EBCS 11

Ethiopian Building Code Standard

Mechanical Ventilation and Air-Conditioning in Buildings

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Ethiopian Building Code Standard Revision Committee on "Mechanical Ventilation and Air-Conditioning in Buildings"

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NATIONAL FOREWORD

The Proclamation to define the powers and duties of The Executive organs of The Federal Democratic Republic of Ethiopia Proclamation No 691/ 2010 and Ethiopian Building Proclamation No 624/2009 empowers the Ministry of Urban Development, Housing and Construction to prepare the Country's Building Code, issue Standards for design and construction works, and follow up and supervise the implementation of same.

This Ethiopian Standard is the official English language version of "MECHANICAL VENTILATION AND AIR-CONDITIONING IN BUILDINGS - **EBCS 11:2014**". It supersedes part of "MECHANICAL VENTILATION AND AIR-CONDITIONING IN BUILDINGS" which is withdrawn. With an eye on the latest technological advancements and trends worldwide and with the aim of bringing the Ethiopian Construction Standard at par with the present state-of-the-art, this edition has brought a major shift in terms of contents and comprehensiveness. The major benefits to be gained in applying this standard is the harmonization of professional practice and the ensuring of appropriate level of workmanship, level of safety and quality of construction work.

EBCS 11:2014 is prepared by a Technical Committee "MECHANICAL VENTILATION AND AIR-CONDITIONING IN BUILDINGS" the secretariat of which is held by Addis Ababa University. The document is intended to be used in conjunction with EBCS 0:2014 to EBCS 14:2014 for the design of services of buildings and civil engineering works. The normative part of this Ethiopian Building Code Standard is chosen based on the local needs and construction practice. As this standard is technical document which, by their very nature, require periodic updating, revised edition will be issued by the Ministry from time to time as appropriate.

This document does not purport to include all the necessary provisions of a contract. Users are responsible for their correct application.

Compliance with this Ethiopian Building Code Standard does not of itself confer immunity from legal obligations.

The Ministry of Urban Development Housing and Construction as mandated acknowledges this document as a national resource tool and reference document which comprises a front cover, an inside front cover, a title page, National foreword, Table of Contents, pages 1 to 92 and a back cover. This Ethiopian Construction Standard, having been prepared under the direction of the Ethiopian Building Proclamation No 624/2009, was published under the authority of the Ministry of Urban Development, Housing and Construction on 01 December 2014.

Ministry of Urban development, Housing and Construction

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INTRODUCTION

EBCS 11, Code of Practice for Ventilation and Air- conditioning of Buildings, was issued in 1995. The 1995 version was developed when air-conditioning systems were seldom incorporated in design of buildings in Ethiopia. Hence, the focus was mainly on ventilation.

Due to accelerated modernization of the building construction sub-sector after 2000 in Ethiopia, four and five star hotels, referral hospital, conference and convention centers, and financial center are being built with air-conditioning systems and basement car park ventilation system. Moreover, air conditioning is being considered as input to increasing productivity in hot areas of Ethiopia and offices, social services and residence in extremely hot areas are being furnished with air-conditioning systems. Due to this new development, the need to update the existing code to make it inclusive of all aspects of mechanical ventilation and air conditioning was felt.

The purpose of this code is to specify:

- Minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects;
- Design methodology and climatic and other data for cooling and heating load calculation of air-conditioning system of building;
- Compliance requirements of air conditioning and mechanical ventilation equipment including control and electrical power supply;
- Design methodology and compliance requirements of duct construction; and
- Testing, commissioning and maintenance procedure of mechanical ventilation and air conditioning

SECTION 1 General

1.1 Scope

This code of practice provides general guidance in the design, construction, installation, testing and commissioning, operation and maintenance of air-conditioning and mechanical ventilation systems in all commercial, office, and institutional buildings except hospitals, laboratories, industries, etc. The purpose of this code is to establish minimum requirements in mechanical ventilation and air-conditioning engineering practice such that an acceptable indoor thermal environment can be attained in an energy efficient manner with general consideration for the indoor air quality (IAQ), and maintainability of the equipment.

The intention of this code is not to impose unnecessary restrictions design and installations of systems, nor on the development and use of new improved or unusual materials, design or methods of constructions or installation not covered by this code. However, in the event that this code is applied as a requirement by regulations of regulatory authorities, any departure from this code will require the specific approval of the regulatory authority.

1.2 References

The following documents are referenced for the application of this code.

- SS 533:2009 Singapore standard for air conditioning and ventilation in Buildings.
- CIBS 1976:- Ventilation and air conditioning (Requirements)
- ANSI/ASHRAE Standard 6.2.1 2007 Ventilation for acceptable indoor air quality.
- EBCS-11 1995 Ventilation and air conditioning of buildings.
- National Building code of India 2005
- EN 12101-6:2005 Stair case pressurization system.

1.3 Definitions

For the purpose of this code, the following definitions apply:

Activated carbon	A form of carbon made porous by special treatment by which it is capable of absorbing various odors, anesthetics and other vapors

Air, ambient	Generally speaking, the air surrounding an object.
Air changes	A method of expressing the rate of air entering or leaving a space by natural or mechanical means in terms of the number of volume of the space.
Air-conditioning	The process of treating air so as to control simultaneously its temperature, humidity, cleanliness and distribution to meet the requirements of the conditioned space.
Air diffuser	A circular, square or rectangular air-distribution outlet, generally located in the ceiling and consisting of deflecting members discharging supply air in various directions and planes, and arranged to promote mixing of supply air with room air.
Air exhaust	Air other than recycled air, removed from an enclosure and discharged to atmosphere.
Air-handling system	A system for the purpose of providing air in a controlled manner to specific enclosures by means of one or more air-handling plants, ducts, plenums, air distribution devices and automatic controls.
Air outdoor	Ambient air entering the system or opening from outdoors before any air treatment.
Air re-circulated	Enclosure air that passes through a local air cleaning unit and returns to the same or other enclosures
Air return	Air returned of air delivered to each or any space in the system, or the total delivered to all spaces in the systems.
Air supply	The quantity of air delivered to each or any space in the system, or the total delivered to all spaces in the system.
Air transfer	Air moved from one indoor space to another.
Comfort, Thermal	Condition of mind derived from satisfaction with the thermal environment. Thermal comfort is the combined thermal effect of environmental parameters including air temperature, relative humidity, air movement, mean radiant temperature (fixed factors) and clothing and

