the installation of the door and window frames in order to verify the correctness of their installation. In this way, possible adjustments and improvements could be made directly by the tradesmen assigned to the installation of the shutters. We performed the test by choosing two different apartments than the predecessors. In this way, we could obtain further proof of the actual airtightness of the structure.

The first test was passed without too much difficulty; while in the second, we detected a conspicuous loss in correspondence with a French door. The frame appeared adequately taped; however, the tests with the anemometer detected a leak in one of the vertical studs of the frame in correspondence with the contact with the panel in CLT. The frame was not cohesive to the panel in CLT: air passed because the expanded butyl tape interposed between the CLT and the frame was not sufficiently compressed. It was sufficient to tighten the screws that anchor the frame to the panel in CLT and improve the taping to solve the problem. The next test in fact gave a positive result.

For precaution, we checked all the mechanical fastenings of the frames that had been installed up to that moment (Fig. 8.22).

8.4.3 Final Test: Testing on the Finished Building

The test on the finished building has had some dramatic moments!

We had to ensure the airtightness of each of the 8 apartments. In a multi-residential building, the requirement of airtightness should be guaranteed not only towards the outside, but also in relation to the neighbouring apartments, to eliminate acoustic bridges and the transmission of odours. If we consider all the apartments as inhabited and with active ventilation systems, air leaks between one apartment and another do not affect the energy performance but can have an affect on the comfort. It was therefore necessary to investigate.

From the first test, only 6 of the 8 apartments were verified, the remaining two had in common the same floor slab and had air infiltrations in correspondence with the discharge columns of the bathrooms.

Fig. 8.19 Search for air infiltrations with the anemometer

Fig. 8.20 Installation of the fan for the blower door test (internal view)

Fig. 8.21 Closing of the holes of the windows with taped PVC sheets

To locate the air leakages correctly, it was necessary to demolish a portion of the structure in plasterboard which had the discharge tubes, remove the insulation in mineral wool in which the tubes were wrapped and investigate the loss using the anemometer. The same procedure was carried out in both apartments. The infiltration was measured at the point where the exhaust pipes pass through the layers of the interfloor slab.

The manufacturer has tried to solve the problem by removing the sealing tapes fitted on the tubes, introducing expanded polyurethane for sealing the joint between the tubes and the floor slab, then applying a new taping on the suture. The operator would return the following week to carry out a new test. All of us were in anxious anticipation during that week.

The second final test had a positive result, the plasterboard was restored, as well as the part involving the cladding of the bathroom, so everything got back to normal. Fortunately, the contract stipulated that any extra work due to problems of airtightness would be borne by the construction company.

Once we had verified in each apartment that there are no air leaks, we installed the communication of the ventilation systems of each apartment and carried out the ***final blower door test, the result of which was equal to*** $n_{50} = 0.4$ ***1/h,*** value that was inserted in the certification of the building (Fig. 8.23).

Fig. 8.22 Tightening of the screws to compress the expanded butyl tape

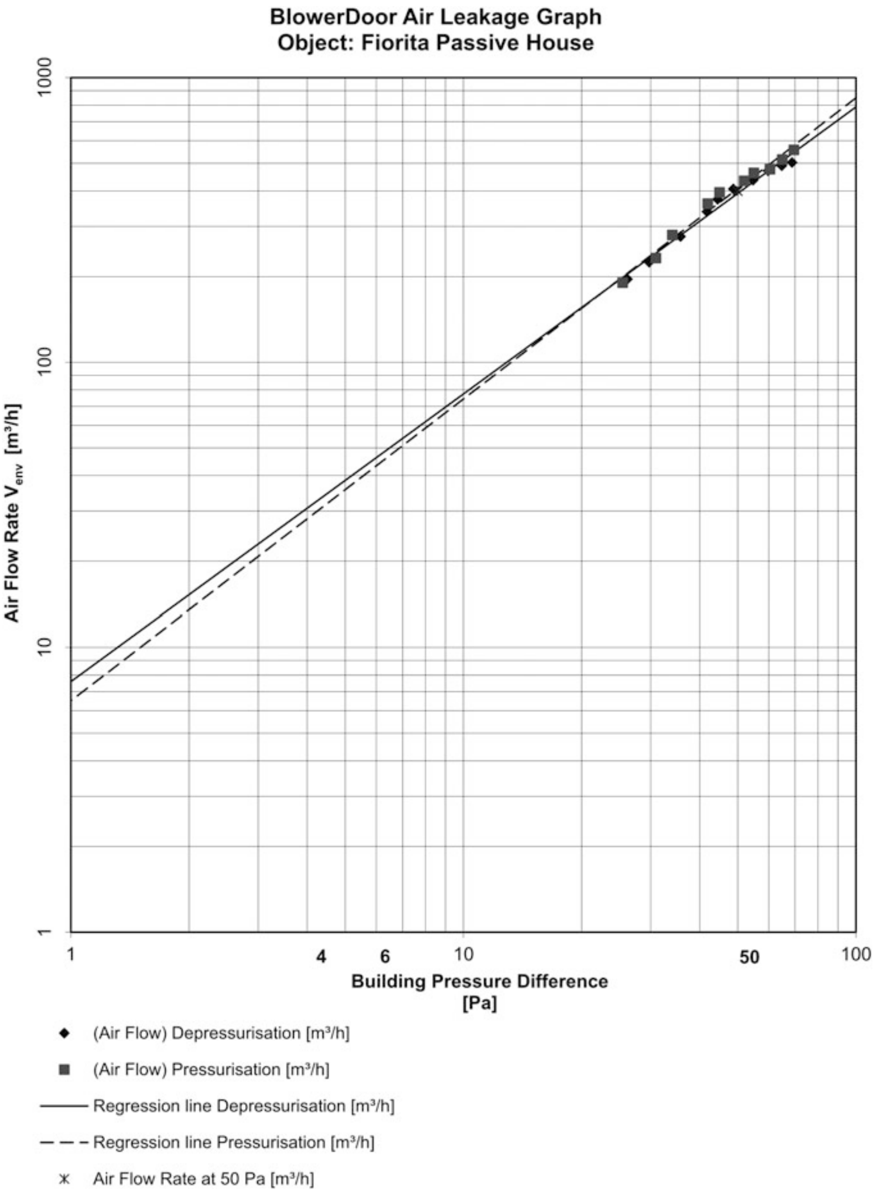


Fig. 8.23 Graph of the airtightness extracted from the certification of the final blower door test

References

Lovecraft HP (1924) The shunned house, weird tales. October 10/1937, Chicago, United States of America. Italian version: Giuseppe Lippi (ed) (1990), Lovecraft HP tutti i racconti 1923–1926, Arnoldo Mondadori editore s.p.a, Milan, Italy

EN 12207:2000 Windows and doors—air permeability—classification

EN 13829:2002 Thermal performance of buildings—determination of air permeability of buildings—fan pressurization method (withdrawn)

ONORM EN 12114:2000 Thermal performance of buildings—air permeability of building components and building elements—laboratory test method

EN 9972:2015 Thermal performance of buildings—determination of air permeability of buildings—fan pressurization method

Chapter 9
Designing the "Interferences" with the Technical Systems

What kind of HVAC system should a Passive House be equipped with? Is it possible to use ordinary technical systems? What technical requirements should be adopted? What are the interferences with the components of the envelope? Should the technical systems also be insulated?

The technical systems present in a Passive House are the same as those of traditional buildings, with one exception: that of the heating, ventilation and cooling system. The Passive House standard contemplates the use of a controlled mechanical ventilation system with heat exchanger and pre-heater controller, all connected to a heat pump. In relation to the building's heating and refrigeration requirements, controlled mechanical ventilation can supplement traditional HVAC systems or it can completely replace them.

By traditional HVAC systems, we mean: radiators, radiant floors, air treatment units, whether they are connected to a boiler or to a heat pump.

The use of only controlled mechanical ventilation and induction hobs for the kitchens means that the building can be disconnected from the gas distribution network.

As we saw in Chap. 8, in the *Fiorita Passive House,* the following types of technical systems were used:

- wiring system;
- photovoltaic system;
- domestic hot water distribution system;
- rainwater recovery system;
- wastewater drainage system (sinks, washing machines, dishwashers, toilets);
- controlled mechanical ventilation (CMV) system;
- recycling system of the condensation produced by the CMV (Fig. 9.1).

The innovations, compared to traditional building methods, apply only to the last two points on the list:

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_9

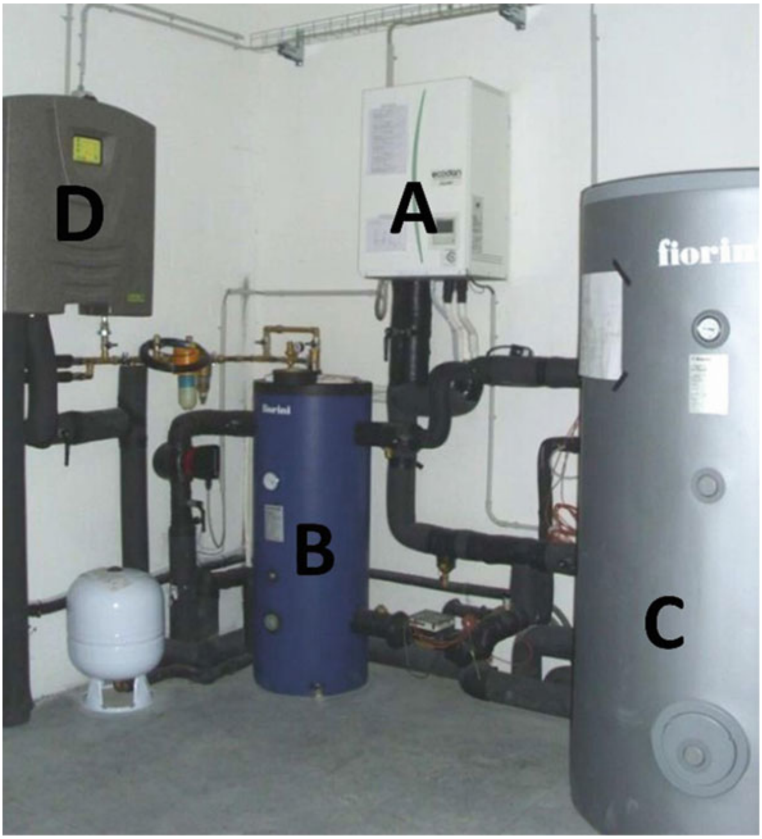


Fig. 9.1 Technical systems room of the *Fiorita Passive House*

- the CMV system that, at least in Italy, markets itself as a novelty, especially when used as the building’s only HVAC system;
- condensation recycling is, instead, a simple system we designed that conveys the condensation produced by the ventilation units into a tank with a standard faucet at the base.

Usually, condensation is drained into the sewer system, but in our case, it can be used by each tenant as water for irons: condensation is, in fact, deionized water, so why throw it away? Recovering the condensation from the ventilation units has nothing to do with the design of a Passive House, but it remains a coherent strategy towards achieving sustainable design.

In this chapter, it is not our intention to illustrate the design methods of each technical system but to provide the reader with practical information on the strategies to be adopted for the integration of a Passive House built in CLT. We are talking about out-of-the-ordinary technical solutions that are not adopted in traditional buildings. Therefore, this chapter will provide:

- a brief explanation of how the controlled mechanical ventilation system works;
- the necessary measures to adopt to check for interferences generated by the technical systems.

The integration of the technical systems in the architecture is a dilemma which has been present for a long time, especially since the technical installations are so widespread. In this regard, Jun'ichirò Tanizaki began his book "In Praise of Shadows" with the following incipit:

> What incredible pains the fancier of traditional architecture must take when he sets out to build a house in pure Japanese style, striving somehow to make electric wires, gas pipes, and water lines harmonise with the austerity of Japanese rooms. (Tanizaki 1962, p. 1)

9.1 Controlled Mechanical Ventilation in the *Fiorita Passive House*

The *Fiorita Passive House* is equipped with a controlled mechanical ventilation system with heat exchanger and pre-heater controller. When the transportable heating/cooling load from the supply air is superior to the heating/cooling load needed for the climate control of the building: that means that it is possible for controlled mechanical ventilation to be the only climate control system present in the building, generally when the heating load is <10 W/m^2 and the cooling load is <8 W/m^2.

The PHPP processes the data and confirms whether or not the result is acceptable: in the event of a positive outcome, "Yes" appears in the box "*can the building be heated and cooled strictly through ventilation?*" Otherwise, you will need to install additional heating or cooling generators (radiators, air conditioners, radiant floors, and so forth).

In substance, a controlled mechanical ventilation system consists of:

- ventilation units, which generate air movement;
- heat exchanger, which migrates the heat from the consumed air into the extracted air;
- pre-heater controller, which pre-cools or heats the extracted air;
- heat pump, which heats or cools the water fed into the coil of the tubes inside the pre-heater controller;
- channel for the extracted air, which draws air from the outside and feeds it into the ventilation units;
- channel for the consumed air, which returns to the outside environment the air expelled from the rooms through the ventilation units;
- delivery circuits, which transport the air into the main rooms (living room, bedroom) from the ventilation units;
- recovery circuits, which conduct the air taken in from the service rooms (bathroom, kitchen) to the ventilation units.

The heat exchanger in the controlled mechanical ventilation system allows the passage of the heat of the consumed air toward the extracted air. In relation to the effectiveness of the ventilation unit’s yield due to such exchange, it could be approximately 90%. In essence: I take from the consumed 20 °C air and I heat the extracted 18 °C air. It will be up to the internal loads (heat produced by the sun, by the human body and the electrical appliances) or by the pre-heater controller, to come up with the missing 2°. In the *Fiorita Passive House*, ventilation units have been used with certified Passive House yields, having an average value of 89%.

The use of a certified Passive House controlled mechanical ventilation system with heat recovery (MVHR) has allowed us to introduce in the PHPP the yields of the technical systems present in the technical data sheets of the product. Otherwise, we would have had to apply precautionary coefficients, lowering the declared yield of the ventilation unit.

The larger apartments are fitted with an autonomous controlled mechanical ventilation system (ventilation units, heat exchanger, pre-heater controller), while the smaller ones, the studio apartments, have a shared system. The air flows sized for a single studio apartment were so low that they do not fall within the range of certification of the ventilation unit. The only way to fall within the range of certification is to increase the flow rate, but in this case, the air would become too dry: datum that is indicated by the PHPP. However, every studio apartment has been equipped with a pre-heater controller, connected to the centralised CVM, to allow autonomous temperature control.

The use of a single CMV system for two studio apartments has proven itself to be an effective and economical solution. The shared ventilation units were placed inside the garage that is accessible to both the tenants; the remaining ones were all located inside the apartment in cabinets or false ceilings in plasterboard. All the pre-heating controllers of the ventilation units were connected to a single heat pump, whose indoor unit is located in a technical systems room, while the external one is located in a common courtyard.

The systems used to allow one to adjust the air flow to three levels:

1. low flow, for use when the apartment is not inhabited;
2. medium flow, for use in mild environmental conditions;
3. high flow, for use mainly in the summer season or in the event of a large amount of people in the apartment.

Through a thermostat, it is possible to act on the pre-heating controller by setting the desired temperature; the unit, connected to a heat pump, will enable:

– *during the summer season*, when the internal thermal loads (heat produced by the sun, by the human body and by the electrical appliances) are such as to not be entirely disposed of by the air circulation;
– *during the winter season*, when the thermal loads are not sufficient to ensure the desired temperature.

In the seasons of the year when the external temperature is mild, the ventilation system will go into free cooling, the heat exchanger will interrupt its function to allow the external air to cool the internal environments and at the same time dispose of the consumed air. In this season, as during the warmer months, when the outside air has a pleasant temperature, one can open the windows and use the natural night-time ventilation, calculating it by using the PHPP.

9.2 Expedients for the Project and the Laying of the Technical Systems

When designing a Passive House, in the designing of the technical rooms and networks for the distribution of the technical systems, it is advisable to check the following interconnections to locate interferences between the technical systems and the building envelope:

- the continuity of the airtightness;
- the continuity of the insulating layers of the building envelope;
- the insulation of the pipeline network for the distribution of hot water and for ventilation.

To check for all interferences, the design of the technical systems must be detailed and it has to show *all* the passages of the tubes and cable ducts, the passages of the wastewater drains, the discharge columns, the ventilation system, the hot and cold water system, the position of the hydraulic manifolds, the position of the switchboards, the position of the light spots, of the electrical sockets, of the light switches … in essence, it has to show everything! In order to avoid surprises, we designed each pipe, cable duct or other element without the use of icons or symbols, but by using diameters and actual size.

The detailed representation is further justified by the need to protect some technical systems present within the climate-controlled building envelope with thermal insulation.

The design of the localisation of the technical systems was used to prepare the holes for the passage of the distribution networks in the panels in CLT. Holes were made in the factory on the basis of the panel-cutting design (Fig. 9.2).

9.2.1 Pipes to Be Insulated

In a Passive House, the hot water pipes must be insulated with a thickness of insulating material equal to twice their diameter: this requirement drives most plumbers mad, as they are accustomed, in traditional buildings, to using insulation that is only 1 cm thick. Greater insulation of the hot water pipes allows one to

Fig. 9.2 Passage of the wastewater drains through the panel in CLT of the interfloor slab

reduce losses in the winter season and internal loads in the summer season. The pipe wrapped with a thickness of insulating material double its diameter considerably increases its overall dimensions; therefore, it is important that the design foresees functional layers of suitable size for the integration of the technical systems.

The insulating material must be used even in the ducts of the controlled mechanical ventilation: the delivery ducts must be insulated to limit dispersions in the winter and eliminate condensation phenomena in the summer; while the ducts for the extracted and consumed air, that connect the ventilation units to the external environment, contain air at the external temperature, so they must be sufficiently insulated so as not to generate heat losses toward the outside environment. The length of the tubes of the extracted and consumed air, the type and the thickness of the insulating material are inserted in the PHPP which calculates the dispersions.

In an ideal situation, we should use insulating so as to achieve the efficiency of the building envelope; however, it is not always possible to arrange for such generous spaces for the technical systems.

To reduce the losses of the ducts for extracted and consumed air, we have positioned, where possible, the ventilation units directly in contact with the perimeter walls, so as to reduce the extension of the two tubes. The ducts were insulated predominantly with 4.5 cm thick insulation, except in some cases where it was possible to use insulation with a thickness of 8.5 cm.

In the *Fiorita Passive House*, for the integration of the technical systems, we have designed a 12-cm-thick lightened screed on the floor slabs and false ceilings in correspondence with the kitchens and bathrooms with a 30.7 cm thickness. Even greater thicknesses would have simplified both the task of designing and that of installation; however, the small size of the apartments and the compliance with the local urban planning regulations related to the height of the rooms and the building have not allowed us to use even one extra centimetre (Figs. 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 9.10 and 9.11).

9.2.2 Interferences with the Building Envelope

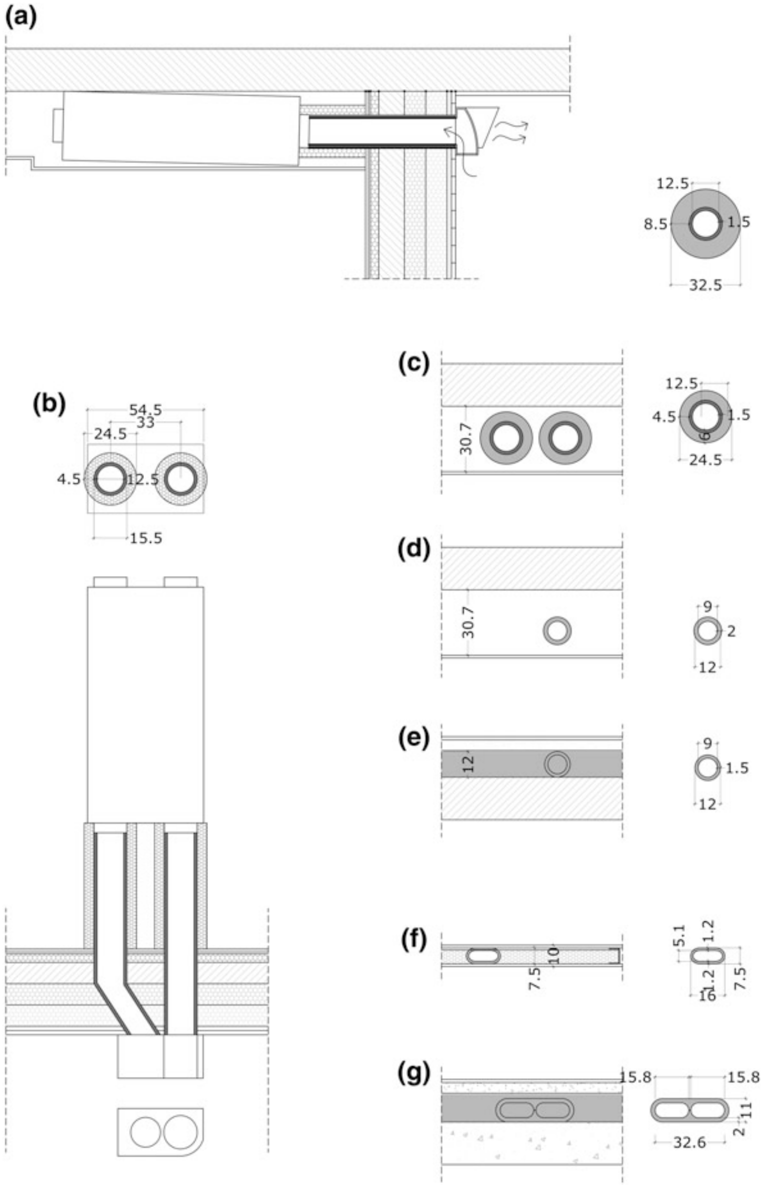
In traditional buildings, certainly in Italy, it is common practice to remove or cut an insulating panel in order to allow the passage of a technical system. Designers and installers are not usually very concerned after everything is closed within a gap or below a lightened screed; no one gives it a second thought. On the contrary, in a Passive House, the thermal insulation must always be preserved; therefore, when designing the technical systems, it is advisable to verify any interference with the insulating layers.