	activity level of occupants.
Condensate	The liquid formed by the condensation of a vapor, such as water which is extracted from moist air as it flows across the cooling coil of an air-conditioner.
Condenser	A vessel or arrangement of pipes or tubing's in which vapor is liquefied by removal of heat.
Contaminant, airborne	An unwanted airborne constituent that may reduce acceptability of the indoor air quality.
Control	A device for the regulation of a system or component in normal operation, manual or automatic. It automatic, the implication is that it is responsive to changes of pressure, temperature or other property whose magnitude is to be regulated.
Cooling tower, water	An enclosed device for the evaporative cooling of water by contact with air.
Covering duct	Duct covering includes materials such as adhesives, insulation banding, coating(s), film and jacket used to cover the outside of duct, fan casing or duct plenum.
Damper	A device used to vary the volume of air passing through an air out inlet or duct.
Direct digital control (DDC)	The use of microcomputer to directly perform the control logic for control loops
Duct	A passageway made of sheet metal or other suitable materials, used for conveying air.
Evaporator	That part of a refrigeration system in which the refrigerant is vaporized to produce refrigeration.
Ex-filtration	Air that flows outward through a wall, door, window, crack, etc.
Exhaust opening	Any opening through which air is removed from a space which is being air-conditioned or ventilated.
Exit	A means of egress from the interior of the building to a exterior space which is provided by the use of the following either singly or in combination; exterior door openings, exit staircases, exit ramps or exit

	passageways but not including access stairs, corridor doors or corridors
Grille	A louvered or perforated covering for an air passage opening which can be located in the side-wall, ceiling or floor.
Humidity, relative	The ration of the mole fraction of water vapor present in moist air to the mole fraction of water vapor in saturated air at the same temperature and pressure.
Infiltration	Air that flows inward through a wall, door, window crack, etc.
Insulation, thermal	A material having a relatively high resistance to heat flow and used principally to retard the flow of heat.
Kilowatt	Kilowatt is the unit of measure of power. It can be used to quantify power (electrical) or rate of energy transfer (thermal).
Lining, duct	Duct lining including materials such as adhesive, insulation, coating and film used to line the inside surface of a duct, fan casing, or duct plenum.
Plenum chamber	An air compartment connected to one or more distributing ducts.
Register	A grille and damper assembly covering an air opening.
Service agency	An agency capable of providing caliber testing, or manufacture of equipment, instrumentation, metering, or control apparatus, such as contractor, laboratory, or manufacturer.
Smoke	An air suspension (aerosol) of particles, usually but not necessarily solid often originating in a solid nucleus, formed from combustion or sublimation. Also defined as carbon or soot particles less than 0.1 micro in size which results from the incomplete combustion of carbonaceous materials such as coal, oil, tar and tobacco.
Temperature, dry-bulb	The temperature of a gas or mixture or gases indicated by an accurate thermometer shielded from effects of radiation.

Temperature, mean radiant	The temperature of a uniform black enclosure in which a body or occupant would exchange the same amount of radiant heat as in the existing non-uniform environment.
Temperature, Operative	Arbitrary index that combines into a single number the effects of dry-bulb temperature, radiant temperature and air motion on the sensation of warmth or cold by the human body. The operative temperature can be taken as average of mean radiant temperature and dry-bulb temperature.
Temperature, wet-bulb	Thermodynamic wet-bulb temperature is the temperature at which water (liquid or solid state) by evaporating into air can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychomotor, constructed and used according to specification.
Vapor barrier	A moisture-impervious layer applied to the surfaces enclosing humid space to prevent moisture travel to a point where it may condense due to low temperature.
Ventilation	The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.
Zone	A space or group of spaces within a building with sufficiently similar cooling requirement.

SECTION 2 Mechanical Ventilation System

2.1 Ventilation Rates

2.1.1 General Requirements

All rooms and occupied spaces which are not naturally ventilated or air-conditioned shall be mechanically ventilated to achieve removal of heat and possible contaminants such as product of respiration, bacteria, odors, product of combination, etc and maintain acceptable indoor air quality.

2.1.2 Design considerations

(1) The quality of outdoor air supply for mechanical ventilation for any room or floor space in a building shall be based on its volume and determined according to the rates given in Table 2.1.

(2) The rates of ventilation given in Table 2.1 apply to normal types of buildings with normal heat gains from occupants and activates. When abnormal conditions prevail, the ventilation rate may be increased to prevent undue concentration of body odors, bacteria-carrying practices, gas, vapor or dust and to prevent undue accumulation of carbon dioxide and to remove products of combustion.

(3) For any type of room or floor space not specified in Table 2.1, the ventilation rate shall be assumed considering the value assigned for similar space listed in the table.

Table 2.1. Minimum Outdoor Air Supply for Mechanical Ventilation in Non Air-Conditioned Buildings or Parts of Buildings with No Natural Ventilation

Type of building/Occupancy	Minimum outdoor air supply air-change/h
Office	6
Restaurant, canteens	10
Shops	6
Workshop, factories	6
Classrooms	8
(i) **Car parks**	6
(ii) **Toilets, bathrooms**	10
(iii) **Lobbies, concourse, corridors,**	4

staircases and exits	
Kitchens (commercial, institutional and industrial)	[iv]20-60

NOTE:

i) Where the ceiling height exceeds 2.5m, the air change rate will be calculated based on 2.5m ceiling height.
ii) For heavily used public toilets, a higher air change value shall be considered.
iii) Lobbies of area of 10 m^2 or less are exempted from being mechanically ventilated
iv) The air supply can be reduced to 10 air-change/h when the kitchen hoods exhaust system is not in operation.

2.2 Car park ventilation

2.2.1 General

(1) It is required to ventilate the car parking areas in a building in order to remove carbon monoxide and other combustion products from the areas.

(2) Except where natural ventilation is available as described in clause 2.2.2, a mechanical ventilation system incorporating a supply part and an exhaust part, and capable of providing six air changes per hour is required for car parking areas in a building.

(3) The mechanical ventilation system in commercial car parks may be operated at a lower rate at times of low occupancy subject to the condition that the carbon monoxide concentration is maintained below the permitted level of approximately 25 ppm averaged over an hour period.

(4) The mechanical ventilation system in residential car parking areas may be switched off if the carbon monoxide concentration is below 25 ppm averaged over an hour period.

(5) For the exhaust part of the ventilation system, at least 50% of the exhaust air shall be extracted at low level not exceeding 650 mm above the finished floor, as measured from the top of the grille to the finished floor.

(6) The supply air shall be drawn directly from the exterior and its intake shall not be less than 5m from any exhaust discharge openings. Outlets for the supply air shall be adequately distributed over the car park area.

(7) The discharge points of the exhaust ventilation system:

(a) Shall be arranged to discharge directly to the exterior and shall not be less than 5m away from any intake openings, doorways or apertures to prevent the re-entry of objectionable odors or flammable vapor into the premises; and

(b) Shall not face or discharge in the direction of any adjacent residential building.

2.2.2 Aboveground car park ventilation

(1) For aboveground car park, no mechanical ventilation is required for any part of the car park where natural ventilation opening of not less than 15% of the floor area served is provided. The naturally ventilated part of the car park shall be within 12m from the ventilation opening except where cross-ventilation is provided.

(2) For aboveground car park without cross ventilation, where additional natural ventilation opening of two less than 15% of the area beyond 12m of the opening is provided, a reduced mechanical ventilation system in the form of fume extract may be provided to these areas as follows:

(a) The extract system shall be above the provide 1.2 air changes per hour;

(b) The supply part can be omitted; and

(c) The extract points shall be wholly located at low level not exceeding 650mm above the finished floor, as measured from the top of the grille to the finished floor.