To avoid these situations, it is good practice to place the technical systems away from perimeter walls unless there are gaps that are so capacious as to not affect the insulating layers.

In the *Fiorita Passive House*, we need to minimise the thickness of the perimeter walls so as to gain usable surface area; therefore, inside the stratigraphy, we find a false wall in plasterboard just 5 cm thick behind which there is a panel of 4 cm thick mineral wool. With such small sizes, any passage of technical systems involves the cutting of the insulation: in these cases, it is therefore necessary to cut the panel according to the size of the technical system positioned therein. Removing the insulating material in correspondence with the technical system that passes through a layer of the envelope brings about a thermal bridge: it is therefore advisable to prevent that from happening.

Fig. 9.3 Ventilation unit positioned vertically. The two tubes that connect the unit to the external environment were individually insulated with 8.5 cm thick insulation

Technical systems were placed in the perimeter walls of the *Fiorita Passive House* and, where this was not possible, we have increased the thickness of the false wall in order to prevent the cutting of the insulation. We used the internal walls, where the suppression of the insulation does not generate thermal bridges, dividing neighbouring heated environments. It is important to develop the awareness that any pipe, cable duct, electrical box, hydraulic manifold, WC drainage boxes, etc. may cause interferences with the insulating layers.



The same problem can be found in the ground slab, in the case in which (as for the *Fiorita Passive House*), the thermal insulation is in the extrados of the foundation. In this case, it is advisable to provide functional layers of thickness sufficient to ensure the passage of each technical installation, whereas the distribution of the ducts may generate overpassing and overlapping.

◂**Fig. 9.4** Diagram of the tubing of the controlled mechanical ventilation used in the *Fiorita Passive House*: **a** position of the unit within a false ceiling adjacent to the perimeter walls, so as to reduce the extension of the tubes of the extracted and consumed air that connect the unit with the outside of the building. The tubes of the extracted and consumed air have 8.5 cm thick insulation; **b** the horizontal section of the ventilation unit positioned within a false ceiling and 4.5 cm thick insulation of the tubes of the extracted and consumed air; **c** tubes of the extracted and consumed air placed within the false ceiling with 4.5 cm thick insulation; **d** delivery tube within the false ceiling, 2 cm thick insulation; **e** air delivery tube located within the lightened screed of the interfloor slab, 1.5 cm thick insulation; **f** air delivery tube, flat shaped, placed inside a plasterboard wall, 12 cm thick insulation. The narrow and elongated shape of the tube simplifies the integration of the technical systems in absence of gaps with adequate thickness; however, its cost is twice as much that of the standard tube with circular cross section; **g** pair of air delivery tubes, flat shaped, positioned in the lightened screed, 1.5 cm thick insulation

Fig. 9.5 Detail of a recovery vent located in a bathroom

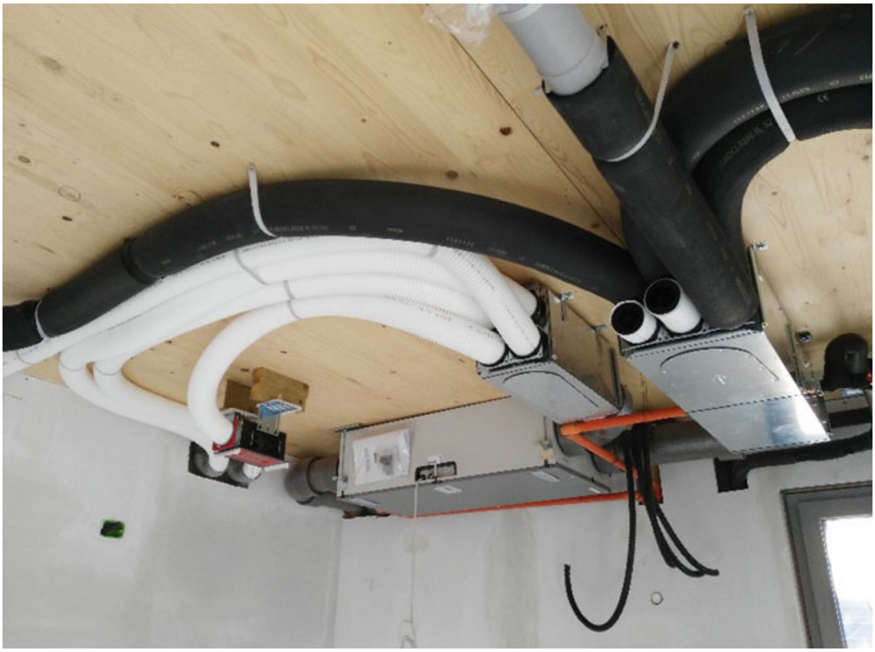


Fig. 9.6 Installation of the controlled mechanical ventilation system in the false ceiling of a kitchen consisting of: ventilation unit with heat exchanger, pre-heating controller and an air recovery vent. The insulation is placed in the delivery tubes (black) and in the tubes of the extracted and consumed air (grey)

In the *Fiorita Passive House*, in the ground slab, only 12 cm of lightened screed was used, it was not possible to increase it due to issues of regulations regarding the height of the rooms and of the building. Normally, we have managed to avoid damaging the insulating layers and in the rare cases where this was not possible, we have made injections of high-performance polyurethane foams.

We encountered fewer problems in the roof where the amount of technical systems is reduced: the chimneys and discharge columns were insulated, while the power to the photovoltaic system is supplied by a shaft outside the heated building envelope that provides electrical energy to the entire building (Figs. 9.12, 9.13, 9.14, 9.15, 9.16, 9.17, 9.18, 9.19, 9.20 and 9.21).

Fig. 9.7 Detail of the previous image after further insulating material has been introduced in the tubes of extracted and consumed air

Fig. 9.8 Studio apartments are equipped with a shared ventilation system, while the ventilation unit with heat exchanger is located in the garage; each apartment has its own pre-heating controller, together with a recovery vent, placed within a false ceiling in plasterboard

Fig. 9.9 Insulation of a flat air delivery tube placed within a false wall

Fig. 9.10 Detail of a delivery air vent placed in a living room

Fig. 9.11 Hot water pipes insulated with a thickness equal to twice the diameter of the pipe. The pipes are surmounted by a cable duct (black) and by a wastewater drainage pipe (orange)

Fig. 9.12 Interferences between the two hot water pipes and the insulation of the ground slab. The interference will be resolved by placing insulation that has been specially shaped to adhere to the section of the tubes, all of it to be sealed with injections of polyurethane foam

Fig. 9.13 Electrical boxes and delivery vent of the mechanical ventilation arranged in an internal wall. The polyurethane foam has the sole function of fastening

Fig. 9.14 Interfloor slab with wastewater drainage systems (orange), cable ducts (black), cold water pipes (grey)

Fig. 9.15 Distribution of the technical systems in an apartment. The ventilation tubes that have a circular section on the interfloor slab and a smaller cross section when they are introduced into the internal wall

Fig. 9.16 Distribution of the technical systems in an apartment seen from the stairwell

Fig. 9.17 Technical systems are covered by the 12-cm-thick lightened screed

Fig. 9.18 Ventilation duct that emerges from the lightened screed. To allow good airtightness of the 5-cm-thick cement screed, it is necessary that the pipes do not protrude from the lightened screed by more than 1 cm

Fig. 9.19 Technical systems on the ground slab. The insulation is continuous and there is no interference with the technical systems

Fig. 9.20 Installation of photovoltaic panels in the roof

Fig. 9.21 Main distribution of the wiring situated outside of the heated envelope

Reference

Tanizaki J (1962) In Praise of shadows (original title, In ei raisan), Chunokoron-Sha, Tokyo, Japan. Italian version: Tanizaki J (1995/2016) Libro d'Ombra, Bompiani/Rizzoli Libri S.p.a., Milan, Italy

Chapter 10
Monitoring Campaign

The design and construction of the building are the most interesting aspects of the design project. Once the building is finished, the designer delivers it to the end users, the inhabitants, who are the ones able to verify whether or not the intentions of the design—low energy consumption and comfort—have been fulfilled. Following the approach of Lord Kelvin "if you cannot measure it, you cannot improve it", with the aim of improving the skills of the designer and of the construction companies, together with the owner, it was decided to install a system of monitoring during the construction, to assess and measure the performance of what had been built. The monitoring campaign concerns the building envelope (roof slab and vertical wall) and the indoor microclimate of a room. In this chapter, we present the content and results of the monitoring campaign.

10.1 Measure in Order to Know

The construction of the *Fiorita Passive House* involved a series of efforts and risks taken by:

the owner, with regard to the expected low energy costs and the guarantee of indoor comfort during the arc of the entire year;
the designer and the Passive House consultant, relative to the actual behaviour of the technical solutions adopted, in particular, those which are difficult to evaluate with the calculation software, such as the phase displacement and the Indoor Air Quality;
the construction company that took the risk of ensuring both the owner and the designer that the work would be correctly executed;
therefore, all three of the subjects are interested in having the confirmation of the quality, effectiveness and efficiency of the strategies adopted; in other words, the three subjects require "proof" that demonstrates that the experiment has been successful, and that it is replicable.

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_10

From the beginning of the design phase, it was therefore decided to implement a monitoring campaign realised with the installation of monitoring instruments and probes for in situ measuring during the construction for the duration of a year.

The monitoring campaign began on 22 April 2016, coinciding with the inauguration of the Passive House, and it ended on 22 April 2017.

In this chapter, we shall describe the content of the monitoring campaign and the results.

Monitoring of the Dynamic Performance of the Opaque Closures

In the previous chapters, we have described the construction technologies adopted in order to meet certain performance specifications: the stratigraphy of the wall was designed to reduce the thermal exchanges of the building envelope, between the indoor and outdoor ambients, thanks to high thermal resistance and reduced transmittance value, and to reduction of the phase displacement, i.e. the input of solar radiation within the building.

Has the Solution Adopted in the Design and Then Built, Proven to be Effective?

As regards the insulation, it is possible to express an ex-post judgement by evaluating the energy consumption for heating and cooling, but this depends on many parameters: thermal insulation, the period of activation of the heating and cooling system, the discontinuity of the presence of persons in the ambients, the external climatic conditions and so forth. All of these are elements that do not allow one to correlate directly and with a linear connection, the physical parameters that characterise the construction with its energy consumption.

By way of example, the thermal transmittance can be evaluated through the use of a thermofluxometer (according to ISO 9869), but this procedure only provides data in a single point—where the probes are located—and constitutes a redundant measurement, given that the calculation of the transmittance according to the EN 6946 standard uses the data of thermal conductivity of the materials certified by the manufacturers; for this reason, we can assume that the in situ measurement of the transmittance constitutes information that is not useful in the case of new construction.

The datum that is the most difficult to evaluate at the design stage and in situ is the periodic thermal transmittance (YIE) and the phase displacement according to EN 13786. The calculation according to the standard shows the trend of the indoor, outdoor and wall surface temperatures, provided as an average datum in relation to the thermophysical properties of the materials and of the entire stratigraphy of the wall or of the floor or roof slab.

To find out the actual behaviour, a temperature monitoring system was installed during construction, in contact with a vertical wall and the roof slab. The thermocouple probes have been positioned for each layer of the wall and floor slab, in such a manner as to be able to verify the trend of the temperatures within the wall.

Monitoring of the Indoor Air Quality

Low energy buildings are guaranteed also as being "healthy" and comfortable buildings, thanks to the reduction of both the dispersions and the risk of overheating as well as due to guaranteed control of the microclimate with good airtightness of the building and the adoption of controlled mechanical ventilation (CMV) systems.

This is true, at least from the point of view of "Building Physics", by following the logic that a reduction of the dispersions is accompanied by a condition of greater thermal comfort.

Personally, this certainty has been challenged during a debate in a conference on Indoor Air Quality, to which I was invited by colleagues in the Department of Civil, Chemical, Environmental and Materials Engineering (DICAM). During this conference, I realised, with surprise, that some design criteria which are generally considered to be positive, such as the reduction of air leakage, are negative elements if addressed from the point of view of the concentration of indoor chemical pollutants. In other words, the airtightness is likely to increase the concentration of indoor pollutants coming from furniture, detergents and so forth, precisely because it lacks the dilution guaranteed by "air leakage". This does not mean that the buildings with airtightness are more polluted, but it was a good opportunity to reflect on whether or not some technological and design solutions implemented by default are indeed useful and effective in the actual context, taking account of the characteristics and the presence of the CMV.

Given the choice of activating the monitoring campaign of the Passive House, we decided to also monitor the indoor microclimate of an ambient, a room, with the use of probes for measuring the air temperature (°C), relative humidity (%) and the concentration of CO_2 (ppm), considering CO_2 as a tracer for assessing the dilution of all chemical pollutants that may be present in the ambient: particulates, volatile organic compounds (VOC) and so forth.

This measurement allows us to obtain information on the manner in which the apartment is used and, especially, on the opening of the windows and the activation of the CMVs.

Measuring and Monitoring

The measurements can be carried out by means of technical equipment, probes, data loggers, microclimatic stations and so forth. Measurement can be of the spot type (in a single ambient) or distributed (in several ambients).

Monitoring consists in the activity of measurement for an extended period and may also involve a series of instruments and variables, arranged in multiple points of the ambient being studied. The characteristics of the "monitoring plan" or "monitoring campaign" may depend on several factors:

- the period and the duration;
- the number of points and rooms to be surveyed;
- the accuracy of the measuring instrument, compared to the measured variable;

- the cost and management of the devices, data recovery, including the procedures and continuity of access to the site and to the instrumentation. An "inexpensive" monitoring system (with a low cost and consequently less accuracy) may be accompanied by the need to have a great deal of data in a timely manner;
- on the downside, a very extensive evaluation can, in the case where many points are surveyed, risk a loss of accuracy of the measurement due to;
- the security of the installation against damage, theft, tampering, etc.;
- the data control and its retrieval, on site or remotely (online platforms).

Monitoring should be carried out with suitable instruments to continuously measure the thermohygrometric magnitudes. Monitoring is typically constituted of microdata collectors such as the data logger, today also available in the wireless version.

Carbon dioxide as an Indicator

The concentration of carbon dioxide (CO_2), measured in ppm or mg/m^3, constitutes the main indoor pollutant due to the presence of people, given that a greater concentration of persons corresponds to a greater concentration of CO_2. The health effects from an excessive concentration of CO_2 (greater than 1200–1500 ppm) may correspond to sensations of fatigue and headaches if the situation is prolonged over time, while the WHO (World Health Organization) and ASHRAE 62 indicate that the concentration that can lead to death is equivalent to 5000 ppm, condition which occurs very rarely in the indoor ambients of buildings. In spite of this, the evaluation of the concentration of CO_2 constitutes a useful indicator to characterise the indoor microclimate, current and historic, because it allows the description some of the ambient characteristics and of other pollutants introduced by people: particulates and water vapour (breath).

The cycle and the fluctuations of the concentration of CO_2 depend on the density of people and on the ventilation of the ambients. In the monitoring of CO_2, it is possible to check the fluctuations of CO_2 and correlate the difference to the presence of people, to the ventilation or to both phenomena. Procedures for the dilution of the concentration of CO_2 can be compared with the other two pollutants related to the presence of persons: water vapour and particulates.

In other words, carbon dioxide (CO_2) is an indicator of the IAQ that allows one to determine both the rate of pollution due to the presence of people, given that the CO_2 is mainly caused by human respiration, and the quality of the ventilation rate of the ambient. Moreover, it is also an indicator that is easily detected both from the instrumental point of view and, especially, from the perceptual point of view, in that a person perceives the air of an ambient as "stale" and, therefore, full of pollutants.

The use of CO_2 as an indicator of Indoor Air Quality is provided in the EN 15251 standard. It defines the criteria for the design of the indoor ambient and for the evaluation of the energy performance of buildings, in relation to the Indoor Air Quality, the thermal ambient, the lighting and acoustics. CO_2 is the indicator that the EN 15251 standard identifies where people are the main sources of pollution.

The Instrumentation Used for the Monitoring Campaign

The monitoring system of the Passive House was carried out with a series of probes positioned in the selected room and within a wall and horizontal roof slab. The monitoring system used is a Henesis Beesper Wireless Sensor Network (Beesper-WSN) system, consisting of:

probes or *sensors* for the measurement of the physical variables, in particular: air temperature, relative humidity, CO_2 concentration, luminance and contact temperature (with thermocouple);
Beesper nodes, with GPS sensor, which collect the data recorded by the probes and transmits them via Wi-Fi to the data collection bridge to the "*node*" where one or more probes are connected;
Beesper Bridge for the collection and processing of data from the "Beesper nodes" and transmission to the Web portal using the GPRS signal;
Web portal (*Beesper console*), with remote access, from which one can consult and download the monitoring data. It allows one to import the set-point conditions for the detection of the data.

In the specific case for the *Fiorita Passive House* were installed:

two Beesper nodes, with probes for measuring the data concerning the indoor microclimate, one positioned on the wall and the other on the ceiling; to these "*nodes*" are also connected some contact probes inserted within the wall and the ceiling slab;
two Beesper nodes, to which are connected the contact probes within the wall or the ceiling slab, positioned in the external side of the building.

The chains of the contact temperature thermocouple probes were placed during the construction phase of the walls and the ceiling slab.

The external probe, positioned in the roof, is powered by a photovoltaic panel that allows one to obtain information on the solar radiation and the external climatic data; *therefore, all the external climatic data refer to data measured directly* "in situ".

The arrangement of the chains of the probes was performed in the room at Level 3 of apartment no. 8 as specified below:

one chain of probes on the west wall, internal side;
one chain of probes on the west wall, external side;
one chain of probes through perforation of the roof slab on the north wall, external side.

The ends of the cables were sealed with tape to prevent air infiltration. All the cables have been marked with a label to identify them as "temperature probes". All the holes for the insertion of the probes were closed and sealed (Figs. 10.1, 10.2, 10.3, 10.4 and 10.5).

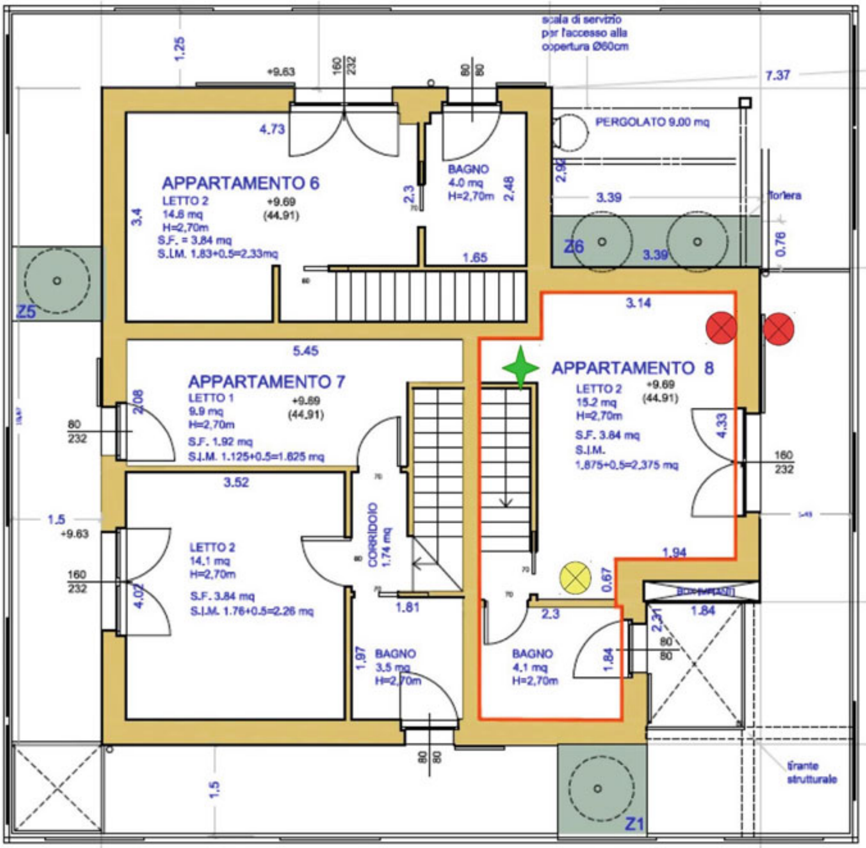


Fig. 10.1 Apartment 8: arrangement of chains of temperature probes (coloured circles). The yellow circle corresponds to the chain positioned in the roof. The green cross identifies the point in which the bridge will be installed, in correspondence with the electrical outlets available in the room. The red circle corresponds to the contact temperatures

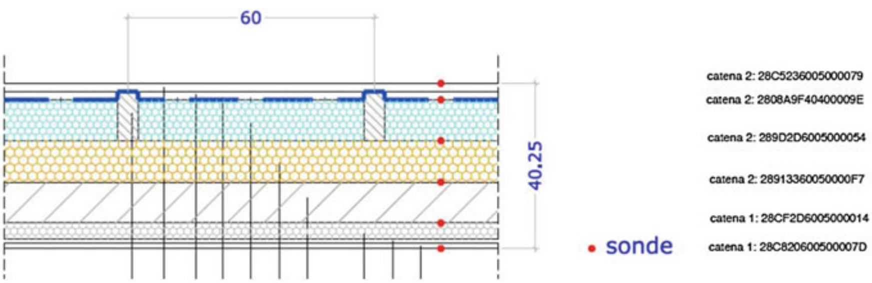


Fig. 10.2 Arrangement of the contact temperature probes (red circles) within the layers of the wall with western exposure (apartment 8)

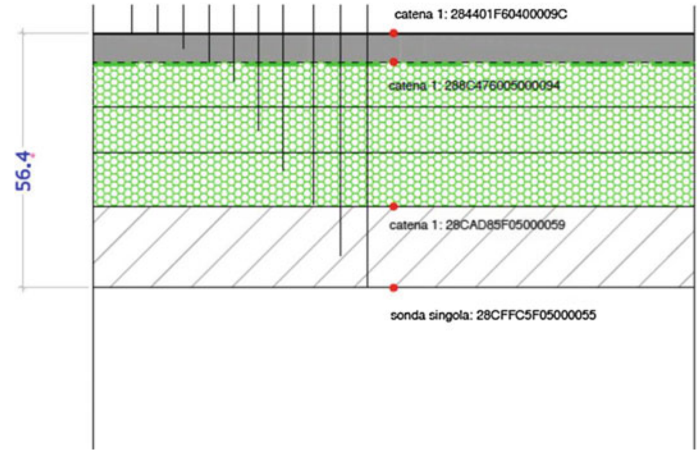


Fig. 10.3 Arrangement of the contact temperature probes within the roof slab layers (apartment 8)

Fig. 10.4 Installation of the wall probe, detail of the contact probes

10.2 Results of the Monitoring Campaign

The results of the monitoring campaign confirm most of the forecasts of the project, such as, for example, the dynamic behaviour of the building envelope, roof and wall, which allow one to obtain an optimum phase displacement; the same applies for the building's indoor thermal comfort: the indoor temperature always remains within the

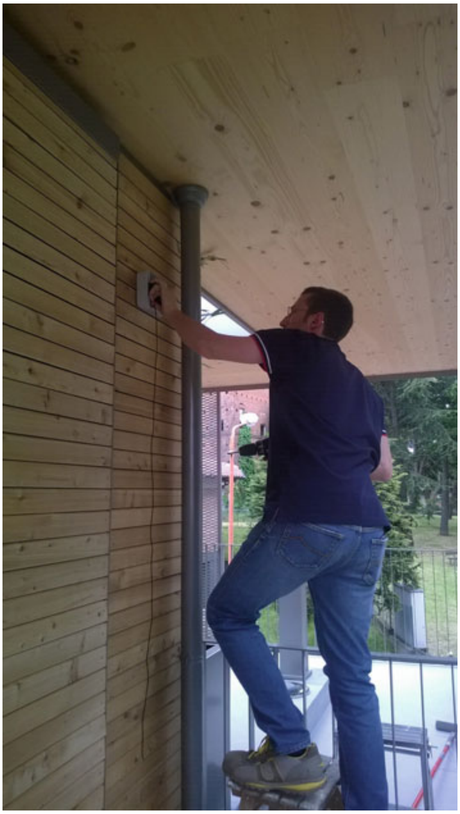


Fig. 10.5 Installation of the wall probe

comfort range of air temperatures and relative humidity, i.e. 20 °C (±2 °C) in the winter season and 26 °C (±2 °C) in the summer season, and with 45–65% relative humidity.

The most surprising data concern the concentration of indoor CO_2, which shows different results than those expected: there has been a greater indoor concentration of CO_2 compared to the outside, with peaks of concentration in some periods of the year, perhaps due to the way in which the ambient was used, as regards to both the natural ventilation (the opening of windows) and the CMV system. This aspect is not negative; i.e., the IAQ of the *Fiorita Passive House* is always good and there are never critical or chronic conditions, but the results show some aspects linked to ventilation and airtightness, and to the habit of the occupants which it is necessary for us to take account of, both in our professional activity and in the context of scientific research.

We have discussed this aspect with the designer, also regarding the opportunity of making the fact clear that, in the opinion of the author, some of the data are not different from what "common sense" expects them to be, simply confirming how important good design is in this case, as well as the intellectual honesty of those involved; in other words, if everything were perfect, it probably would not be *scientific or precise, and it might turn out to be—probably—something false that is not supported by the actual data.*

Added to this is the fact that there were errors in the balancing of the MVHR system in the first phase of activation, with the entrance of the new tenants, the anomalies were also due to this malfunction.

Below are the graphs of the monitoring campaign with the relative considerations and observations.

Indoor Microclimate and Thermal Comfort

The perception of indoor thermal comfort depends on several variables—air temperature, mean radiant temperature, wind speed and relative humidity; among these, the indoor air temperature and indoor relative humidity are those which can be controlled directly by the users through the set-point of the HVAC systems and the opening of windows. The monitoring system allows us to study the relationship between the measured indoor and outdoor data, so as to be able to evaluate the dynamic behaviour of the building and the air inside the ambient; in reference to the calculation procedure of the energy performance, this behaviour is called "*Building time constant*" (ISO 13790) and depends on the "*internal heat capacity of the building zone*" and on the "*heat transfer coefficient*" by transmission and by ventilation. In essence, the greater the Building time constant, the more time it takes for the indoor air temperature to become equal to the outdoor one. In our case, indoor monitoring allows one to check the relationship between the indoor and outdoor temperatures.

The minimum and maximum *outdoor* temperature during the monitoring campaign, was—2.76 °C registered on 19 December 2016 and +39.09 °C registered on 12 July 2016, while the minimum indoor temperature was 17.50 °C (in the absence of occupants) and 27.86 °C (Fig. 10.6).

The difference between the outdoor and indoor air temperature, and the average value is equivalent to −6.79 °C; that is, on average, there is an approximately ±6–7 °C difference between the indoor and outdoor temperature; therefore, if outside it is 30 °C, the indoor temperature is approximately 24 °C (about 6 °C lower) and if outside it is 12 °C, the internal temperature is approximately 18 °C, although in both cases it is necessary to take into account the possible activation of the HVAC system. The interesting aspect is that the greater the difference encountered during the winter season allows us to assume that the indoor temperature is ensured by the "*continuous*" activation of the heating system, while in summer the "*continuous*" activation is not always necessary (Figs. 10.7, 10.8 and 10.9).

The minimum and maximum outdoor relative humidity during the monitoring campaign were 21% registered on 17 July 2016 and 95–100% registered in several days of rain or fog, while the minimum indoor relative humidity was 19% in the month of January, probably in the period of the absence of the inhabitants (holiday), and the maximum relative humidity recorded was 76%.

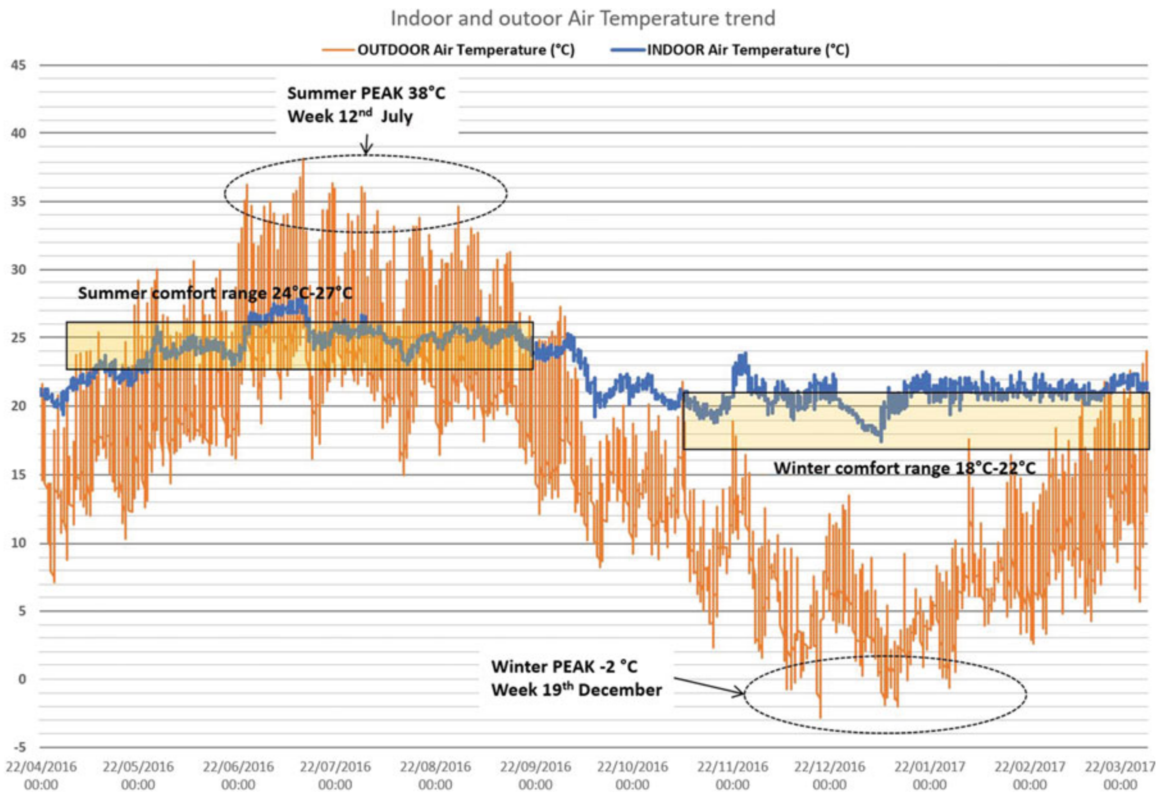


Fig. 10.6 All-year outdoor and indoor air temperature trend, with the comfort range in the winter and in the summer and the weeks with the maximum and minimum values

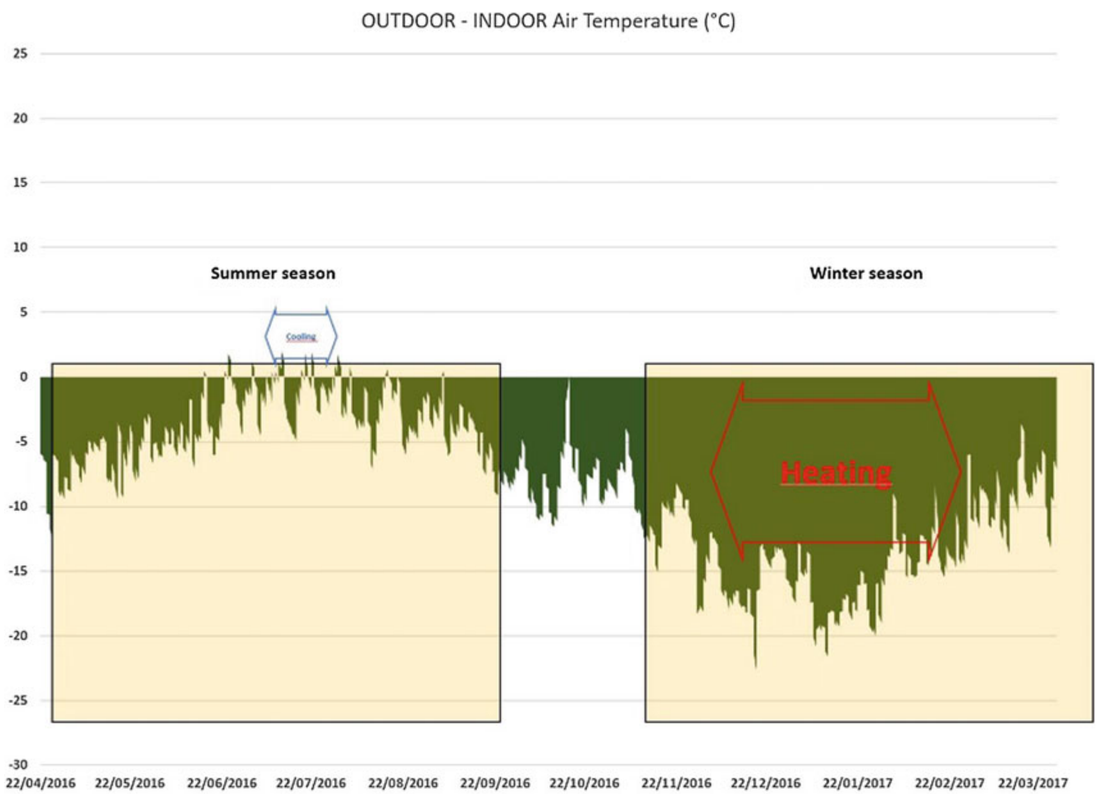


Fig. 10.7 Trend of the difference between the outdoor and indoor air temperature (outdoor minus indoor), with the identification of the possible activation period of the HVAC systems

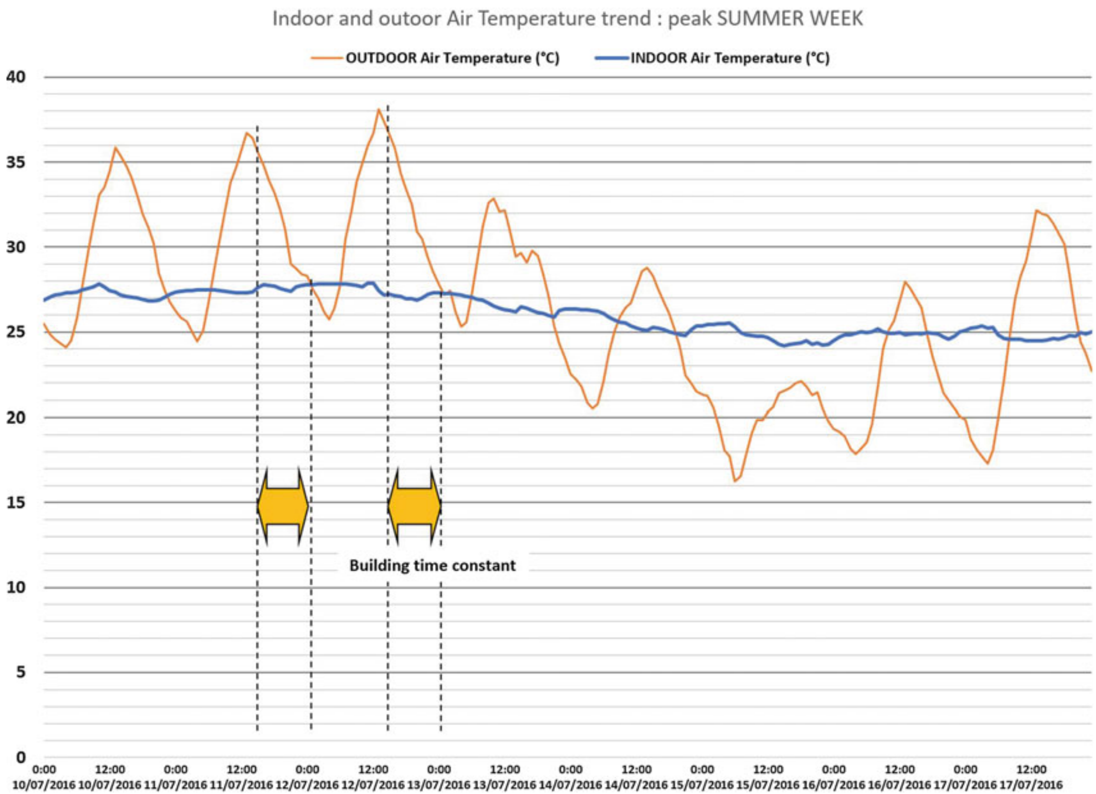


Fig. 10.8 Trend of the hottest summer week (10–18 July 2016) of the indoor and outdoor air temperature. You can note that the indoor temperature always remains in the 26 °C ± 2 °C range with a temporal thermal lag compared to the peak outdoor temperature

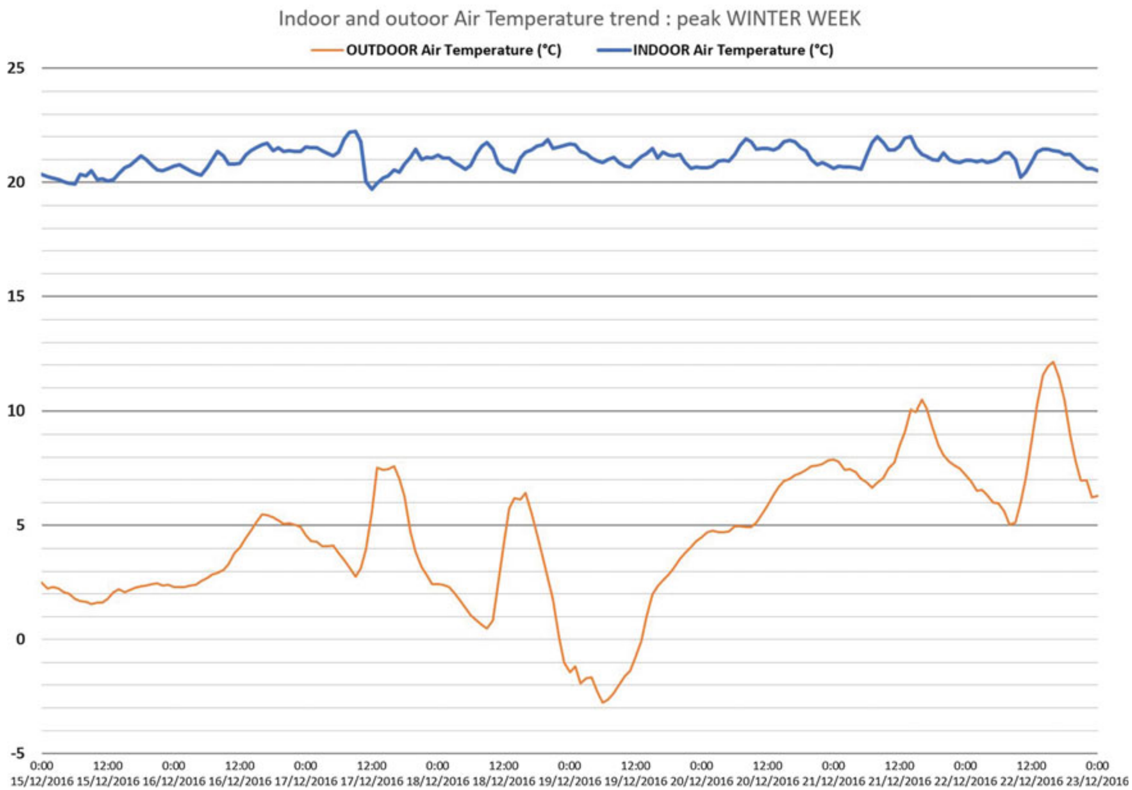


Fig. 10.9 Trend of the coldest winter week (15–23 December 2016) of the indoor and outdoor air temperatures. You can note that the indoor temperature always remains in the 20 °C ± 2 °C range. Given the difference, it can be assumed that the HVAC system is turned on

The relation between indoor and outdoor relative humidity depends both on the respective air temperatures and on the mode of use of the ambient, as regards the generation of water vapour (in this case, the bathroom, i.e. in communication with the room where the probes are placed), and on the manual opening of the windows, as well as on the activation of the CMV system. In substance, from the monitoring it is not possible to identify a univocal relationship between the conditions of indoor relative humidity and the causes which determine the value. Considering the comfort range for the relative humidity between 45 and 65%, it turns out that for most of the year (71%), the value is in the RH wellness range and for 27% of the time the air is "dry", especially during the winter period, while for the remaining 2% of the time the air is "humid", greater than 65% in some days of the summer and autumn. There is no direct or evident correlation between the indoor and outdoor value, demonstrating that the outdoor value is not the only variable, while it can be assumed that during the winter, due to the shorter time of manual opening of the windows, the indoor relative humidity is linked to the ventilation rate of the CMV system (Figs. 10.10, 10.11 and 10.12).

The last processing of the data relating to indoor thermal comfort concerns the relationship between the microclimate data and the comfort parameters. We consider the comfort range comprising, in the winter season, between 40 and 60% RH and air temperatures of 18–22 °C, and in the summer season between 45 and 65% RH and air temperatures of 24–28 °C. The monitoring data show that, in the majority of the year, the measured data fall within the comfort range. During the winter period, there are a few points of time in which air is "dry", with a reduced humidity rate. We can assume that it coincides with when people are absent, i.e. when there is no source of water vapour (respiration, shower use, etc.). The summer season is more stable and less dependent on the presence of persons or on the operation of the systems.

The comparison between the indoor and outdoor air temperatures and relative humidity data shows that the indoor microclimate is much more stable and always comprised in the 18–28 °C range and with a moisture content of less than 75%; i.e., there is no risk of indoor condensation. Moreover, the variation of the outdoor climatic conditions does not affect the indoor microclimate, the fact that confirms, once again, how the RH value is not directly related to the outdoor climate and how the indoor air temperature is guaranteed by the *Building time constant* and by the activation of the HVAC systems (Figs. 10.13 and 10.14).

Wall and Roof Phase Displacement: Contact Temperatures

The installation of the "*contact probes*" inside the walls and roof allows us to evaluate a parameter that is difficult to assess, even when calculated according to the specifications: the phase displacement, i.e. the dynamic behaviour of the building envelope.