(3) Where natural ventilation opening equivalent to not less than 2% of the mechanically ventilated areas is provided, the supply part may be omitted.

(4) In a large car park, a combination of natural and mechanical ventilation may be provided as illustrated in Table 2.2.

Table 2.2. Mode of Ventilation for Aboveground Car Park

Size of ventilation opening (% of floor area)	**Mode of ventilation to be provided (Natural 'NV', mechanical 'MV', or fume extract)**	
	Zone 'A'	**Zone 'B'**
15% of A + 15% of B	NV	Fume extract
15% of A + 2% of B	NV	MV without supply
15% of A	NV	MV
2% of A + 2% of B	MV without supply	MV without supply
2% of A	MV without supply	MV

Zone ‘A’ refers to part of car park within 12m of natural ventilation opening
Zone ‘B’ refers to part of car park beyond 12m of natural ventilation opening

2.2.3 Smoke purging for above ground car parks

Upon detection of fire /smoke a ventilation rate of ten air changes per hour shall be considered for smoke purging. Smoke extraction fans shall also be fire rated.

2.2.4 Basement car park ventilation

(1) For basement car park, the mechanical ventilation system shall be designed in such a way that the quality of replacement air shall not exceed that of the exhaust air. This requirement is necessary so that the car park can be maintained under negative pressure at all times to prevent the spread of noxious gases into adjacent occupied areas. In addition, the system shall be so designed that it can be operated in two or more section conforming to the following requirements:

(a) The capacity of each section shall be such that in the event of breakdown the remaining sections should at least be able to provide half of the total required air for the storey;

(b) The sections may operate through a common duct work;

(c) Each section of the ventilation system shall be so controlled that in the event of failure of one section, the other shall continue to operate;

(d) The exhaust and supply parts of each section shall be electrically interlocked such that failure of any section of the exhaust part shall automatically shut-down the corresponding section of the supply part;

(e) The exhaust and supply parts shall be such that they can continue to run automatically in the event of a failure in the principal source of electrical supply.

(2) For basement car park exceeding one level, the supply and exhaust parts shall be designed in such a way as to minimize intermixing of air between the different levels.

(3) For car park located on the first basement level where some degree of natural ventilation is available, the mechanical ventilation requirements as specified in clause 2.2.2(1) may be modified as follows:

(a) Where natural ventilation opening equivalent to not less than 2% of the mechanically ventilated area is provided, the supply part may be omitted;

(b) Where the natural ventilation opening provided is not less than 15% of the car park are served, a reduced mechanical ventilation system in the form of fume extract as described in clause 2.2.2(2) may be provided.

(4) In a large basement car park, a combination of different modes of mechanical ventilation may be provided as shown in Table 2.3.

Table 2.3. Mode of Ventilation for Basement Car Park

Size of ventilation opening (% of floor area)	**Mode of ventilation to be provided (Mechanical 'MV' or fume extract)**	
	Zone 'A'	**Zone 'B'**
15% of A + 15% of B	Fume Extract	Fume extract
15% of A + 2% of B	Fume Extract	MV without supply
15% of A	Fume Extract	MV
2% of A + 2% of B	MV without supply	MV without supply
2% of A	MV without supply	MV

Zone 'A' refers to part of car park within 12m of natural ventilation opening
Zone 'B' refers to part of car park beyond 12 m of natural ventilation opening

2.2.5 Smoke purging systems for basement car parks

Upon detection of fire /smoke a ventilation rate of ten air changes per hour shall be considered for smoke purging. Smoke extraction fans shall also be fire rated.

2.3 Kitchen Ventilation

2.3.1 General

(1) Mechanically ventilated kitchens shall be designed for a ventilation rate of not less than 20 air-changes per hour as given in Table 2.1. When kitchen hoods are in operation, the exhaust air through the hoods can be considered as contributing to the exhaust requirement for ventilation.

In large kitchens, areas are sub-divided to form wash-ups, preparation, pantry, stores and services, etc. These areas shall be provided with a minimum ventilation rate of ten air changes to create a feeling of comfort.

(2) Sufficient make-up air shall be provided and negative pressure in the kitchen area shall be maintained when the kitchen hood is in operation. Whether or not the kitchen hood is in operation, the kitchen shall be provided with ventilation in accordance with Table 2.1.

Considerable quantities of steam and radiant heat are given off and a good rate of ventilation should be provided, and partial air conditioning considered if the restaurant is air conditioned. However, care should be taken to ensure that food is not subject to cold draughts.

2.3.2 Kitchen Exhaust Hoods

(1) Exhausts from hoods designed to capture smoke and/or grease-laden vapor produced by a cooking process, incorporated with grease-removal devices and fire-suppression equipment shall be directed away from roofs and building surfaces. Exhaust discharge shall not impinge on obstacles such as parapets, overhangs and other equipment and higher parts of buildings.

(2) Washable grease filters with standby units shall be located within the hood as close to the major heat source as practical.

(3) Mechanical exhaust system for the cooking area of a kitchen in a hotel, restaurant, coffee house or the lime shall be independent of those serving other parts of the building.

(4) Kitchen-exhaust hoods shall be installed above appliances of heating capacity greater than 8 kW and likely to generate grease vapor (e.g. ranges, fryers, barbecues). Where grease is present, kitchen hoods incorporating grease filters shall be used.

(5) Exhaust air flow shall be suitably distributed over the exhaust hood to capture the cooking vapor emission under still air conditions, which will be considered as room air motion not exceeding 0.15 m/s velocity.

(6) Kitchen exhaust hoods shall be manufactured from rigid impervious hard-faced and non-combustible materials, such as mild steel, stainless steel or aluminum.

(7) The seams shall be made liquid-tight seams and the joints made by fusion welding, lapping, and riveting, soldering; or other approved methods.

(8) Hoods shall be fitted with washable grease fitters mounted in frames in positions enabling convenient removal and replacement, and installed so as to prevent significant leakage of air around the filters.

(9) All internal surfaces of hoods shall be vertical or sloped at an angle not greater than 40^{O} from vertical. The faces of filters shall be vertical or sloped at an angle not greater than 30 ^{O} from vertical.

(10) It should be possible to assess the pressure drop of the ventilation air as it flows across the grease filter.

(11) Gutters shall be located beneath any protruding surface or edges such as lower edges of filters, except light fittings inside hoods. Internal gutters not greater than 50mm or less than 35mm wide and not less than 10mm deep shall be located around the lower edges of hoods. Plugged drainage holes shall be provided at intervals not greater than 6m along the gutter.

2.3.3 Canopy Type Hoods

(1) The lower edges of canopy type exhaust hoods shall be not higher than 1.2m above the cooking surface nor lower than 2m above floor level; and extend not less than 150mm outside the plan perimeter of the appliance over which the hood is installed.