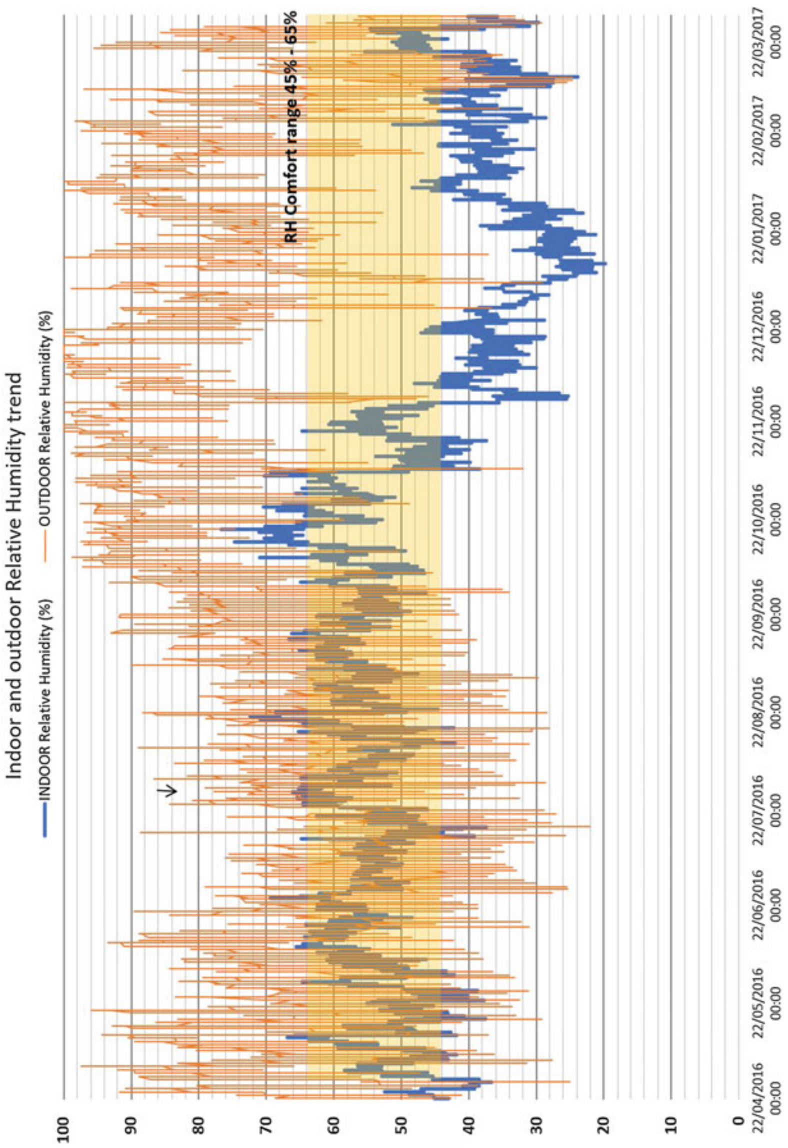


Fig. 10.10 All-year trend of outdoor and indoor relative humidity (RH), with the comfort range identified between 45 and 65% RH

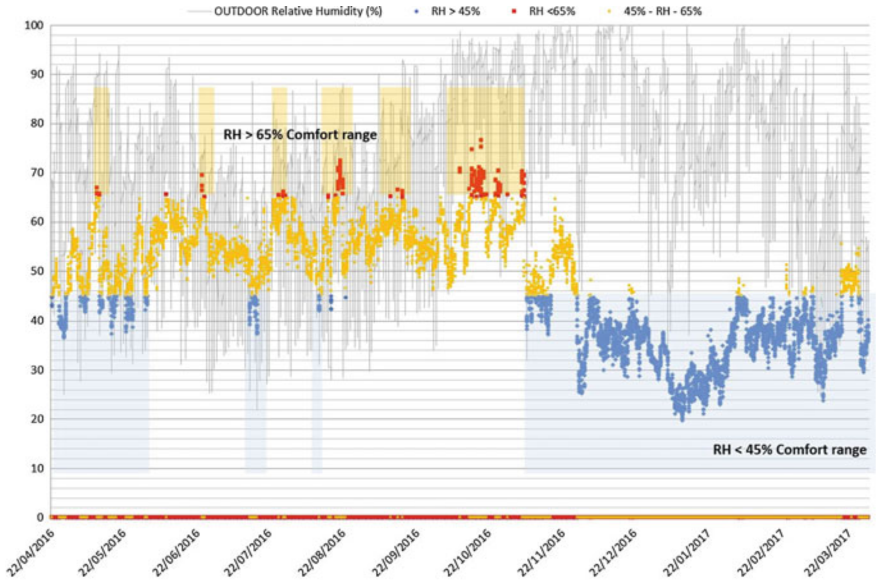
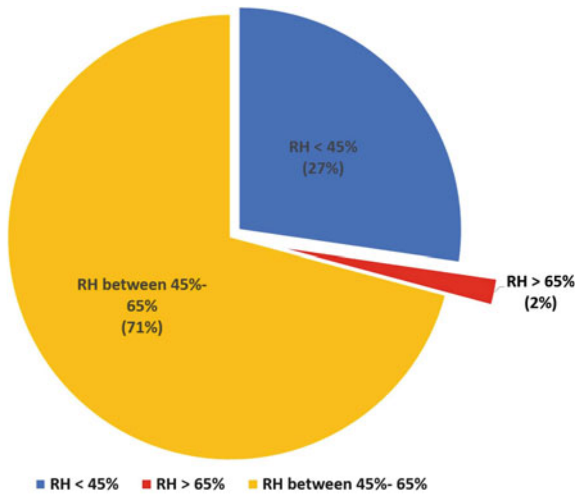


Fig. 10.11 All-year trend of indoor relative humidity (RH), with highlighting of the hours in which the values are lower than 45%, higher than 65% and in the comfort range of 45–65%. The chart also shows the trend of the outdoor RH; as is apparent, there is a direct relationship between the different variables, while it appears that the indoor air during the winter period is "*drier*"

Fig. 10.12 Breakdown by percentage of the hours of indoor relative humidity (RH), showing where the values are lower than 45%, greater than 65% and comprised in the 45–65% range. The percentages are given as the sum of the hours in which the value is comprised between the different thresholds, compared to the hours/year of the monitoring campaign



The contact probes allow one to evaluate the trend, on a daily, monthly and annual basis, of the temperatures inside the building envelope, with actual, true measured data and not only based on the results of the calculation or the "sense" of the designers, and the results confirm the effectiveness of the choices.

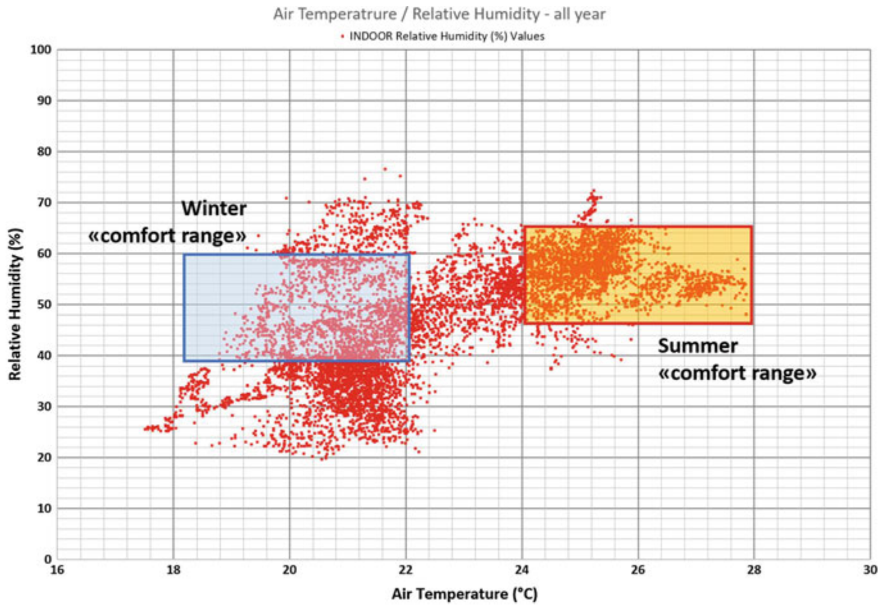


Fig. 10.13 Indoor air temperature/relative humidity chart

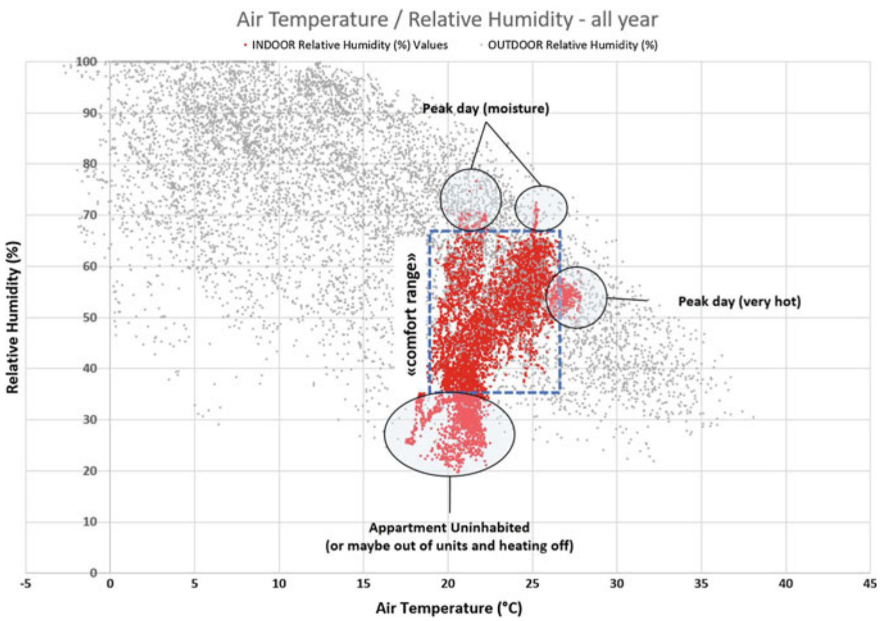


Fig. 10.14 Indoor and outdoor air temperature/relative humidity chart

The all-year trend of the temperatures, both that of the air and that of contact, indoor and outdoor for the vertical wall and the horizontal roof, shows a wide daily excursion of the outdoor temperature, in particular in the summer, where, on the roof, the daily thermal excursion of the outdoor contact temperature in (ΔT_{out} in °C) reaches as much as 30 °C. The results show how important the role of solar radiation is. The indoor temperature, both of the ambient and of contact, remains in the ±2 °C range of the winter comfort (20 °C) and summer comfort (26 °C) values.

In regard to the trend of the internal contact temperatures, it is evident that during the winter season, there is a greater difference of surface temperatures between the individual layers, while in the summer season this difference is not evident. This is due to the heat exchange which occurs between the inside and the outside through conduction during the winter season when the heat flow traverses the structure from the inside towards the outside due to the difference in temperature. *In this case, the effect of the solar radiation and therefore the heat flow from the outside towards the inside is lesser* (Figs. 10.15 and 10.16).

The all-year trend of the temperatures of the individual layers does not allow one to clearly understand what happens inside the wall; to have more useful data, it is better to refer to a shorter period, consisting of two days. The ISO 13786 standard provides the calculation referred to a period of 24 h, but from the measured data, and given the characteristics of the building envelope, it is necessary to extrapolate the monitored data relating to a period of 48 h.

From a comparison between two days that are representative for each season (April, July, October, January), it may be noted that, compared to the peak outdoor temperature, the indoor temperature and that of the inward layers remain constant; this demonstrates the effectiveness of the stratigraphy and of the materials used for the thermal lag of the thermal wave. The data are confirmed for both the vertical walls for the horizontal roof slab. The indoor values in the months of October and January are influenced by the operation of the heating system and by internal sources of heat, and this also confirms the role of the thermal insulation.

As regards the roof slab, it should be noted that the outdoor air temperature and contact temperatures, both linked to solar radiation, have a greater variability, despite the fact that a horizontal plane is involved, and thus always subject to solar radiation. This is due to the fact that the direct solar radiation that strikes the roof depends on the local weather conditions, such as the presence of clouds, overcast skies, whereas with regard to the vertical wall, the direct solar component is smaller, and it also depends on diffused solar radiation (Figs. 10.17 and 10.18).

For a better understanding of the trend of the temperatures in the individual layers, it is necessary to refer to the two days of the most representative month as regards the phase displacement: July.

If one observes the results of the monitoring of the external wall, and by analysing the variation of the contact temperatures of each single layer, it can be noted that between the outdoor peak ambient temperature (31 °C) and the indoor one (25 °C), the time interval is equivalent to about 24–26 h, from 8:00 in the morning on 23 July to 9:00–10:00 of the next day (even if the indoor temperature remains

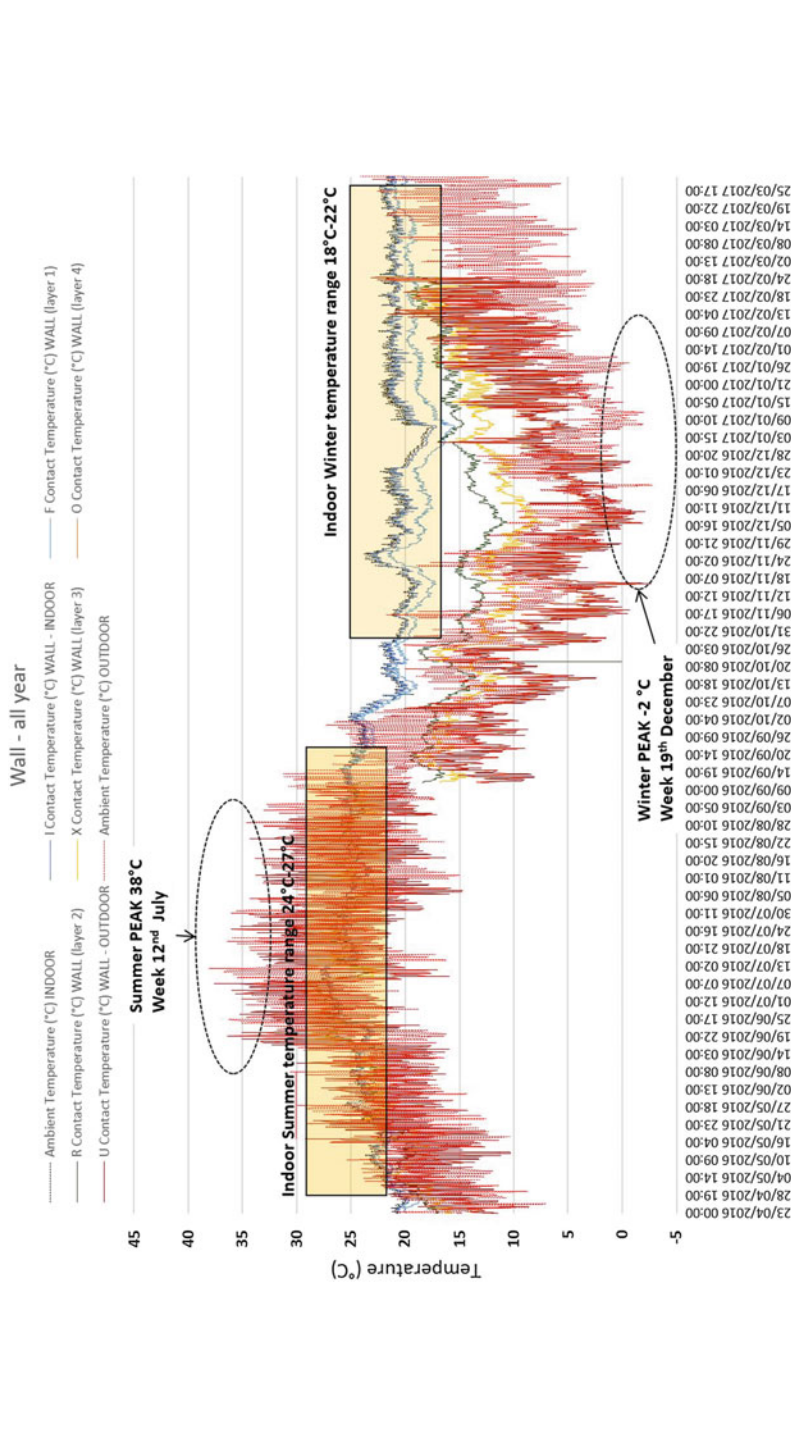


Fig. 10.15 All-year trend of the contact temperature for each layer of the vertical wall: on the right, we can see that the lines of the individual layers during the winter period differ from one another

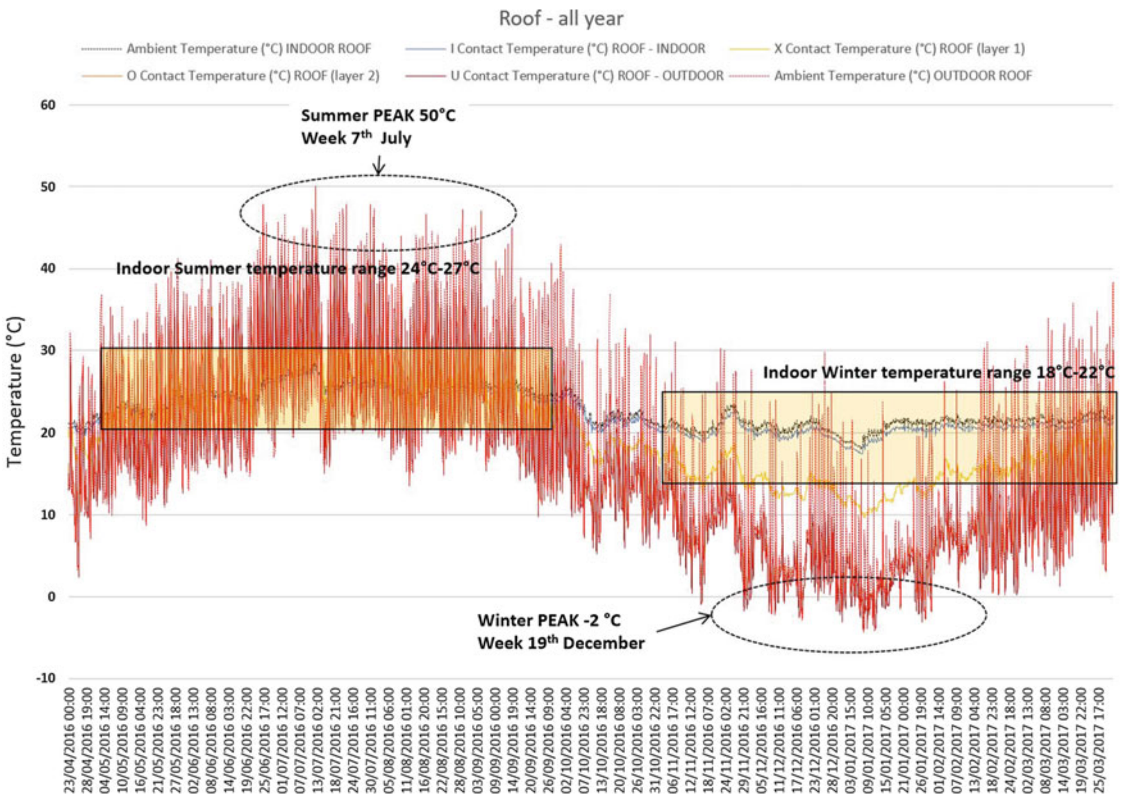


Fig. 10.16 All-year trend of the contact temperature for each layer of the vertical cladding. At the left, note that the temperature peaks reach temperatures higher than 45 °C in the summer, while on the right the difference is evident between the temperature of the outermost layer (yellow) compared to the innermost layers

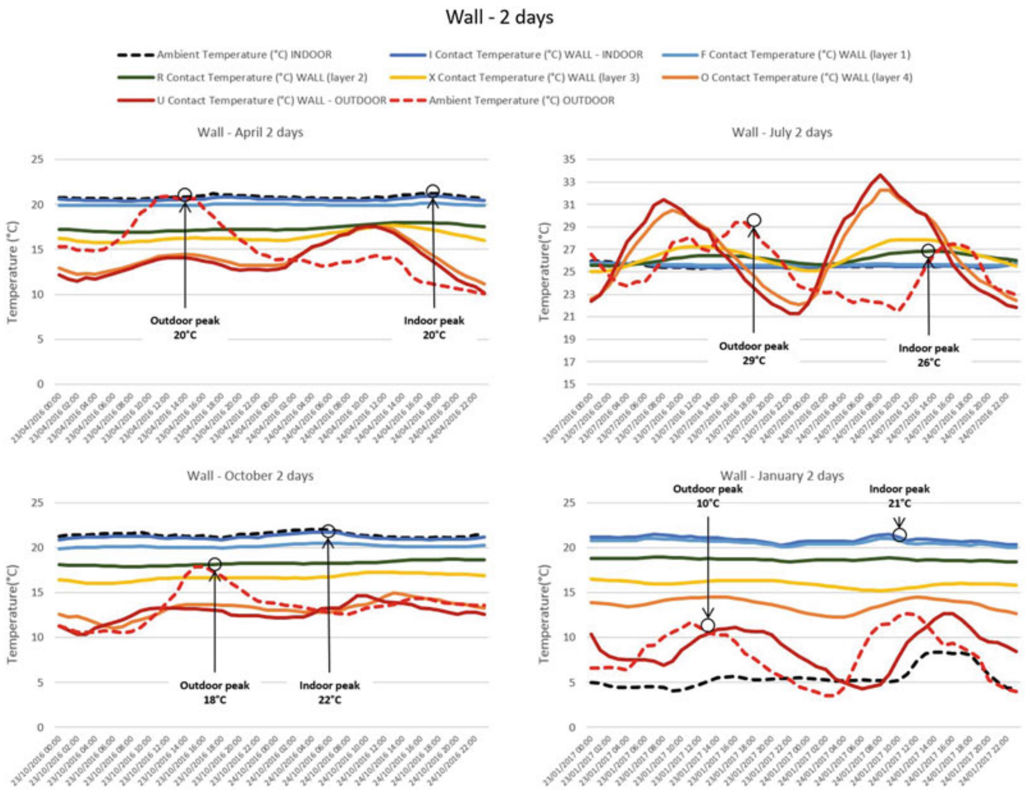


Fig. 10.17 Trend of contact temperatures of the external wall clad in wood for two days for the months of April, June, October and January. The sequence of the charts shows that the indoor temperatures remain almost constant, while the outdoor surface temperature varies, depending on the incident solar radiation. In particular, it can be noticed that in January the solar radiation has no influence on the indoor temperature, while in July it is attenuated thanks to the phase displacement

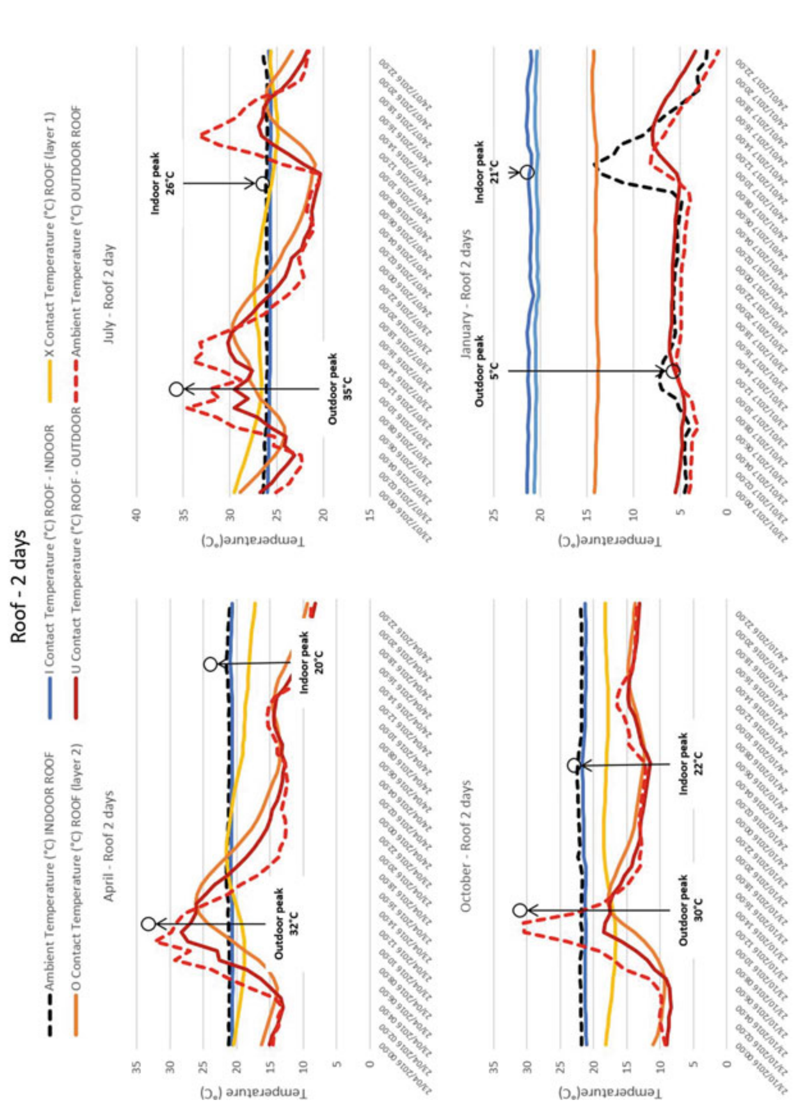


Fig. 10.18 Trend of the contact temperatures of the roof for two days for the months of April, June, October and January. The observations are similar to those of the previous chart

constant). Much more interesting is to observe how and with what "speed" the thermal flow traverses the structure:

in the face of the 31 °C of the outdoor ambient, the peak surface contact temperature is equivalent to about 30 °C already in the successive hour and the difference is due to the convective phenomena, the colour of the wall and, probably, the presence of shade.
the peak temperature of layer 1 (wood fibre), equivalent to about 27 °C, is reached at 12:00, after approximately 4 h, while the peak temperature of the next layer (fibreglass), equivalent to about 26.5 °C, is reached at 14:00, after approximately 6 h.
the two successive layers, i.e. the surface temperature at the intrados and extrados of the layer in CLT, have temperatures that are equivalent to about 25.5 °C, that is, similar to the surface contact temperature and to that of the ambient, which is about 25 °C, and this temperature is reached in the early hours of the morning of the following day.
the indoor temperature, both of the ambient and contact, also depends on other factors linked to the air volume, to the ventilation of the ambient, to the possible activation of the CMV systems in the summer.