(2) For appliances requiring a kitchen exhaust hood, the exhaust flow rate Q[m3/s] shall not be less than that given in the following formula, if it is an "island" hood:

$$Q = 1.4V * 2(L + W)H * F$$

Where:

V = Capture velocity which shall not be less than 0.30 m/s for commercial type kitchens

L = Length of cooking surface, m

W = width of cooking surface, m

H = Distance of hood to emitting surface, m

F = 1.0 for heavy duty high temperature, grease burning, deep-fat frying cooking with equipment such as works, broilers, char-broilers normally associated with solid or gas fuel burning equipment

F = 0.7 for light duty, medium and low temperature cooking with equipment such as ovens, steamers, ranges, griddles and fryers.

For wall-mounted hood, it can be considered as part of an island type hood composed of actual hood and its mirror image in the wall. Thus the above formula can also be applied and corrected.

Kitchen exhaust shall be discharged directly to the exterior and away from the habitable areas of the building. It shall not be less than 5m from any air intake openings.

2.3.4 Ducts

(1) Kitchen-exhaust ducts and shafts shall be sized and installed for the flow rate of air necessary to remove the effluent. Velocities of not less than 9m/s are recommended with the provision of access doors for cleaning at approximately 3m centers.

(a) Ducts forming part of a kitchen exhaust system shall be manufactured from:

(b) Mild steel of thickness not less than 1.2 mm, or

(c) Stainless steel of thickness not less than 0.9mm, or

(d) Other approved materials.

(2) Ducts shall be installed with a fall in the direction of flow of not less than 0.5%. To enable cleaning of all the ductwork, openings large enough shall be provided at suitable intervals and locations, and/or appropriate cleaning apparatus/systems shall be incorporated. A drain shall be provided at the lowest point of each run of ducting.

(3) The hood and ducts for the exhaust shall have a clearance of 500 mm from unprotected combustible materials.

(4) Where the exhaust duct runs outside the kitchen it shall either be enclosed in a structure or be constructed to give at least the same fire rating as the kitchen or that of the room through which it traverses, whichever is higher. The rating shall apply to fire exposure from both the internal and external part of the duct or structure. Where the duct riser is required to be enclosed in masonry shaft, it shall be compartmentalized from the rest of the shaft space containing other ducts or services installations.

(5) Fire damper shall not be fitted in kitchen exhaust ducts.

2.4 Bathrooms and toilets ventilation

Bathrooms, toilets and locker rooms shall be mechanically ventilated according to the following.

(1) Air shall be supplied through a ventilation duct directly from the outdoor or from a permanently air-conditioned or naturally ventilated room through louvers in the doors or undercutting the doors or by other openings;

(2) The exhaust system shall dispel the ventilated air directly to outdoors; and the quantity of replacement air shall not exceed that of exhaust air.

2.5 Exit facilities ventilation

2.5.1 Exits staircase and internal exit passageway

The ventilation system for exit staircase and internal exit pass way shall comply with the following.

(1) Mechanical ventilation systems and internal exist staircase and internal exit passageway shall provide ventilation at the rate of four air changes per hour.

(2) Supply air shall be drawn directly from the exterior with intake point not less than 5m from any exhaust discharge or opening ventilation.

2.5.2 Smoke stop and fire fighting lobbies

(1) The ventilation system shall function I supply mode only and it shall provide ventilation at the rate of four air changes per hour .Upon activation by the building fire alarm system it shall supply at not less than ten air changes per hour.

(2) Supply air shall be drawn directly from the exterior with intake point not less than 5m from any exhaust discharge or openings for natural ventilation.

2.6 Pressurization systems

Design and operation of pressurization systems for exit facilities shall comply with the requirements ES EN 12101-6:2005

SECTION 3 Air Conditioning system

3.1 General

Air conditioning is the control of the temperature and humidity of a zone inside a building that accommodates internal heat gains and exchanges heat and air with the surrounding. The air is filtered, heated or cooled as necessary and moisture is added or extracted to give a controlled humidity.

This section deals with data assumption and methodologies necessary to determine the cooling or heating load and fresh air requirement.

3.2 Design Requirements

3.2.1 Equipment used in air-conditioning shall have minimum performance in accordance with the level of current technology.

3.2.2 Cooling systems design loads for the purpose of sizing systems and equipment shall be determined in accordance with generally accepted engineering standards and handbooks using Heat Balance (HB) and Radiant Time Series (RTS) or equivalent methods given in annex II.

3.2.3 The normal design dry-bulb temperature for comfort air-conditioning can vary from 23 °C to 25 °C with the lower temperature applicable to zones with solar load and the higher value in all other zones.

3.2.4 When a space has significant sensible equipment load, care should be taken for situations when the equipment is operating at part-load.

3.2.5 The specification of indoor conditions shall take into considerations the anticipated mean radiant temperature and air movement.

3.2.6 The design outdoor air conditions shall be taken for dry-bulb and wet-bulb with a daily range calculated between maximum and minimum temperatures. The dry-bulb temperature value shall exceed more than 2.5% of the total hours during and the wet-bulb value is the average of the coincident wet-bulb temperature occurring at the design dry-bulb temperature. These temperatures are given in Annex I for some cities in Ethiopia.

3.2.7 The load contribution from the outdoor air introduced into a building for ventilation shall be calculated.

3.2.8 The load contribution from outdoor air infiltrating into a building shall be calculated by the procedures in Annex II.

3.3 Indoor thermal environment

When the air-conditioning system is in operation, the operative temperature should be maintained within 23 °C and 25 °C and the air movement should not exceed 0.3 m/s, measured at the occupants' level 1500 mm from the floor.

3.4 Outdoor fresh air supply

The rates of ventilation given in Table 3.1 apply to normal types of buildings with normal heat gains from occupants and activities and no-smoking in air-conditioned spaces. When abnormal conditions prevail, the ventilation rate may be increased to prevent undue concentration of body odors, bacteria-carrying particles, gas, vapor or dust and to prevent undue accumulation of carbon dioxide and to remove products of combustion.

3.4.1 For any type of room or floor space not specified in this section, the ventilation rate shall be determined by the qualified person subject to the approval of the relevant authority.

3.4.2 In air-conditioned office premises, classrooms and theatres, the supply of outdoor air can be varied according to occupancy.

Table 3.1. Outdoor Air Supply Requirement for Comfort Air-conditioning

Type of building/ Occupancy	Minimum outdoor air supply		
	l/s per m^2 floor area	m^2/h per m^2 floor area	l/s per person
Restaurant	3.4	12.2	5.1
Dance halls	7.0	25.0	10.5
Offices	0.6	2.0	5.5
Shops, supermarkets and department stores	1.1	3.8	5.5
Theatres and cinemas seating area	2.0	7.3	3.0
Lobbies and corridors	0.3	1.1	3.3
concourses	1.1	4.0	3.3
Hotel guest rooms	15 l/s per room	54 m^3/h per room	5.5
Primary school children	2.8	10.0	4.2

and above			
Childcare centers	2.8	10.0	8.4

NOTE:

i) Dance halls refer to night clubs. The outdoor air supply in discotheques requires 50% more than that in dance halls.

ii) The use of higher outdoor air supply in hotel guest rooms stipulated in Table 3.1 should take precedence.