The same sequence in the variation of the contact temperatures of the individual layers can also be observed in the case of the roof, where the peak temperature is higher (approximately 35 °C) at 14:00, corresponding to a peak indoor temperature in the early hours of the morning of the following day, about 16–18 h later. In this case, the phase displacement has a shorter duration, because the solar radiation and, therefore, both the heat flow and the outdoor contact temperature are greater (Figs. 10.19 and 10.20).

Indoor Air Quality and Carbon dioxide Concentration

The results of the monitoring campaign, relating to the measurement of the amount of CO_2 (ppm), allow us to make some observations about the Indoor Air Quality (IAQ) of the *Fiorita Passive House*, in regard to the relationship between the energy efficient and low-energy-oriented design and the healthiness of the ambients. As has already been mentioned, the choices aimed at reducing the thermal exchanges for ventilation involve the adoption of specific solutions, in particular a high airtightness of the building, and the adoption of controlled mechanical ventilation.

These design solutions are deemed to be default solutions and mandatory, if addressed from the energetic point of view, but are they also mandatory as regards the IAQ?
The results of the monitoring campaign help to confirm the validity of these solutions, but, at the same time, they focus some attention on various aspects.

The analysis of the all-year trend in the amount of CO_2 (ppm), indoor and outdoor, compared with the all-year trend of indoor relative humidity (%) and indoor air temperatures (°C), shows that there is a direct correlation between the

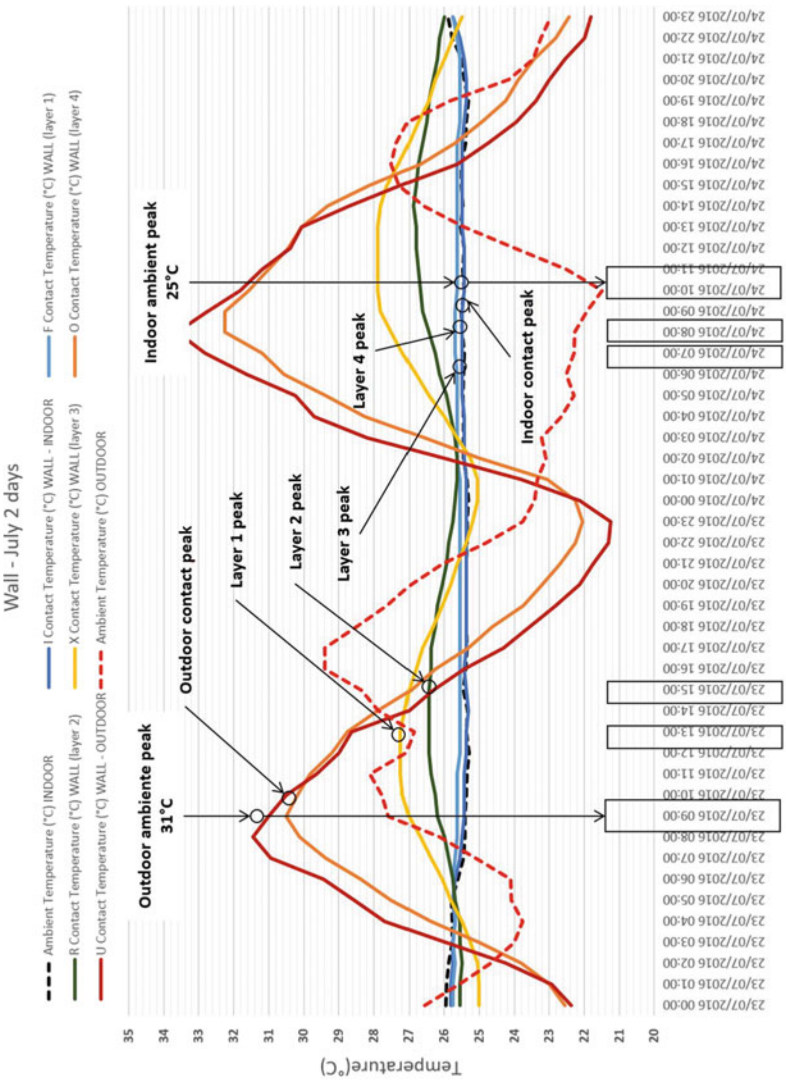


Fig. 10.19 Trend of the contact temperatures of the vertical wall in the days of 23rd and 24th July 2016

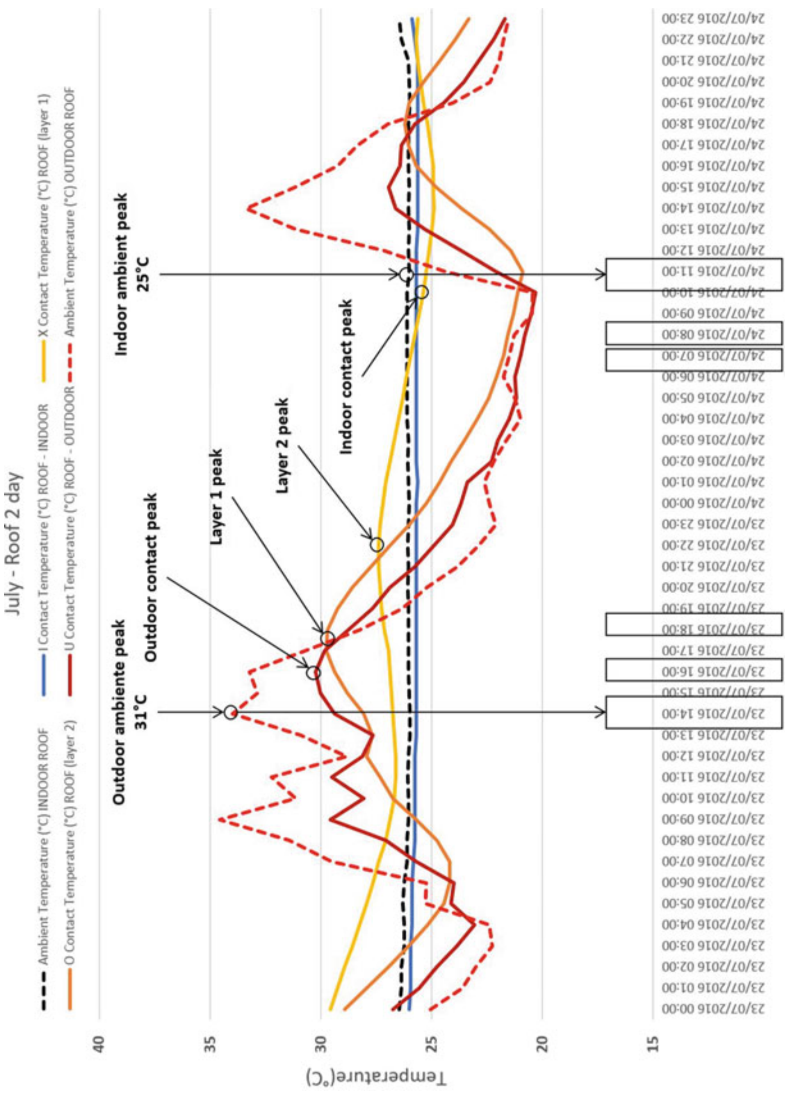


Fig. 10.20 Trend of the contact temperatures of the horizontal roof in the days of 23rd and 24th July 2016

physical variables, air temperature and RH, and the amount of CO_2. In the same way, there does not seem to be a strong direct correlation between the amount of indoor and outdoor CO_2. The clearest result is that there are periods in which the amount of indoor CO_2 is *medium* (December–March), *high* (April–June) and *very high* (September–November) and the only moment in which the quantity of indoor CO_2 is equal to the outdoor quantity is when the inhabitants are absent (during holidays) (Fig. 10.21).

The most detailed analysis of a week in which the v high indoor concentration CO_2 is found (September 2016) shows that the greater concentration of CO_2 occurred during the night time, when the polluting sources (2 persons) are present, the windows are closed because the outdoor temperature is about 15 °C, and the CMV does not ensure the correct flow rate of air ventilation (m^3/h); in fact, in the morning (8:00) upon waking up, it is assumed that the window is opened to ventilate the ambient and the amount of CO_2 passes rapidly from about 2000 ppm to about 500 ppm, a value that remains for the entire day until 21:00. The quantity of outdoor CO_2 does not affect the quantity of indoor CO_2.

The absence of a direct correlation between the quantities of CO_2 is confirmed by the indoor and outdoor X/Y chart, where it is clear that indoor CO_2 values increase even if the outdoor ones do not vary (Figs. 10.22 and 10.23).

The monitoring data reported an annual average concentration of CO_2 equivalent to 660 ppm, with minimum CO_2 values equivalent to 200 ppm and maximum CO_2 values equivalent to 2371 ppm.

The ASHRAE 62 reports as a concentration value harmful to health a CO_2 concentration equivalent to 5000 ppm; thus, in our case, there are never any situations which can be harmful to health, but in some hours, the airtightness of the building is linked to the lack of natural ventilation (opening of windows, air leakage, etc.) and the excess of generation of CO_2 by people compared to the ventilation rates of the controlled mechanical ventilation (CMV) brings about periods in which the concentration of CO_2 is greater than 800 ppm. Through the monitoring, it is not possible to attribute the concentration peaks to one of three factors: airtightness, CMV or the generation of CO_2; in order to be able to evaluate these aspects, laboratory analysis on buildings would be necessary, where it would be possible to isolate the single element, for example a building without CMV and airtightness or vice versa.

The analysis of the distribution of the indoor concentration of CO_2 (histogram) shows that the indoor concentration is comprised between 200 and 740 ppm during most of the year and that it is above 800 ppm for only about 20% of the entire period; thus, the condition of Indoor Air Quality (IAQ) of the Passive House is, generally, in Category I.

The comparison between the indoor and outdoor concentration of CO_2 shows that the indoor condition has a greater variability of the values; in fact, the quantity of outdoor CO_2 is, in most cases, between 340 and 500 ppm and the quantity of indoor CO_2 varies between 400 and 520 ppm and between 520 and 1000 ppm.

To confirm this, it is useful to refer to the EN 15251 standard that defines the IAQ Category reported in Table 10.1; the categories refer to the concentration of

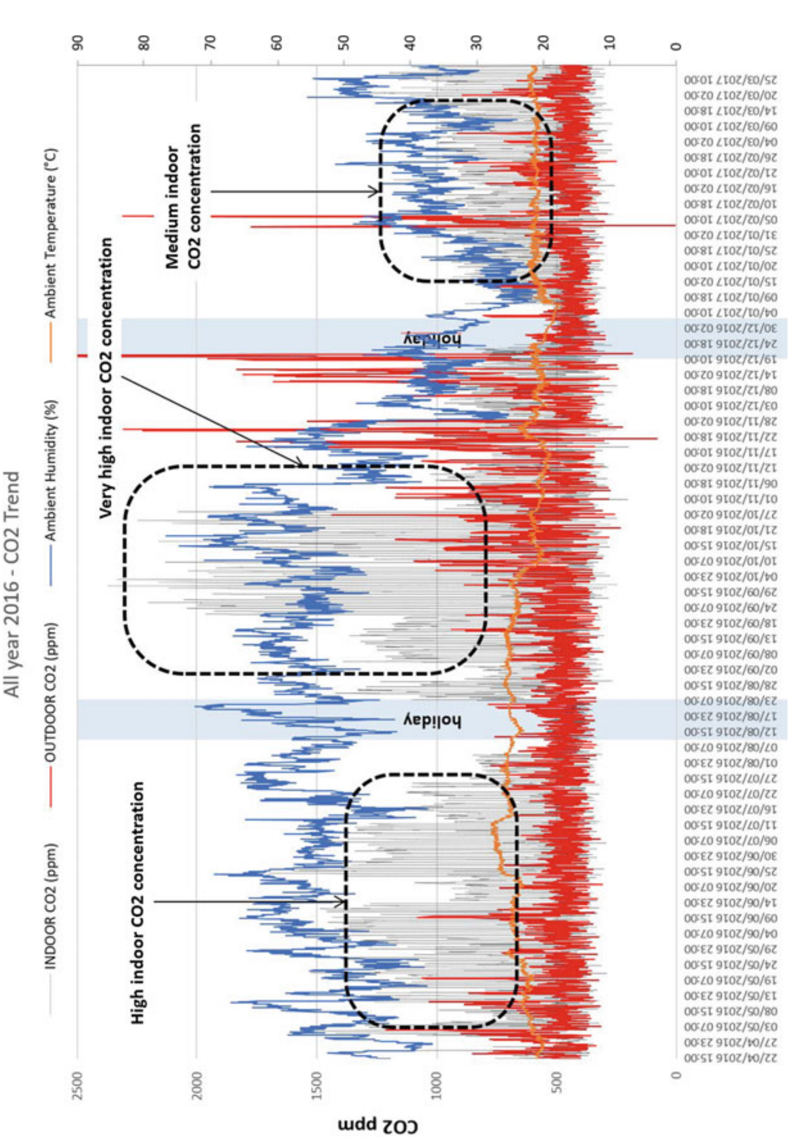


Fig. 10.21 All-year trend of the indoor air temperature (°C), relative humidity (%) indoor and outdoor quantity of CO_2 (ppm)

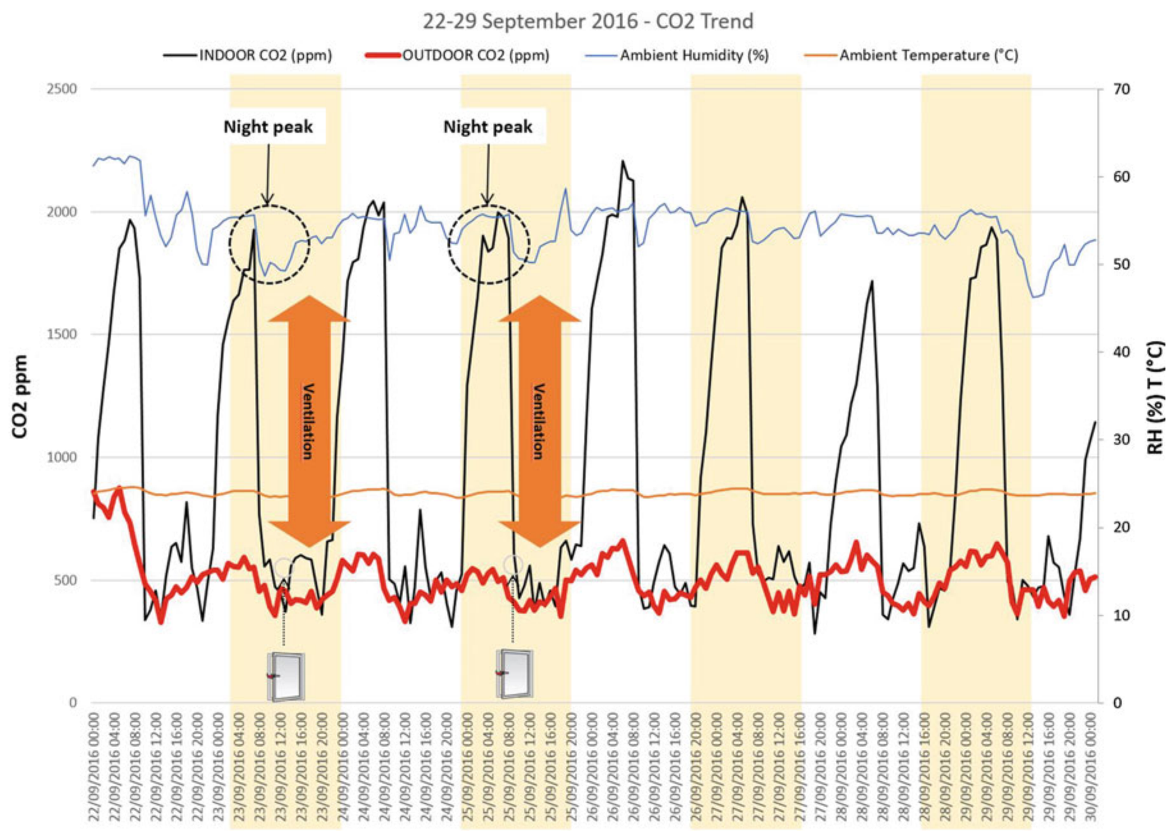


Fig. 10.22 One week in September: trend of the indoor air temperature (°C), relative humidity (%) indoor and outdoor quantity of CO_2 (ppm)

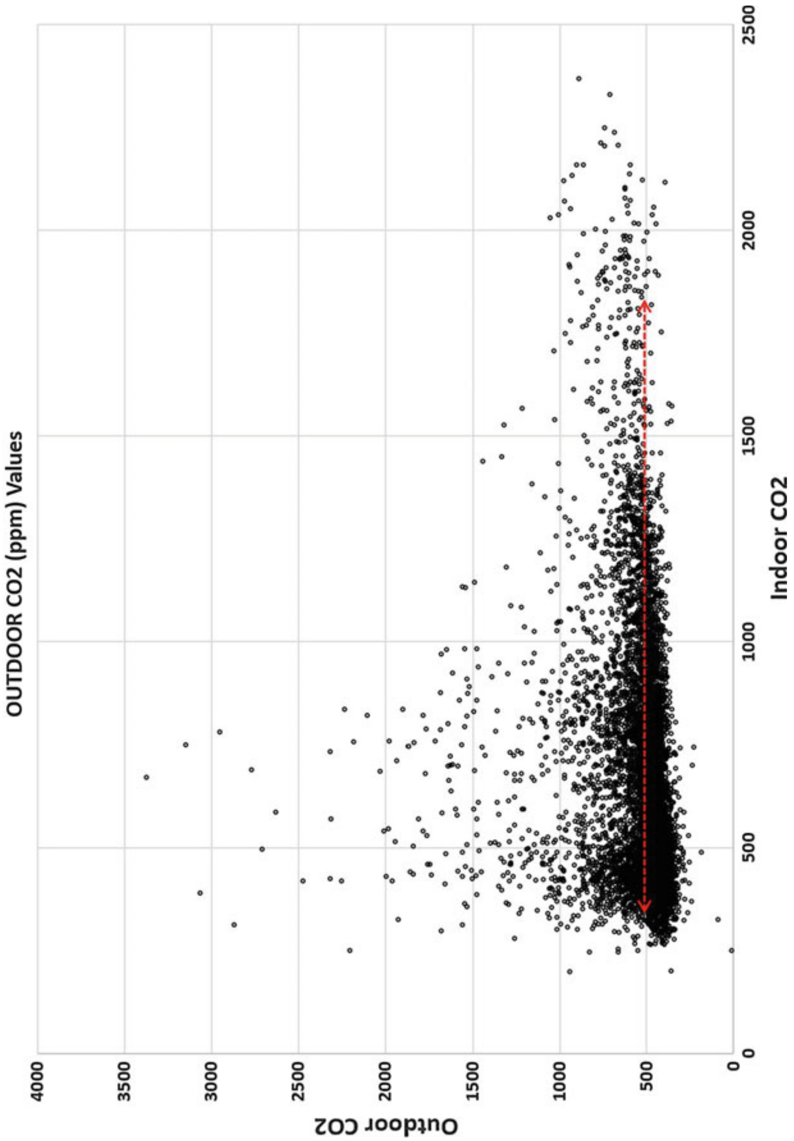


Fig. 10.23 X/Y indoor and outdoor quantity of CO_2 (all-year) chart

Table 10.1 Example of recommended CO_2 concentrations above outdoor concentration for energy calculation and demand control

Category	Corresponding CO_2 above outdoor concentration in *ppm* for energy calculations	Indoor Air Quality (IDA)	Description following EN 13799
I	350	IDA 1	High Indoor Air Quality
II	500	IDA 2	Medium Indoor Air Quality
III	800	IDA 3	Moderate Indoor Air Quality
IV	<800	IDA 4	Low Indoor Air Quality

CO_2 above the corresponding outdoor value. The same categories are given in EN 13799. The results of the monitoring report that for 80% of the hours/year, the IAQ of the *Fiorita Passive House* falls into Category I (IDA 1—high Indoor Air Quality) while for 16.5% of time it falls within Category II or III and for 3.6% in Category IV, aspect that—as has been said—can be linked to the lack of natural ventilation or incorrect functioning of the CMV (Figs. 10.24, 10.25 and 10.26).