3.4.3 Unless there is monitoring and control of the concentration of carbon dioxide indoors, the design outdoor air quantity should be maintained during the air-conditioning operation.

3.4.4 In existing building, where the air-conditioning systems have been designed for a lower ventilation rate, the indoor air quality can be improved by using suitable filters for the particulates or gases.

3.5 Indoor supply air

3.5.1 The cool supply air should be directed away from the fenestration glazing or the glazing adjacent to a non air conditioned area to prevent moisture condensing on the outside surface.

3.5.2 The cool air leaving the supply diffuser should be designed at a temperature less than 2 °C above the room dew point to prevent moisture condensing on the diffuser surface.

3.6 Purging of indoor air

In the event that the indoor air quality becomes unacceptable, because of renovation or other reasons, it should be possible to purge the contaminants from the affected floor without affecting the rest of the building.

3.6.1 For air-conditioned buildings, an air purging system should be provided at each floor so that contaminated air can be exhausted when necessary to improve the indoor air quality.

3.6.2 The air purging system should be able to introduce outdoor air into the space and then discharge the indoor air to outside the building at a minimum rate of 2 air-changes per hour.

3.6.3 The capacity of the exhaust fans shall be higher than the flow rate of the outdoor air introduced in to the space.

3.6.4 For building with fixed windows, the outdoor air for purging can be supplied by the fan for air- conditioning or others

3.6.5 The exhaust discharge shall be at least 5m from the outdoor air intake of another system

3.7 Air filtration

The particulate contaminants in the air in an air-conditioned space should be continuously removed in order to maintain the cleanliness of the air.

3.7.1 Outdoor air for ventilation and indoor air that is to be re-circulated should be filtered for particulate.

3.7.2 It should be possible to assess at any time the condition of the air filter and the pressure drop across it.

3.8 Control

3.8.1 The design of the control system shall allow operation to utilize energy efficiently while maintaining the desired indoor conditions.

3.8.2 When an air-conditioning system has to serve areas with different cooling requirements, sufficient number of zones shall be provided.

3.8.3 At least one thermostat of suitable operating range shall be provided to each separate air-handling system and zone for the regulation of space temperature.

3.8.4 A readily accessible manual or automatic means shall be provided to partially restrict or shut of the cooling to each zone.

3.8.5 Air-conditioning systems shall be equipped with at least one of the following to enable them to shutdown automatically.

(1) Controls that can start and stop the system under different time schedules for seven different days per week with manual override, or equivalent function that allows temporary operation of the system for up to two hours.

(2) An occupant sensor that is capable of shutting the system off when no occupant is sensed for a period of up to 30 minutes.

3.8.6 The following systems are exempted from automatic shutdown requirements given in 3.8.5.

(1) Systems serving hotel guestrooms;

(2) Systems intended to operate continuously; and

(3) Systems having cooling capacity less than 4.4 kW that are equipped with readily accessible manual on/off controls.

3.8.7 Zones that are intended to operate or be occupied non-simultaneously should be grouped into isolation areas.

(1) Central systems and plants serving these zones are provided with controls and devices that enable a stable system and equipment operation for any length of time while serving only the smallest isolation area; and

(2) The systems serving each isolation area, besides meeting the requirements of 3.7.5 for automatic shutdown, are also equipped with isolation devices and controls that can isolate them from the supply of outdoor air and the exhaust system.

3.8.8 The following are exempted from isolation devices and controls requirements of 3.8.5 for automatic shutdown, are also equipped with isolation devices and controls that can isolate them from the supply of outdoor air and the exhaust system.

(1) Exhaust air and outdoor air connections to isolation zones when the fan systems to which they are connected is 2.4 m^3/s and smaller;

(2) Exhaust airflow from a single isolation zone of less than 10% of the design airflow of the exhaust system to which they connect; and

(3) Zone intended to operate continuously or intended to be operated only when all other zones are inoperative.

3.8.9 The dampers used in all outdoor supply air and exhaust systems serving air-conditioned spaces should shutoff automatically when the spaces are not in use.

3.8.10 During the pre-occupancy building cool-down, the outdoor air dampers should shutoff automatically.

3.8.11 Control of indoor thermal environment by reheating the air shall not be allowed except for energy source from site-recovered energy (including condenser head) or site-solar energy.

3.8.12 A minimum of one of the following control technologies shall be required in hotel guest rooms with over 50 rooms such that all the power to the lights and switched outlets in hotel guest room would be turned off when the occupant is not in the room and the space temperature would automatically set up by no less than 3 °C.

(1) Controls that are activated by the room occupant via the primary room access method-key, card, deadbolt;

(2) Occupancy sensor controls that are activated by the occupant’s presence in the room.

SECTION 4 Ventilation and Air Conditioning Equipment

4.1 Ventilation Equipment

4.1.1 Fans

(1) General requirement

(a) For fan systems which provide a constant air volume whenever the fans are running, the power required by the motor for the combined fan system at design conditions shall not exceed .47w per m^3/hr of supply air.

(b) For fan systems which are able to vary system air volume automatically as a function of load, the power required by the motor for the combined fan system at design conditions shall not exceed .74w per m^3/hr of supply air.

(2) Fans selection

Selection of fans shall take the following into consideration.

(a) Fans shall be selected for stable performance based on normal temperature and, where applicable,

(b) Calculations and manufacturer's fan curves shall be part of the documentation procedures. Selection should favor the more efficient fan types and ensure that the fans will be operating at peak efficiency.

(c) Motors driving fans shall have a minimum service factor of 1.15

(d) Motors driving fans shall not be operating beyond their nameplate horsepower (kilowatts) as determined from measurement of actual current draw.

(e) Air volume.

(f) System resistance.

(g) Entering air condition (moisture, industrial, air density,

(h) Barometric pressure, altitude at installation location.

(i) Type of application, industrial, residence, commercial.

(j) Space available for installation.

(k) Fan connection type and size.

(l) Type of drive and arrangement, requirements of drive adjustment, type of bearing, drive guards, speed control, or stand by.

4.2 Air conditioning equipment

4.2.1 Air handling unit

When selecting air handling units, the following shall be considered.

(1) Finned coils used in an air handler should not be more than 8 rows deep.

(2) The air handler should be constructed and installed such that the condensate from the cooling coil can be completely drained out of the AHU.

(3) The condensate from the cooling coil shall be provided with trap on leaving the air handler and there should be an air break between the condensate drain pipe and sanitary drain system to avoid back flow.

(4) The air handler unit shall have sufficient access for cleaning and maintenance and the inner surface shall be easy to clean and shall be abrasion resistant.

(5) The air handling unit shall have electrical power isolating switch on the unit or adjacent to the unit within 3 meters distance for maintenance and quick shut down purpose. For Air handling units installed in open space the electrical isolating switch shall be all weather resistant.

4.2.2 Chillers

When selecting chillers, the following shall be considered.

(1) The refrigerant gas used for the chiller shall be non-CFC.

(2) The chillers shall have COP value of the chiller shall be in the range of current technology.