The results of the monitoring, as regards the periods and the hours during which the IAQ is in categories IDA III and IDA IV, pose some questions to which we shall attempt to answer.

The first relates to the design of the CMV system: *Is the ventilation rate (m^3/h) of the CMV sized correctly?*

The second is whether for the ambient, the volume is too small compared to the CO_2 rate emitted by the people, and lastly, if the excess concentration can be attributed to the airtightness of the building.

To answer these questions, we must refer to the regulations that define the design criteria for the ventilation of the buildings, the *EN 13799 Standard*, *ASHRAE 62* and the *Standard Guide ASTM D6245* which uses the indoor carbon dioxide concentration to evaluate the IAQ and ventilation of the ambients.

The Standard Guide ASTM D6245 provides the criterion for calculation of the *Indicator of Body Odour Acceptability* in relation to the content of CO_2, in ppm, present in an ambient, and the Percent Dissatisfied (PD) index is given by the following formula:

$$PD = 395 \cdot e^{-15.15 \cdot CO_2\ (ppm)^{-0.25}} \quad (\%) \tag{10.1}$$

By applying this formula to the monitoring of the *Fiorita Passive House*, one obtains an average PD index = 19.19%, with a minimum PD value of = 7.05% and maximum PD = 45.50%; specifically, the inhabitants of the apartment are two; therefore, there are some days in which at least one "*complains*" about the IAQ and,

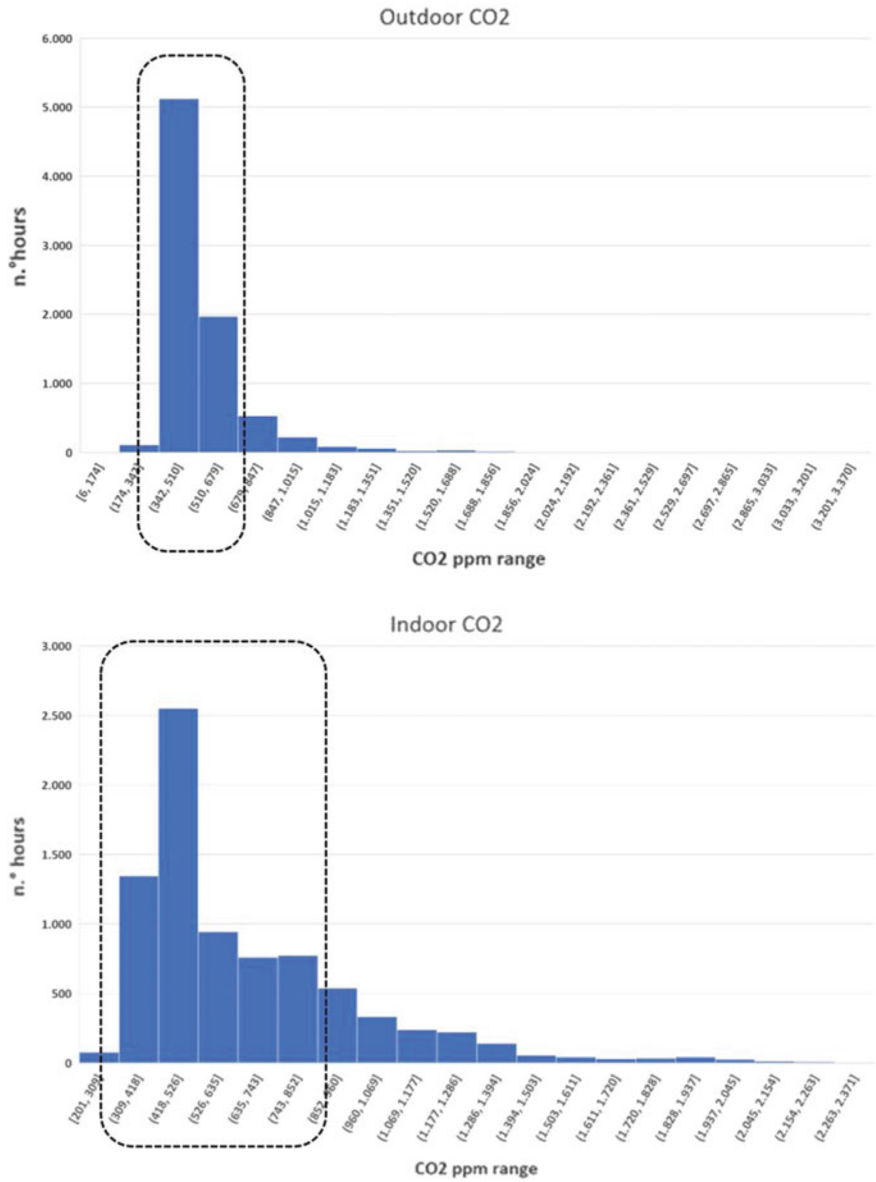


Fig. 10.24 Histograms of outdoor distribution (above) and indoor distribution (below) of the quantity of CO_2

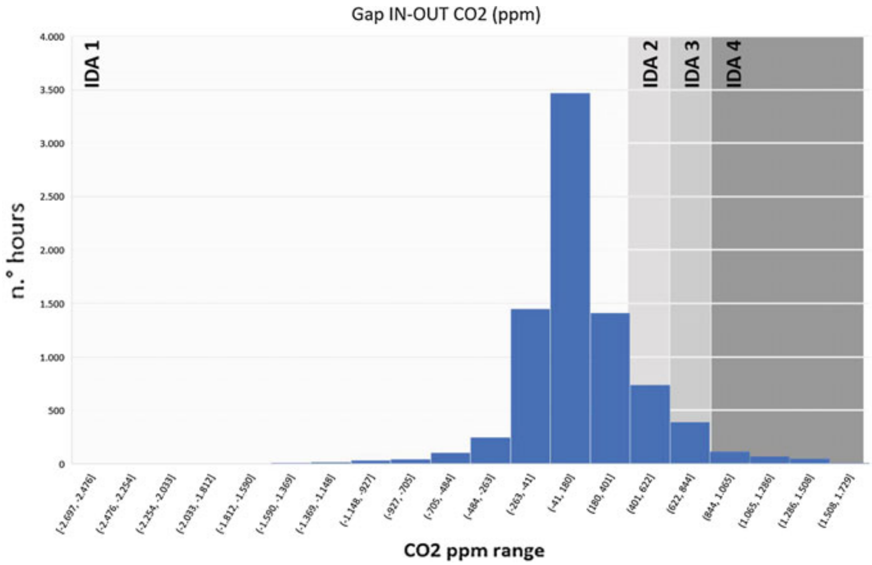
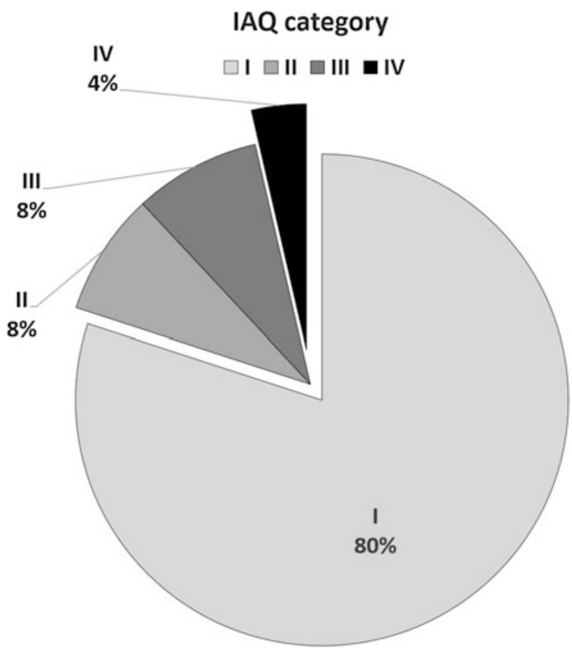


Fig. 10.25 Histogram of the difference between indoor and outdoor distribution of the quantity of CO_2 with highlighted the IDA (Indoor Air Quality) categories

Fig. 10.26 Distribution of the IDA (Indoor Air Quality) categories all year



probably, as previously mentioned, this condition occurs during the night and in some specific days.

Standard Guide ASTM D6245—Ventilation Rate Using Equilibrium CO_2 Analysis

The concentration of the indoor CO_2 is equilibrium between the amount of CO_2 coming from the outside and that, which is generated by persons within the ambient, the calculation of the Outdoor airflow rate (Q_0) can be referred:

to the thermal zone, the following formula is used:

$$Q_0 = 10^6 \cdot \frac{G}{C_{\text{in,eq}} - C_{\text{out}}} \quad (\text{L/s}) \tag{10.2}$$

to the single person, the following formula is used:

$$Q_{\text{p}} = 10^6 \cdot \frac{G_{\text{p}}}{C_{\text{in,eq}} - C_{\text{out}}} \quad (\text{L/s}) \tag{10.3}$$

where

Q_0 outdoor airflow rate into the zone (L/s)
G CO_2 generation rate in the zone (L/s)
$C_{\text{in,eq}}$ equilibrium CO_2 concentration in the zone, ppm
C_{out} outdoor CO_2 concentration, ppm (v)
Q_{p} outdoor airflow rate per person into the zone, (L/s) per person
G_{p} CO_2 generation rate in the zone per person, (L/s) per person

The quantity of CO_2 generation rate in the zone (in L/s) in our specific case is produced exclusively by the two people who inhabit the apartment. The ASTM Standard provides the criterion for calculating the amount of CO_2 generated by human metabolism (CO_2 generation rates) with the equation:

$$V_{\text{O}_2} = \frac{0.00276 \cdot A_{\text{D}} \cdot M}{(0.23 \cdot \text{RQ} + 0.77)} \quad (\text{L/s}) \tag{10.4}$$

where

V_{O_2} rate of oxygen consumption VO_2, L/s
A_{D} DuBois surface area m^2, equal to 1.8 m^2 for an adult
M metabolic rate per unit of surface area, met (1 met = 58.2 W/m^2) equivalent to 1 in the case of sedentary activity and 0.8 in the case of rest
RQ respiratory quotient, equivalent to 0.83 as an average value for an adult, value provided by the standard

The CO_2 generation rate of an individual is equal to V_{O_2} multiplied by RQ. By entering the data of the specific case in the formula, one obtains a CO_2 generation rate per person equivalent to 0.00429 L/s per person, and for two people, it is equivalent to 0.00858 L/s.

The outdoor airflow rate into the zone, calculated with formula 2, referred to the average values of indoor CO_2 (660 ppm) and outdoor CO_2 (531 ppm) *from the monitoring shows an average value equivalent to 66.44 L/s that corresponds to about 240 m^3/h, or 0.07 m^3/s.*

The CMV device used to ensure the ventilation rate of the apartment is the *Zehnder ComfortAir 200* that shows, in the technical data sheet, ventilation rates ranging from 20 m^3/h, in the absence of inhabitants, to 255 m^3/h with maximum operation, at full load. The design of the ventilation system according to the PHPP standard considers an airflow rate of outdoor air per person equivalent to 24 m^3/h, which corresponds to IDA III according to EN 13799—Table 11 (EN ISO 13799) as the typical range that corresponds to about 60 m^3/h for the zone (design data).

10.3 Conclusion

The monitoring activity has confirmed the decisions made during the design phase and the correct execution of the work by the construction company. The stratigraphy of the perimeter walls and roof helps ensure an indoor ambient temperature and contact temperature of the wall within the comfort range and provided for by the legislation; there are no discontinuities or abnormal values. The only datum on which some doubt can be cast, but only of a scientific nature and not involving the design or construction, concerns, as has been mentioned, the concentration of CO_2, but in any case, the guaranteed IAQ is in Category I.

In conclusion to the question "*have the results confirmed the effectiveness of the choices of the designer?*", the answer is yes, because not only the choices follow the certification practices and protocols, but the attention to the quality of the work has been constant, and the decision to create a monitoring campaign (which should always be required) allows it to be proven "*without a shadow of a doubt*", so much so that the monitoring campaign itself can be considered part of the high quality of the project of the *Fiorita Passive House*.

References

ASHRAE Standard 62.1 ventilation for acceptable indoor air quality

ASTM D6245. Standard guide for using indoor carbon dioxide concentrations to evaluate indoor air quality and ventilation

EN ISO 6946. Building components and building elements. Thermal resistance and thermal transmittance calculation method

EN ISO 13786. Thermal performance of building components—dynamic thermal characteristics—calculation methods

EN ISO 13779 Ventilation for non-residential buildings—performance requirements for ventilation and room-conditioning systems

EN 15251. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

ISO 9869. Thermal insulation—building elements—in-situ measurement of thermal resistance and thermal transmittance

ISO 13790. Energy performance of buildings calculation of energy use for space heating and cooling

Chapter 11
Design Plans

The time has come to take my leave from the reader, thanking him or her for having patiently arrived up to this point. I hope the reader will not have been in any way bored, now that we have reached the final chapter of this *logbook* and that a greater awareness has been acquired (certainly not all-encompassing) on the construction of a Passive House.

It is my intention to salute those who have come this far with a concluding chapter that gathers together the most significant aspects of the architectural and the final construction design of the *Fiorita Passive House*, together with some photographic images of the completed building.

While the architectural design describes the distribution of the spaces, the final construction design delves into the scale and describes the main nodes of the building and the materials used. The photographic images of the completed building reinstate (at least for the author) the result of the objectives of the project: a Passive House that does not renounce the qualitative aspects of contemporary architecture, in the idea that architectural quality, energy efficiency, comfort and environmental sustainability are complementary objectives of a cognisant design.

Figures 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 11.10, 11.11, 11.12, 11.13, 11.14, 11.15, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21, 11.22, 11.23, 11.24, 11.25, 11.26, 11.27, 11.28 and 11.29 specifically placed at the end of the book can

S. Piraccini and K. Fabbri, *Building a Passive House*, Green Energy and Technology,
https://doi.org/10.1007/978-3-319-69938-7_11

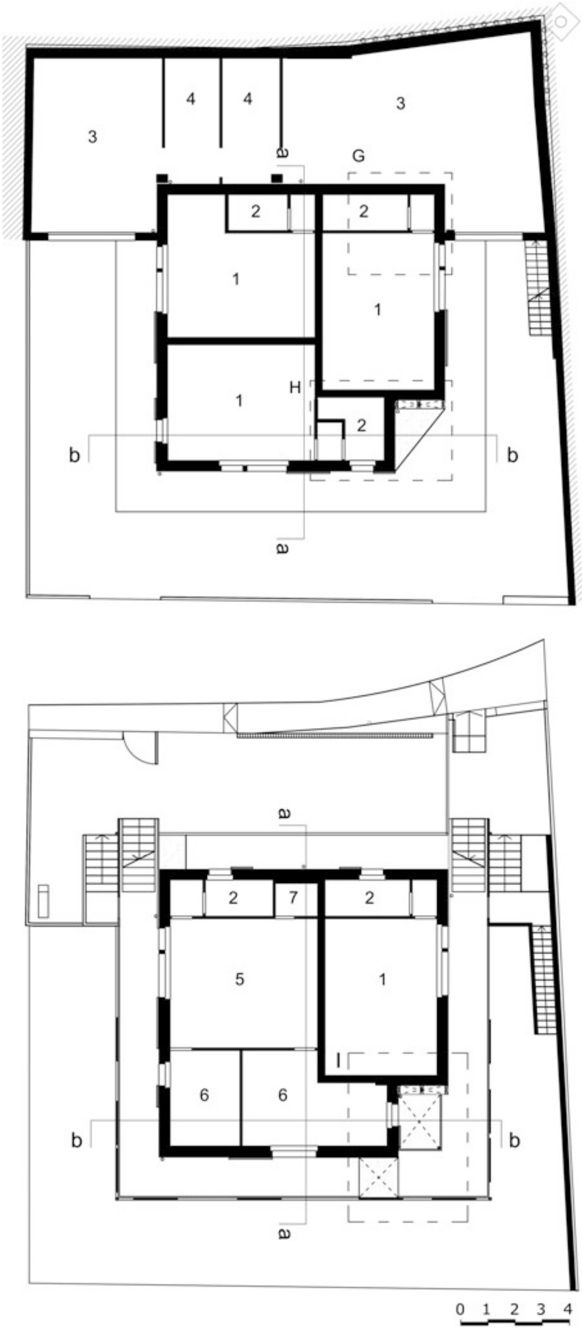


Fig. 11.1 Ground-level floor plan (above), first-level floor plan (below): (1) living room–kitchen–bedroom; (2) bathroom; (3) garage; (4) technical systems room; (5) living room–kitchen; (6) bedroom; (7) vestibule

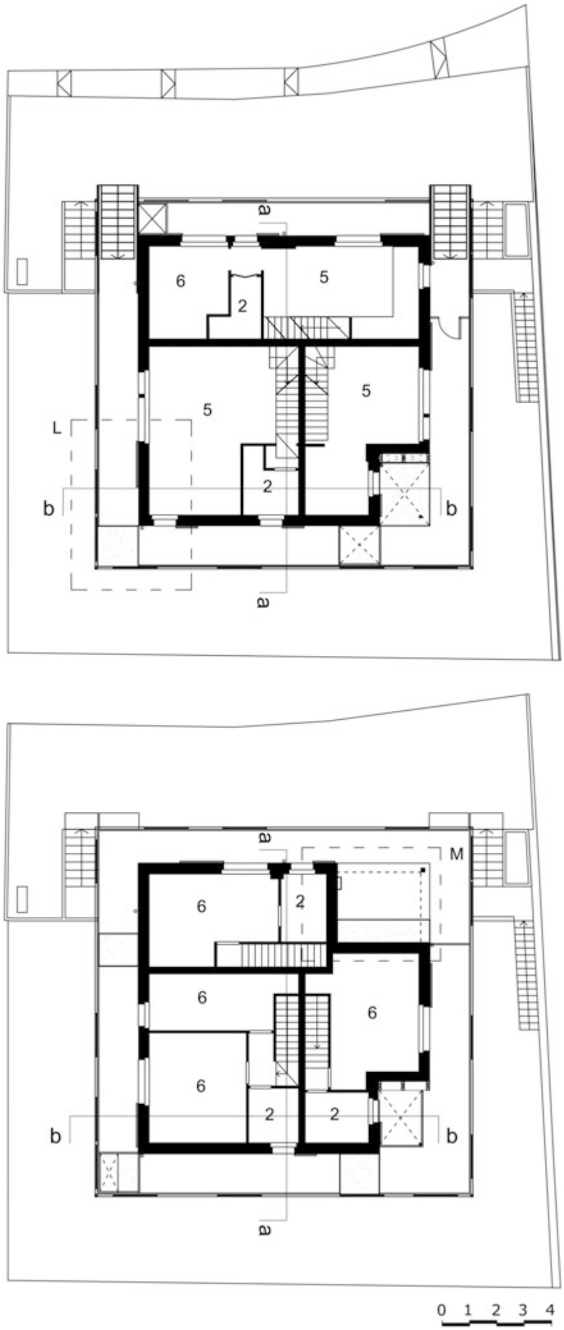


Fig. 11.2 Second-level floor plan (above), third-level floor plan (below): (2) bathroom; (5) living room–kitchen; (6) bedroom

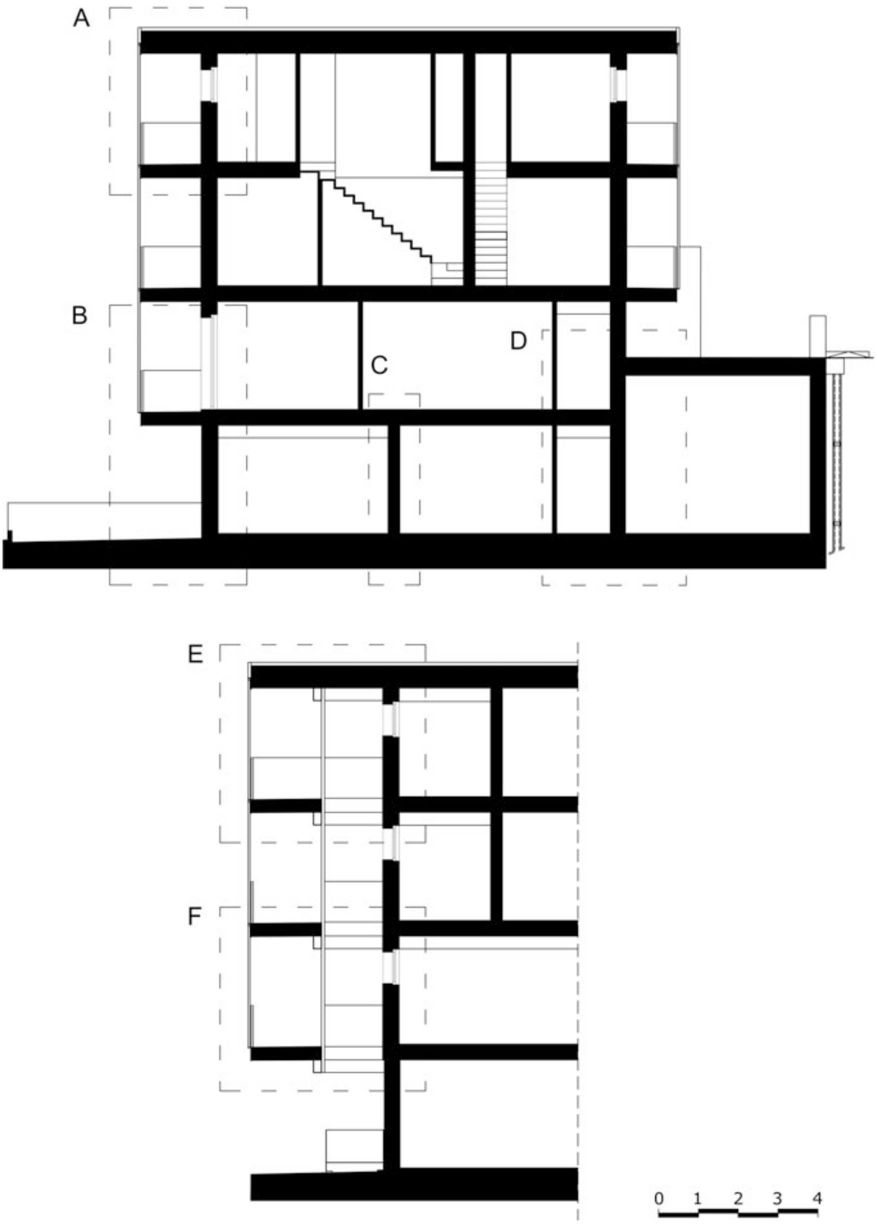


Fig. 11.3 Section a-a (above), section b-b (below)