4.2.3 Direct Expansion (DX) units

In VRF and other DX systems the following shall be taken care of

(1) When brazing copper pipe it is vital that ingress of dirt is avoided as this could lead to internal blockages, especially in systems with capillary tube expansion devices.

(2) The quality of on-site brazing and care to prevent dirt ingress and poor layout is crucial. Installers and blazers shall be qualified and competent personnel following industry good practice working methods.

(3) Particular care is needed where VRF systems are installed in rooms where people may sleep, such as hotel bedrooms. The use of refrigerant detectors and alarms should be considered in these situations.

(4) Refrigerant leakage: demountable flare and screwed joints should be avoided wherever possible to minimize the risk of leakage. The number of joints should be minimized.

4.2.4 Heat recovery units

(1) Heat recovery devices shall be used in ventilation systems to provide heat recovery from exhaust to supply air in winter and can also recover cooling in peak summer conditions.

(2) Selection of equipment should be suitable for process exhaust temperatures. Where the recovered heat is fed to a ventilation system, modulation control is normally required to prevent overheating in warm weather.

4.2.5 Air Heating Equipment

When selecting air heaters the following shall be fulfilled

(1) Air heating media can be electricity, hot water, steam or refrigerant gas.

(2) Air heating coils shall be manufactured from materials which shall resist corrosion and can provide good conductivity.

(3) The operation of heaters shall be through automatic temperature control system, in order to meet the set room temperature value.

4.2.6 Fan coil unit

When selecting fan coil units the following shall be considered

(1) Chassis shall be manufactured from 1.2mm thick Galvanized sheet metal.

(2) Fans have to be direct drive forward curved double inlet centrifugal type. Both the impellers & impeller housings to be made of galvanized steel. Fan & motor assemblies to be mounted separately to the fan deck assembly.

(3) Coils have to be manufactured from seamless copper tube, mechanically expanded onto aluminum fins.

(4) The Condensate Tray / Fan Deck cover and the entire coil shall have a positive fall to the drain point.

(5) Electrical control enclosure has to be fitted on the Fan coil unit.

(6) Filter unit have to be fitted on the suction side and shall be easily removable for maintenance.

4.3 Sound and Vibration

4.3.1 General

(1) Sound and vibration in an air conditioning and ventilation system arise from mechanical and electrical equipment and from the flow of water through pipes and the flow of air through ducts and grills.

(2) Table 4.1 gives recommended design criteria (for guidance only) to assist designers in providing acoustical environment within the occupied spaces in building compatible with the activities and areas mentioned

Table 4.1. Recommended Ambient Sound Level

Area	Low dBA	Average dBA	High dBA
Cinema theatres	-	35	40
Private executive type offices	35	40	45
General offices other private or semi private offices	40	45	50
Conference rooms	35	40	45
Air-Condition Classrooms	40	45	50
Hotel bedrooms	35	40	45
Hospital wards	35	40	45
Places of public resort e.g. shops	40	50	55
Circulation areas e.g. staircases, lobbies, car parks	50	55	60
Factory	70	72.5	75
Studio	25	27.5	30

4.3.2 Noise controlling

(1) General

In HVAC systems, controlling noise that can be generated from equipments and systems shall be implemented through the following guide lines

(2) Fans

(a) Choosing the operating condition of the fan so that it is at a high efficiency point on its characteristic; this minimizes fan noise.

(b) Ensuring good flow conditions for the air stream; the consequent benefits include components behaving more nearly as described in the manufacturer's data and reduced pressure losses, conserving energy and saving operating costs.

(c) Isolating vibrating components, including all machinery, ducts and pipe work from the structure.

(d) Installing flexible duct between equipment (air handler, fans) and duct connection.

(e) Choosing an in-duct silencer or other means to control airborne noise in ducts; a full silencer may not be required, as lining bends with acoustic absorbent may be adequate, but this depends on the results of noise predictions.

(f) Where fan noise will be a problem, sound attenuator should be used to meet the required sound level through attenuation.

(3) Pumps

Pumps produce external noise from the motor, fluid-borne noise from the impeller and vibration into both the structure and the pipes. Noise problems may arise from the airborne noise, controlled by choosing a non-sensitive location or by an enclosure for the pump. It is necessary to:

(a) Use vibration isolators to isolate the pump from the building.

(b) Use a flexible connection from pump to pipes.

(c) Use resilient mountings for supporting the pipe to the structure.

(4) Control of noise transmission in ducts and building elements

Proper installation and duct manufacturing shall be considered to eliminate noise generation and transmission through duct works particularly on the following.

(a) Bends (elbows), right angled or curved.

(b) Branches, which may have one or more take-offs.

(c) Distribution boxes (plenums).

(d) Terminal units, such as grilles, diffusers and registers.

(e) Seal all wall penetration with flexible material. This reduces both noise and vibration.

(f) Choose the location and selection of external plant and air grilles to avoid noise disturbance to nearby properties.

(5) Vibration isolators

Vibration isolators shall be mounted underneath the equipment and type strength of the vibration isolators to match the load requirement. The following types of vibration isolators can be used.

(a) Spring inertia bases

(b) Pads

(c) Elastomeric mounts

(d) Helical spring pedestal mounts

(e) Helical spring/elastomeric hangers

(f) Pipe/duct flexible connectors

4.4 Installation Requirements of HVAC Equipments

4.4.1 General

Ventilation and air conditioning system equipments comprise, but not limited to the following: Fans, air-handling units, fan-coil units, DX terminal units, Chillers, condensers controllers, sensors, fire dampers, and volume dampers.

4.4.2 Installation location

When selecting a site or room for the location of any piece of equipment, various factors shall be considered including the following.

(1) Equipment type (Indoor, outdoor).

(2) Hoisting for initial installation and future maintenance, or replacement works

(3) Transmission of noise to adjacent areas

(4) Discharge of heat to and from adjacent buildings

(5) Ventilation requirements

(6) Space for service access, operational requirements and future expansion

(7) Support structure for equipment, ducts, etc

(8) Utilities connections

(9) Fire hazard, protection and construction of fire rating wall.

(10) Safety of working, and maintaining personnel

4.4.3 Equipment clearance and space requirement

(1) Ventilation equipment shall be installed with sufficient working space for inspection and routine maintenance (e.g., filter replacement and fan belt adjustment and replacement).

(2) All gauges, meters, should be installed in such a way that they are easily readable and replaceable.

(3) All sensors shall be installed in such a way that they are easily accessible for regular calibration.

(4) Access panels shall be provided for VAV boxes, Fan coil units, Electric heaters, Valves, fans and any accessories concealed in a closed space wall or ceiling.

(5) Platform supported equipments shall have enough space for maintenance and shall be provided with cat walk. Such concealed units shall have good sound insulation and vibration isolation devices.

4.4.4 Installation techniques to consider vibration control in HVAC systems

Vibration in HVAC systems shall be controlled by considering the following installation techniques.

(1) Choose a good location for the plant, remote from sensitive areas. This also helps for noise control.

(2) Ensure that vibration isolation is properly installed with no bridging material across the flexible mountings.