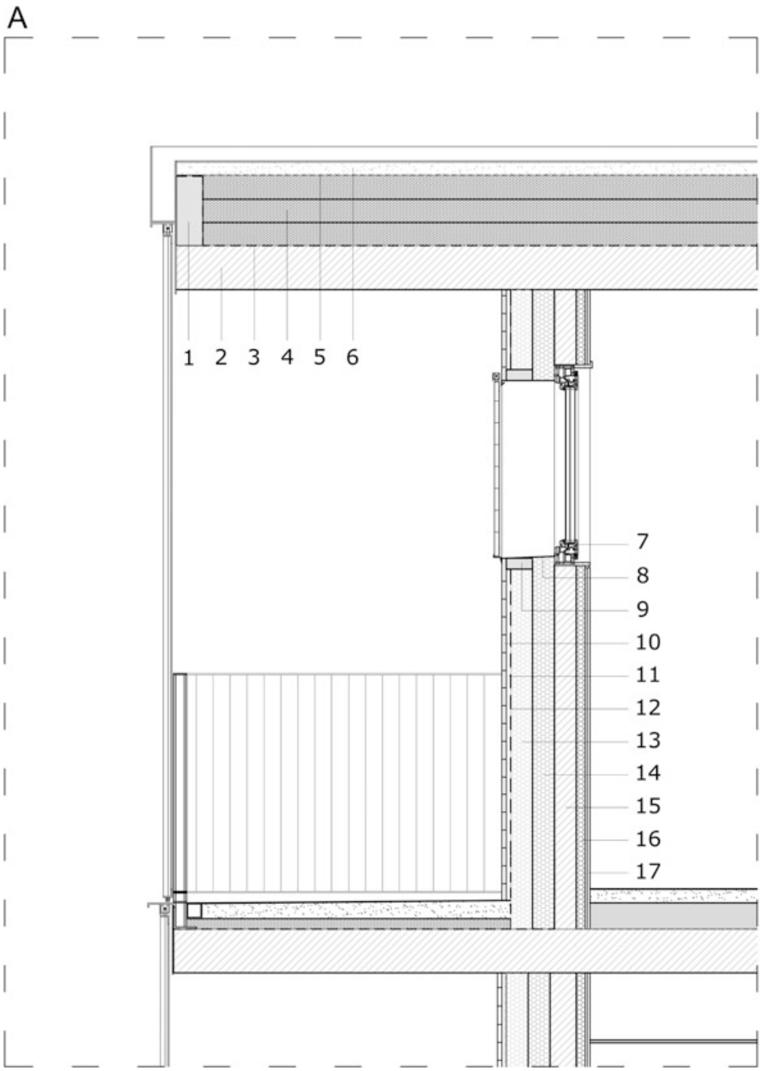


Fig. 11.4 Detail A: (1) element made of fir wood; (2) CLT 20 cm; (3) waterproofing sheath 0.4 cm; (4) XPS 32 cm; (5) cement screed 6 cm; (6) bitumen-based sheath 0.3 cm; (7) frame in PVC; (8) mouldings in aluminium sheet; (9) crossbar in fir wood treated in an autoclave; (10) panels in natural larch wood 2 cm; (11) air 1 cm; (12) wind barrier 0.1 cm; (13) fibreglass 10 cm; (14) wood fibre 10 cm; (15) CLT 12 cm; (16) mineral wool 4 cm; (17) plasterboard 1.3 cm

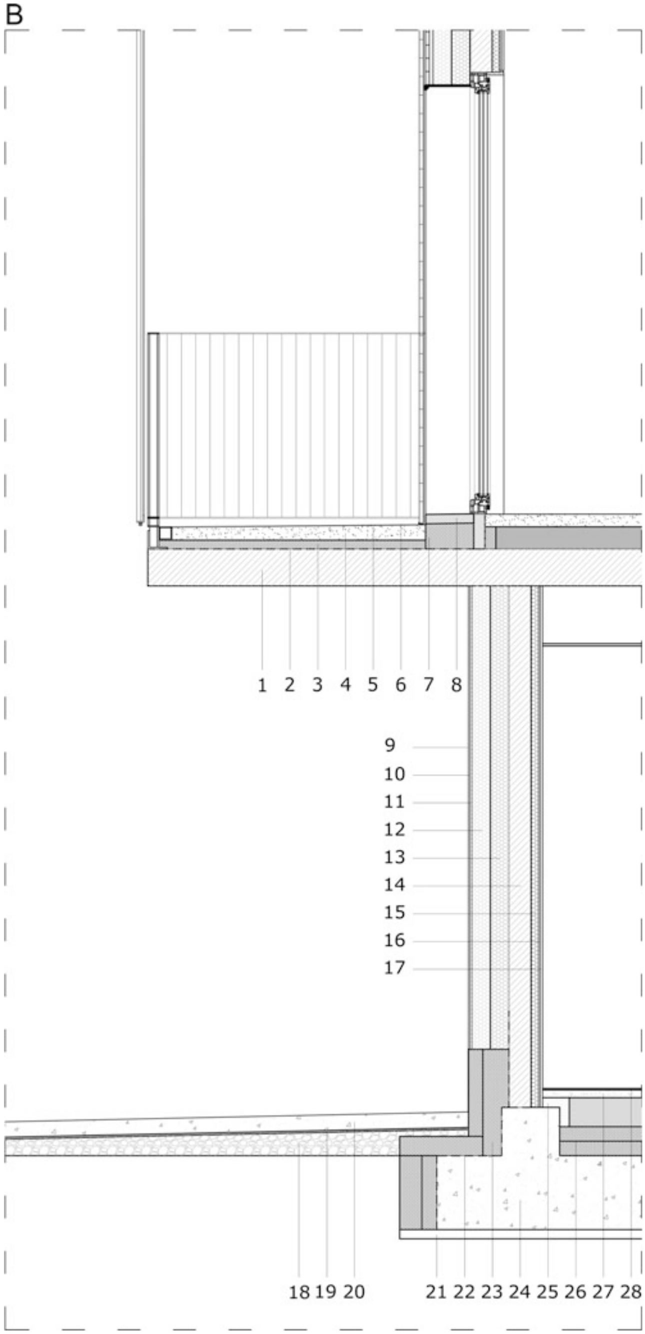


Fig. 11.5 Detail B: (1) CLT 20 cm; (2) waterproofing sheath 0.4 cm; (3) XPS 5 cm; (4) cement screed average thickness 5 cm; (5) resin floor 0.3 cm; (6) higher part of the cement screed; (7) XPS 26 × 14 cm; (8) stone 26 × 4 cm; (9) ceramic slab 0.3 cm; (10) adhesive; (11) cement fibre 1.3 cm; (12) fibreglass 10 cm; (13) wood fibre 10 cm; (14) CLT 12 cm; (15) mineral wool 4 cm; (16) air 1 cm; (17) plasterboard 1.3 cm

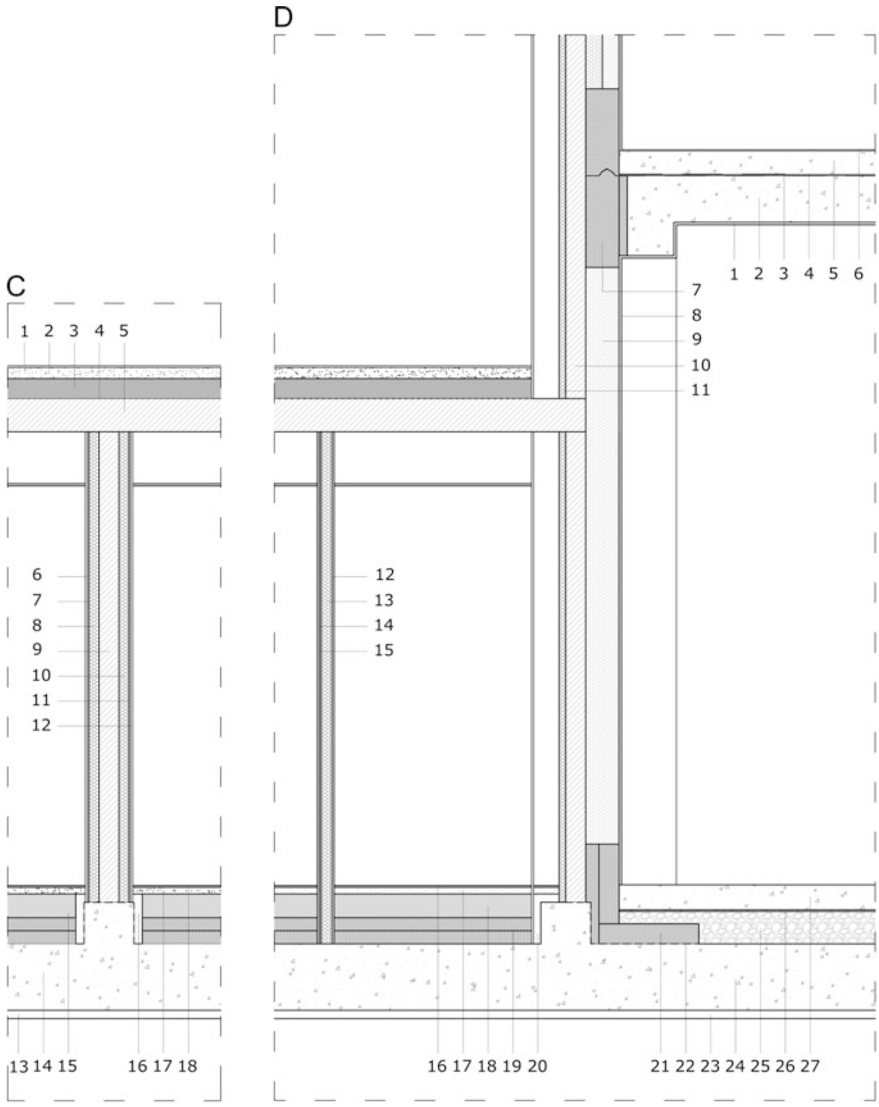


Fig. 11.6 Detail C: (1) resin floor 0.3 cm; (2) cement screed 4 cm; (3) lightened screed 12 cm; (4) PVC 0.3 cm; (5) CLT 20 cm; (6) plasterboard 1.3 cm; (7) air 1 cm; (8) mineral wool 4 cm; (9) CLT 12 cm; (10) mineral wool 4 cm; (11) air 1 cm; (12) plasterboard 1.3 cm; (13) lean concrete 5 cm; (14) reinforced concrete 40 cm; (15) lightened screed 12 cm; (16) polyurethane 5 cm; (17) cement screed 4 cm; (18) resin floor 0.3 cm. Detail D: (1) plaster 1 cm; (2) pedralles slab 25 cm; (3) PVC 0.3 cm; (4) waterproofing sheath 0.4 cm; (5) reinforced concrete 15 cm; (6) quartz-based surface treatment; (7) EPS 20 cm; (8) levelling 0.6 cm; (9) EPS 20 cm; (10) CLT 12 cm; (11) mineral wool 4 cm; (12) plasterboard 1.3 cm; (13) mineral wool 6.5 cm; (14) air 1 cm; (15) plasterboard 1.3 cm; (16) resin floor 0.3 cm; (17) cement screed 4 cm; (18) lightened screed 12 cm; (19) XPS 16 cm; (20) polyurethane 5 cm; (21) XPS 12 cm; (22) waterproofing sheath 0.4 cm; (23) lean concrete 5 cm; (24) reinforced concrete 40 cm; (25) sand 17 cm; (26) PVC 0.3 cm; (27) reinforced concrete 15 cm

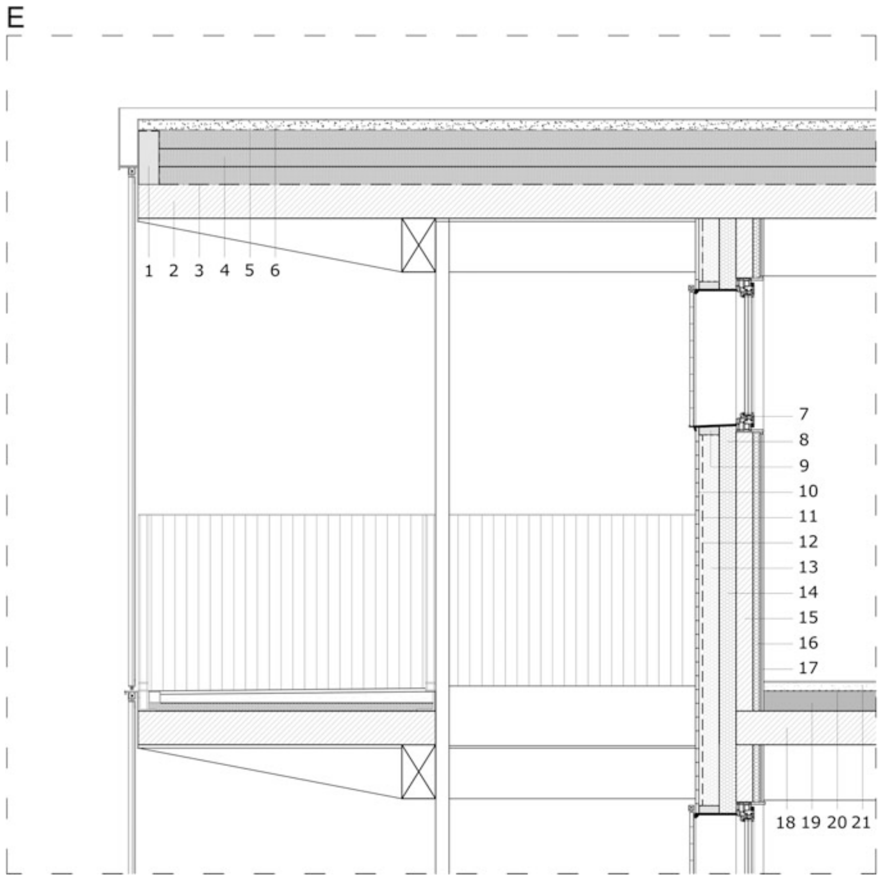


Fig. 11.7 Detail E: (1) element made of fir wood; (2) CLT 20 cm; (3) waterproofing sheath 0.4 cm; (4) XPS 32 cm; (5) bitumen-based sheath 0.3 cm; (6) cement screed 6 cm; (7) frame in PVC; (8) mouldings in aluminium sheet; (9) crossbar in fir wood treated in an autoclave; (10) panels in natural larch wood 2 cm; (11) air 1 cm; (12) wind barrier 0.1 cm; (13) fibreglass 10 cm; (14) wood fibre 10 cm; (15) CLT 12 cm; (16) mineral wool 4 cm; (17) plasterboard 1.3 cm; (18) CLT 20 cm; (19) lightened screed 12 cm; (20) acoustic insulation 0.5 cm; (21) cement screed 4 cm

F

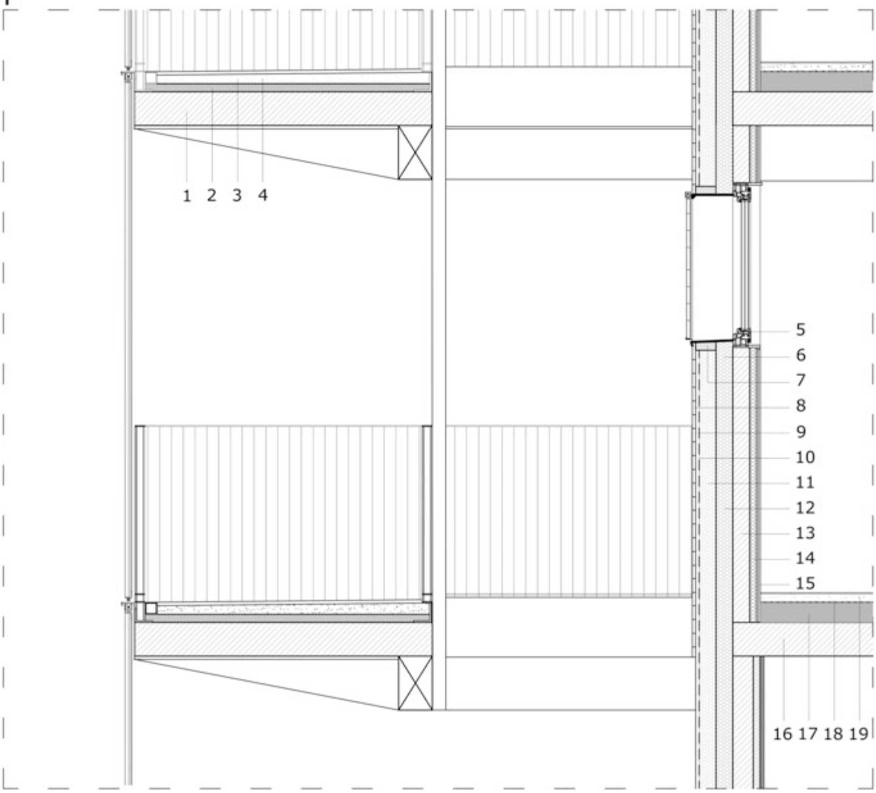
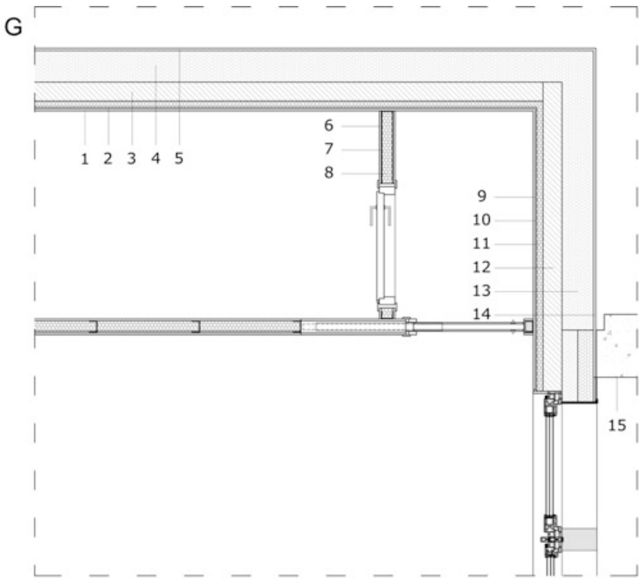


Fig. 11.8 Detail F: (1) CLT 20 cm; (2) waterproofing sheath 0.4 cm; (3) XPS 5 cm; (4) cement screed 5 cm; (5) fixture in PVC; (6) mouldings in aluminium sheet; (7) crossbar in fir wood treated in an autoclave; (8) panels in natural larch 2 cm; (9) air 1 cm; (10) wind barrier 0.1 cm; (11) fibreglass 10 cm; (12) wood fibre 10 cm; (13) CLT 12 cm; (14) mineral wool 4 cm; (15) plasterboard 1.3 cm; (16) CLT 20 cm; (17) lightened screed 12 cm; (18) acoustic insulation 0.5 cm; (19) cement screed 4 cm



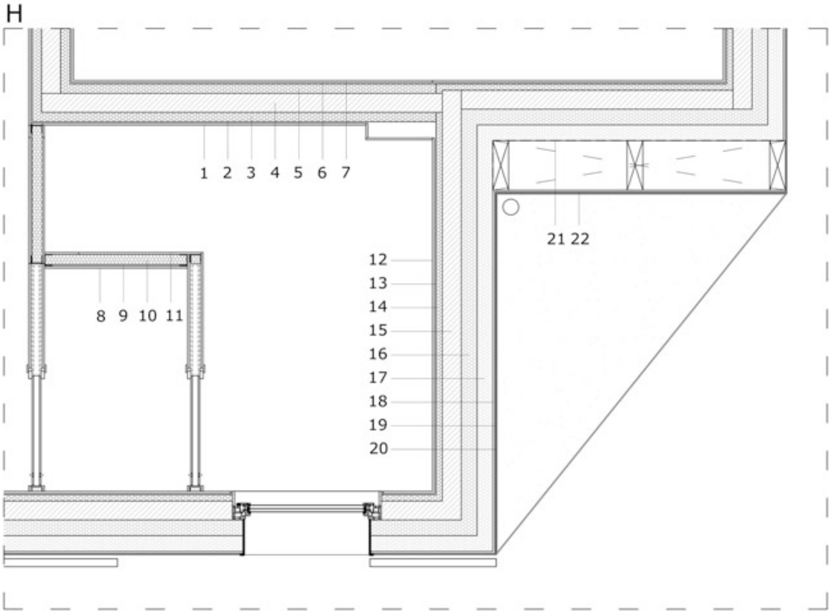


Fig. 11.9 Detail G: (1) plasterboard 1.3 cm; (2) mineral wool 4 cm; (3) CLT 12 cm; EPS (4) 20 cm; (5) levelling 0.6 cm; (6) plasterboard 1.3 cm; (7) air 1 cm; (8) mineral wool 6.5 cm; (9) plasterboard 1.3 cm; (10) air 1 cm; (11) mineral wool 4 cm; (12) CLT 12 cm; (13) EPS 20 cm; (14) levelling 0.6 cm; (15) reinforced concrete pillar. Detail H: (1) plasterboard 1.3 cm; (2) air 1 cm; (3) rock wool 4 cm; (4) CLT 12 cm; (5) mineral wool 4 cm; (6) air 1 cm; (7) plasterboard 1.3 cm; (8) plasterboard 1.3 cm; (9) air 1 cm; (10) mineral wool 6.5 cm; (11) plasterboard 1.3 cm; (12) plasterboard 1.3 cm; (13) air 1 cm; (14) mineral wool 4 cm; (15) CLT 12 cm; (16) wood fibre 10 cm; (17) fibreglass 10 cm; (18) cement fibre 1.3 cm; (19) adhesive; (20) ceramic slab 0.3 cm; (21) wind barrier 0.1 cm; (22) skylight shaft for the electrical system