(3) Ensure that vibration isolators are loaded to give equal deflections and installed to maintain vertical alignment of their springs and other components.

(4) Isolators shall be aligned with the equipment as misaligned isolators are a source of many problems.

(5) Check support bolts for integrity and free movement.

(6) Do not neglect vibration from pipes and ducts.

(7) Use flexible attachments to the structure.

4.4.5 Ventilation Equipment Access

(1) Access doors, panels, or other means shall be provided and sized to allow convenient and unobstructed access sufficient to inspect, maintain, and calibrate all ventilation equipments.

(2) System components for which routine inspection and maintenance, or calibration is necessary.

4.4.6 Fans

(1) Fans shall be supported and restrained by noncombustible devices in accordance with the structural design requirements.

(2) Motors and drives shall be easily accessible for operation, maintenance and repairs, and all rotating parts shall be guarded adequately.

(3) Sufficient clearance and access shall be provided for inspection, cleaning and maintenance.

(4) Air passage duct connection with the fan unit shall be through flexible duct.

(5) The flexible duct materials shall be made of material classified as not easily ignitable and shall not exceed 250mm in length.

4.4.7 Equipment connection to duct

Equipment connection to ducting shall be through the use of flexible duct.

4.4.8 Drain Outlet

(1) The drain pan outlet shall be located at the lowest point(s) of the drain pan and shall be of sufficient diameter to preclude drain pan overflow under any normally expected operating condition and shall have an “S” trap to prevent ingress of smell.

(2) Pipe runs to drain liquid water shall be installed with a minimum of 1% slope.

4.4.9 Air Heating Equipment

(1) When installing Maintenance access shall be provided to access the heating equipment for servicing and maintenance.

(2) Electrical heaters shall be interlocked with the fan motors to avoid the switching of the heaters without the air blowing, and all electric heaters shall have controls such as thermostat and over heat protection.

4.4.10 Pumps

(1) Use vibration isolators to isolate the pump from the building.

(2) Use a flexible connection from pump to pipes.

(3) Use resilient mountings for supporting the pipe to the structure.

(4) Fit non return valve on the discharge side of the pump.

(5) Strainer shall be fitted at the pump suction side for domestic water application.

(6) Isolating valves to be fitted on both suction and discharge side for maintenance purposes.

SECTION 5 Ductwork and Accessories

5.1 General

This section applies to the design, construction and installation of the air duct system including fittings and accessories for mechanical ventilation and air-conditioning.

5.2 Design Considerations

5.2.1 General

(1) In designing the ductwork for an air distribution system, consideration should be given to the air velocities in ducts, choice of materials and construction of the ducts, etc.

(2) For the best economic solution, the duct system shall be designed at the smallest aspect ratio in co-ordination with the space available for duct installation.

(3) Maximum velocity for different applications shall be in accordance with table 5.1 for the pressure class shown in table 5.2

Table 5.1. Maximum Velocities for Low Pressure Ducting Systems

Application	Velocity (m/s)	
	Main duct	Branch duct
Theatres, auditorium, studios	4.0	3.0
Hotel bedrooms, conference halls, operating theaters	5.0	3.0
Private offices, libraries, cinemas, hospital wards	8.0	4.0
General offices, restaurants, department stores	7.5	5.0
Cafeteria, supermarkets, machine rooms	9.0	8.0
Factories, workshops	12.0	7.5

Table 5.2. Duct system classification

Duct pressure class	Static pressure limit		Mean air velocity (m/s)
	Positive (Pa)	Negative (Pa)	
Low	500	500	10
Medium	1000	750	20
High	2500	750	40

(4) Ventilation ducts should not pass through smoke-stop, fire fighting lobbies or fire exits. Where unavoidable, fire or smoke dampers shall be installed at the location where duct crosses fire wall.

(5) A concealed space between the ceiling and floor above it, ceiling and roof, or raised floor and structural floor of a building may be used as a plenum provided that:

(a) The concealed space is free of obstruction, so as to permit free flow of air;

(b) The concealed space contains only materials and services in compliance with the Code of Practice for Fire Precautions in Buildings; and

(c) The supports for the ceiling membrane are of non-combustible material.

(6) Air ducts shall be made substantially air tight throughout, and shall have no openings other than those required for proper operation and maintenance of the system. Access openings shall be provided where debris, paper or other combustible materials may accumulate in plenums and ducts. Removable grilles requiring only the loosening of catches or screws for removal may be considered as access openings.

5.2.2 Outdoor air intakes

(1) Outdoor air intakes shall be covered with an insect screen and protected from rain entrainment. Screening shall be of corrosion resistant material not larger than 10mm mesh.

(2) Outdoor air intakes should be protected from water droplets such that no water droplet can enter the ventilation air stream.

(3) Outdoor air intakes as bird screens/exhaust outlets shall include screening devices designed to prevent by a 15 mm diameter probe.

5.2.3 Locations of intakes and return air openings

(1) The location of outdoor air intakes for air-handling systems shall take due account of any other intake openings for ventilation or exhaust. The intakes of outdoor air to all air-conditioning and mechanical ventilation systems, including those of the ventilation and pressurization of stair shafts, shall be located at external walls or at roof level, arranged so as to pick up outdoor air free of contamination or odors.

(2) Openings for the intakes of outdoor air to all air handling systems, mechanical ventilation systems, pressurization systems of exit staircases and internal corridors, and smoke control systems shall be no less than 5m from any exhaust discharge openings.

(3) Outdoor air intakes shall not be within 5m of exhaust discharges from any buildings, kitchens, toilets, car parks, cooling towers, laundries, rubbish dumps or plant rooms.

The distance from an air intake to a cooling tower is measured from the base of the cooling tower.

(4) All return air openings and outdoor air intakes shall be so located and arranged that sources of ignition such as lighted matches and cigarette butts accidentally entering the openings and intakes shall not be deposited onto the filter media.

(5) For air-conditioned spaces, the bottom of the outdoor air intakes shall not be less than 2.1m above the outside floor level, when the air intakes are adjacent to car parks or busy area.

(6) Exhaust ducts from toilets and domestic kitchens shall not be connected to duct systems serving other areas except at the inlet of the exhaust fan. Where such connection is made, devices shall be installed to prevent the circulation of exhaust air though the dwelling units when the fan is not operating. Exhaust ducts for industrial or commercial kitchens shall be of a separate system.

(7) Exhaust ducts shall discharge directly to the outdoors. When exhausts are adjacent to pedestrians' area, the location of the exhaust air discharge shall not be less than 2.1m above the outside floor level.

(8) Ducts shall not be located where they will be subject to damage or rupture. Where so located they shall be suitably protected.

(9) Return air ducts should be routed away from toilets or places where odors are expected and may re-circulate into the supply air stream.

5.3 Duct Construction

5.3.1 General

(1) The inner surfaces of the ducts for supply and return air should be smooth and resistant to abrasion to reduce dust accumulation.

(2) Where ceiling space is used as a return air plenum, the ceiling and the side-walls should be properly plastered and painted. Masonry ducts should be finished in a similar manner where possible.