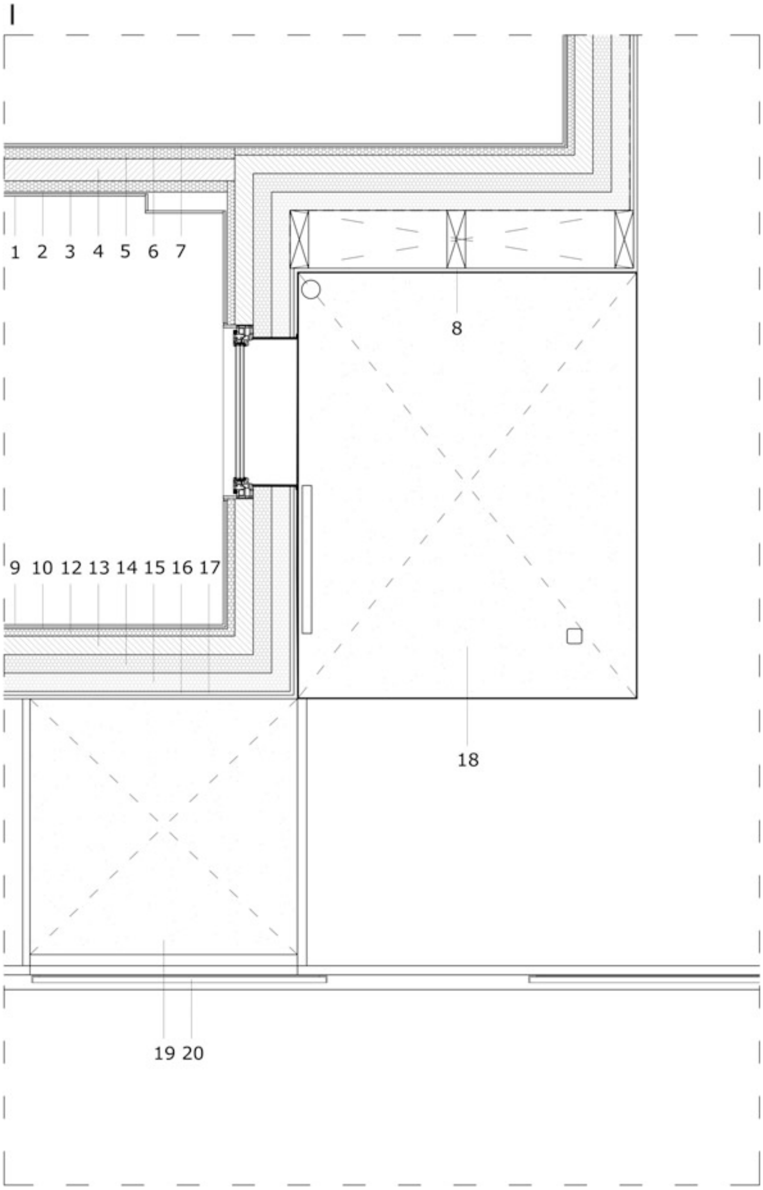


Fig. 11.10 Detail I: (1) plasterboard 1.3 cm; (2) air 1 cm; (3) mineral wool 4 cm; (4) CLT 12 cm; (5) mineral wool 4 cm; (6) air 1 cm; (7) plasterboard 1.3 cm; (8) cavity for the electrical system; (9) plasterboard 1.3 cm; (10) air 1 cm; (12) mineral wool 4 cm; (13) CLT 12 cm; (14) wood fibre 10 cm; (15) fibreglass 10 cm; (16) air 1 cm; (17) panels of natural larch wood; (18) flower box; (19) hole in a terrace in correspondence with the flower box located on the lower floor; (20) sliding awning in expanded metal

L

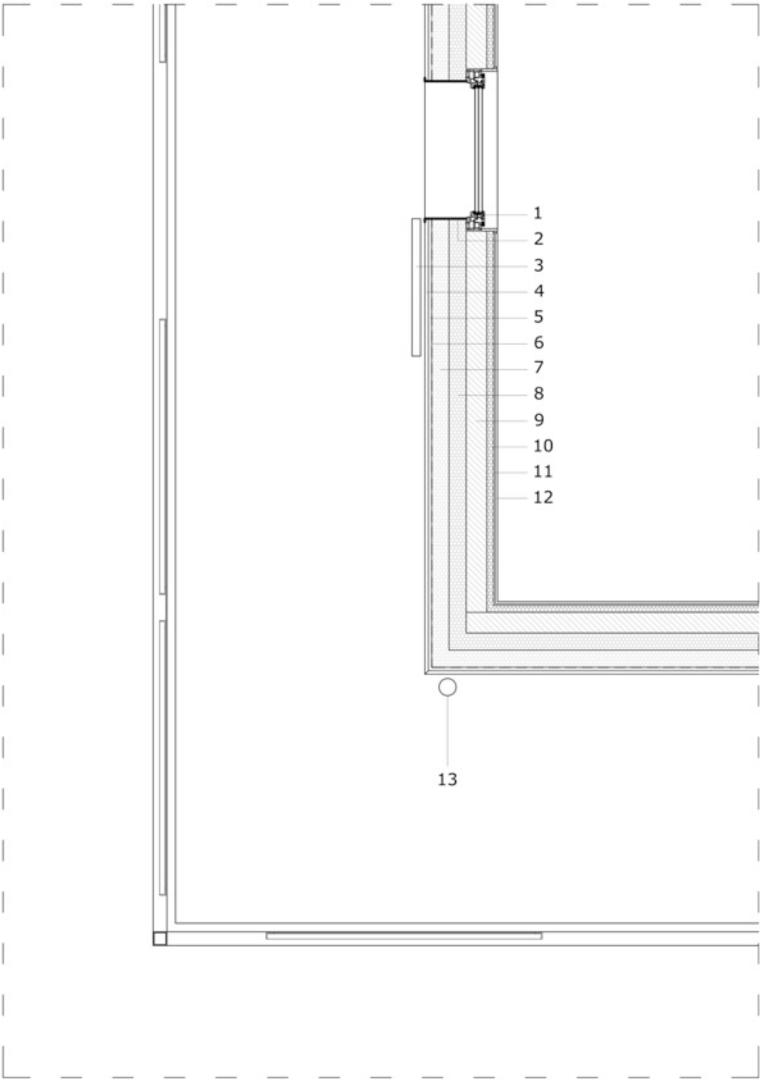


Fig. 11.11 Detail L: (1) frame in PVC; (2) mouldings in painted aluminium; (3) shading element composed of a galvanised and painted metal frame, buffered with natural larch boards; (4) wall cladding in natural larch panels 2 cm; (5) air 1 cm; (6) wind barrier 0.1 cm; (7) fibreglass 10 cm; (8) wood fibre 10 cm; (9) CLT 12 m; (10) mineral wool 4 cm; (11) air 1 cm; (12) plasterboard 1.3 cm; (13) downpipe in painted sheet metal

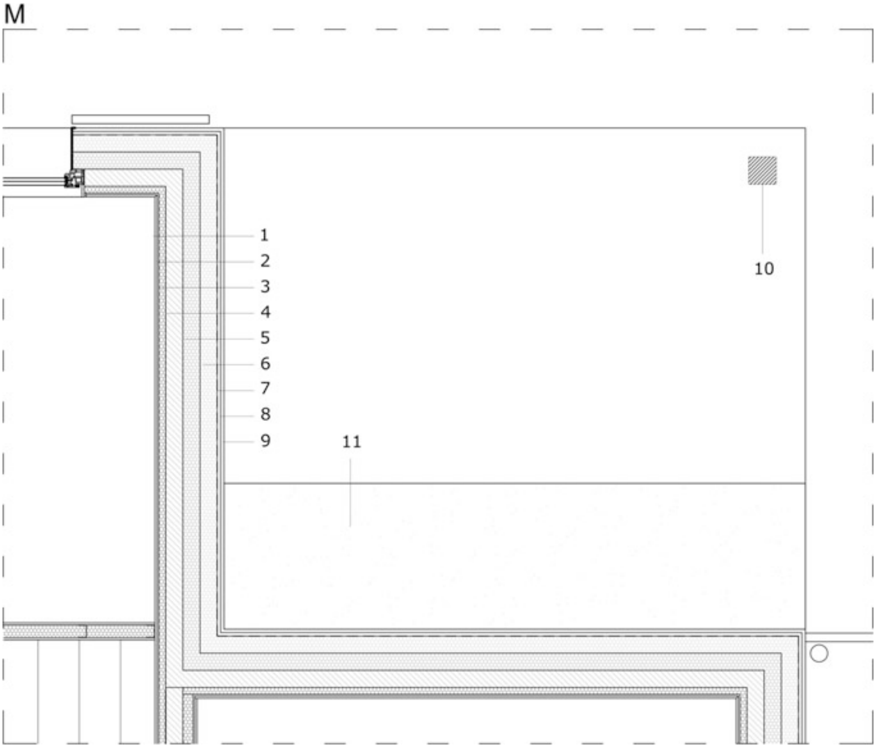


Fig. 11.12 Detail I: (1) plasterboard 1.3 cm; (2) air 1 cm; (3) mineral wool 4 cm; (4) CLT 10 cm; (5) wood fibre 10 cm; (6) fibreglass 10 cm; (7) air 1 cm; (8) panels in natural larch wood; (9) flower box; (10) pillar in fir wood clad in painted aluminium sheet; (11) flower box

Fig. 11.13 View from Via Ariosto, east and north faces

Fig. 11.14 View of the south face from Via Liguria. The photograph was taken in the summer: the awnings systems, overhangs and sliding panels shield the solar radiation

Fig. 11.15 View of the west face on the urban park

Fig. 11.16 Detail of the sliding panels in expanded metal

Fig. 11.17 Shadows produced by the sliding panels inside the terraces

Fig. 11.18 View of an internal staircase

Fig. 11.19 View of the east and north faces

Fig. 11.20 Detail of one of the flower boxes where bamboo was planted

Fig. 11.21 Detail of the accesses on Via Liguria made in Corten steel sheet

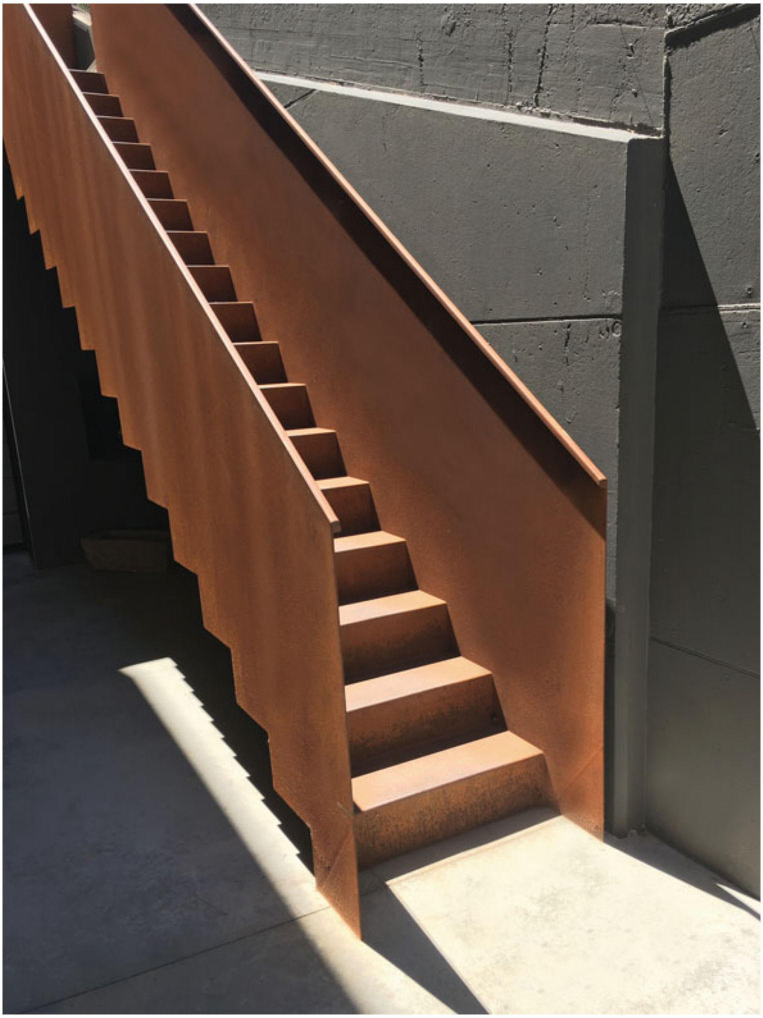


Fig. 11.22 External staircase which links the level of Via Ariosto to that of Via Liguria

Fig. 11.23 Detail of one of the accesses on Via Liguria

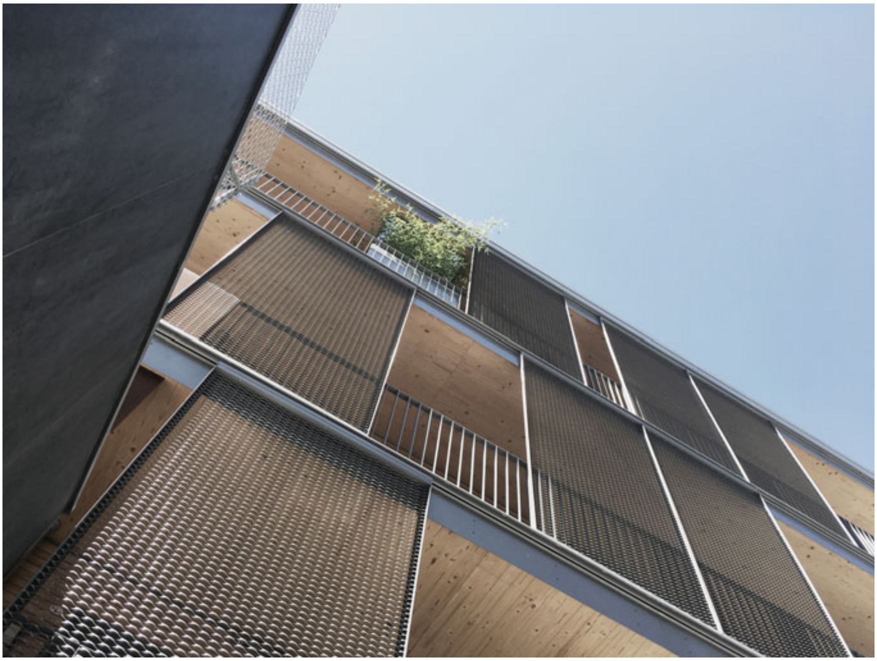


Fig. 11.24 Detail of the sliding panels in expanded metal

Fig. 11.25 Detail of the sliding panels in expanded metal

Fig. 11.26 Detail of one of the accesses on Via Liguria made in Corten steel sheet

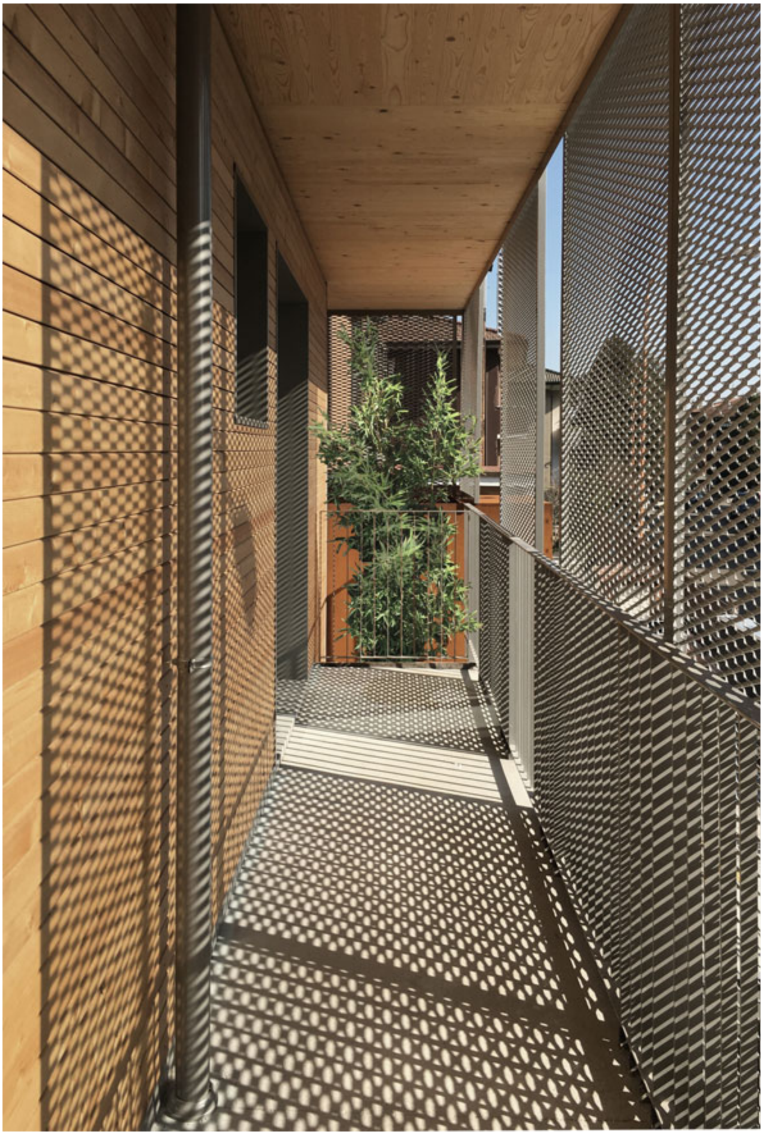


Fig. 11.27 View inside the terraces

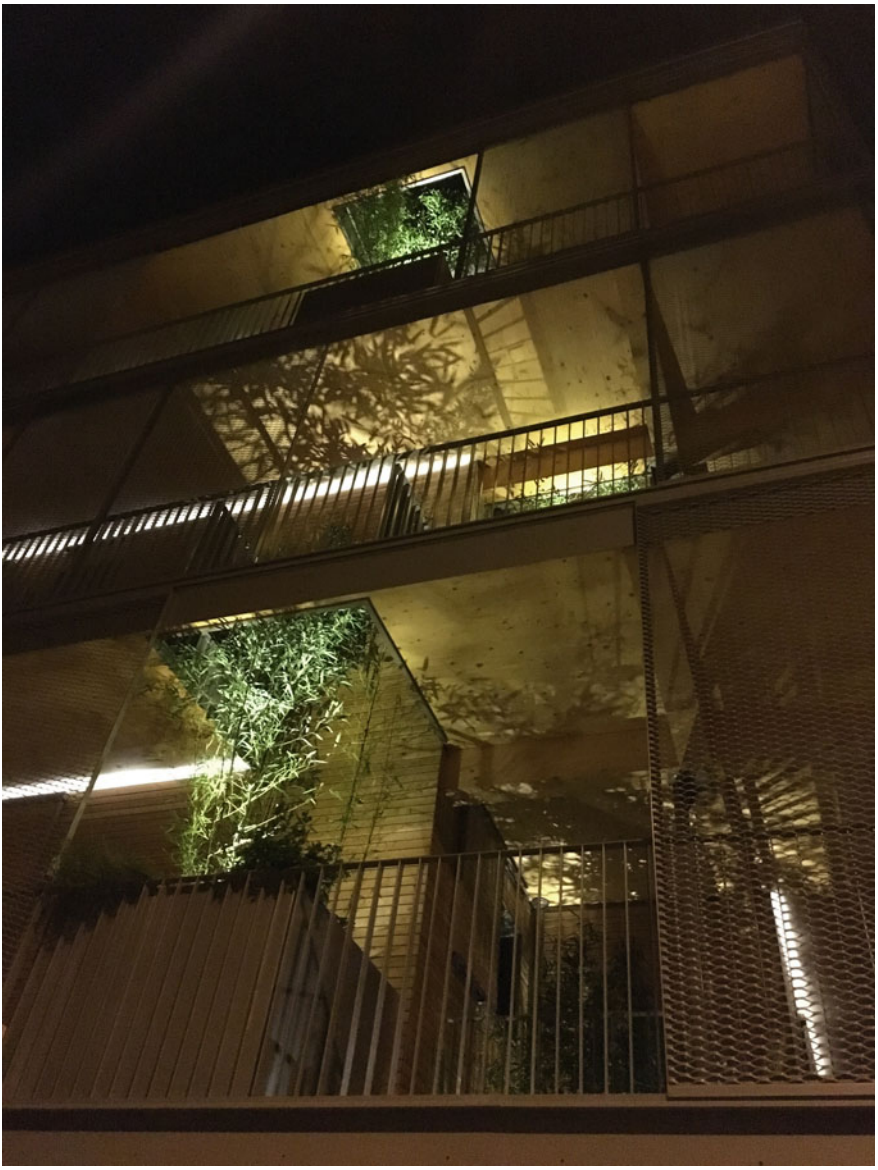


Fig. 11.28 Night view from Via Ariosto

Fig. 11.29 Night view

be used during reading to gain a greater understanding of what is described in the previous chapters.