(3) Rigid ducts shall be manufactured from steel, aluminum, glass-fiber matt or mineral wool or other approved materials. Ducts or duct linings where glass fiber matt or mineral wool is exposed to the air stream shall be suitably protected to prevent erosion of fibers.

(4) Ducts shall be sturdily supported. Hangers and brackets for supporting ducts shall be of metal.

(5) Flexible connections at the extremity of ventilation duct work connecting terminal units, extract units and ventilation grilles shall not exceed 1m.

(6) Flexible joints, which are normally provided to prevent and/or allow for thermal movements in the duct system, shall not exceed 250mm in length.

(7) Flexible joints shall be made of material classified as 'not easily ignitable' when tested under British Standard BS 476: Part 5.

(8) Ducts shall be installed with openings at suitable intervals and locations to enable cleaning of all the ducts.

(9) The construction and support of air ducts, fittings and plenums, including joints, seams, stiffening, reinforcing and access openings shall conform to the appropriate requirements of the duct construction standards contained in ASHRAE Handbook or SMACNA Manuals.

5.3.2 Ducts and plenum sealing

Ductwork and plenums shall be sealed in accordance with table 5.3.

Table 5.3. Ductwork seal requirement

	Duct type		
Duct location	**Supply**	**Exhaust**	**Return**
Outdoor	A	C	A
Unconditioned space	A	B	A
Conditioned space	A	B	A

Where:

A. All transverse joints, longitudinal seams and penetrations in duct wall. Pressure sensitive tape shall not be used as primary sealant.

B. All transverse joints and longitudinal seams. Pressure sensitive tape shall not be used a s primary sealant.

C. Transverse joints only.

Longitudinal seams are joints in the direction of the airflow. Transverse joints are connections of two duct sections orientated perpendicular to airflow direction. Penetrations in duct walls are any openings made by screw, pipe, rod or wire.

5.3.3 Duct leakage test

Ductwork designed to operate at static pressures in excess of $750p_a$ shall be leak tested in accordance with industry accepted test procedures. Representative sections totaling no less than 25% of the total installed duct area for the designated pressure class shall be tested. Duct systems with pressure ratings in excess of $750p_a$ shall be identified on the drawings. The maximum permitted duct leakage shall be in accordance to the formula:

$$L_{max} = C_L (P^{0.55} / 1000)$$

Where;

- L_{max} = maximum permitted leakage in l/s.m2 duct surface area
- C_L = duct leakage class, ml/s.m2 at 1 Pa
- C_L = 8 for rectangular sheet meal, rectangular fibrous and round flexible ducts
- C_L = 4 for round/flat oval sheet metal or fibrous glass ducts
- P = Test pressure, which shall be equal to the design duct pressure rating, Pa

5.3.4 Tapes and sealant

Tapes and sealants used for sealing joints in air ducts, plenums and other parts of air ducts systems shall be subject to approval.

5.4 Fire dampers

5.4.1 Fire damper shall have a fire resisting rating of not less than that required for the compartment wall or compartment floor though which the relevant section of the ventilation duct passes.

5.4.2 Fire dampers shall be installed so that the casing completely penetrates through the compartment wall or floor.

5.4.3 Flanges shall be butted against the face of the compartment wall or floor and fixed to the damper casing.

5.4.4 The space between the fire damper body and the opening on the wall or floor shall be fire stopped.

5.4.5 On big size ducts access door to be provided on downstream or upstream with dimensions not less than 450mm by 450mm.

5.5 Pipe work

5.5.1 General

This section applies to the design and installation of the piping system for air-conditioning installation.

5.5.2 Design considerations

(1) In designing and planning the layout of the pipe wok, due attention should be given to the choice of material, rate of flow, accessibility, protection against damage, corrosion, avoidance of airlocks, water hammer, noise transmission, unsightly arrangement, vibration and expansion of fluid, stress and strains, etc.

(2) Every pipe used shall be designed to have adequate strength and durability. Pipes shall be adequately supported. Hangers and brackets for supporting pipes shall be of metal.

5.5.3 Installation

(1) Materials for piping and associated firings shall be suitable for the intended service.

(2) Sufficient unions or flanged fittings and values shall be provided for disconnecting equipment, controls, etc.

(3) Standard fittings such as tees, elbows, etc, shall be used; fittings fabricated by welding together segmented pieces are not recommended.

(4) The construction and support of pipes, fittings and valves shall conform to the applicable requirements of the pipe construction standards contained in the ASHRAE Handbook, IHVE Guidebooks or other recognized piping Handbooks.

(5) All installed pipe work which is intended to contain/convey pressurized fluid shall be pressure tested at 1.5 times working pressure.

(6) Thermal insulation for pipe work associated with air-conditioning and mechanical ventilation system shall have fire resistance rating equal to the space element of structure through which they are passing.

(7) Any opening in the element of structure or other parts of the building penetrated by the pipe work shall be effectively fire-stopped by replacement of the insulation material at the junction of penetration with fire resistant materials having an equal fire rating. Fire rated proprietary pipe work system may be used if it is tested in the manner acceptable to the relevant authority.

5.6 Thermal insulation

5.6.1 General requirements

(1) Thermal insulation shall be installed in accordance with industry accepted standards.

(2) Thermal insulation shall be protected from damage including that due to sunlight, moisture, equipment maintenance and wind, in accordance with the following:

(a) Insulation exposed to weather shall be suitable for outdoor service, protected by aluminum sheet metal. Cellular foam, where permitted under Code of Practice for Fire precautions in Buildings, shall be protected as above or painted with a coating that is water retardant and provides shielding from solar radiation that can causes degradation of the material; and

(b) Insulation covering chilled water piping, refrigerant suction piping or cooling duct located outside the conditioned space shall be sealed against vapor and located outside the (unless the isolation is inherently vapor retardant), all penetration and joints in the vapor seal shall be sealed.

5.6.2 Duct and plenum insulation

(1) All supply and return ducts and plenums, installed as part of a conditioned air distribution system shall be thermally insulated in accordance with Table 5.4.

Table 5.4. Minimum Duct Insulation R-values for Cooling only Supply Ducts and Return Ducts

Duct location	R-value (m^2K/W)*
Exterior	1.06
Ventilated attic	1.41
Unvented attic above insulated ceiling	1.77
Unvented attic with roof insulation	1.06
Unconditioned space	1.06
Buried	1.06
Indirectly conditioned space	None

*** NOTE:** Insulation R-values (m^2K/W) are for insulation installed and do not include film resistance. The required minimum thickness does not consider water vapor transmission and possible condensation.

(2) The following are exempted from requirements given in (1) above.

(a) Factory installed plenums, casings, or ductwork furnished as part of air-conditioning equipment tested and rated in accordance with the relevant standards;

(b) Ducts of plenums located in conditioned space;

(c) Connections less than 3m in length to air terminals or air outlets, for which the rated insulation thickness need not exceed 0.6m^2k/W; and

(d) Backs of air outlets and outlet plenums exposed to unconditioned or indirectly conditioned spaces with face area exceeding 0.5m^2, for which the insulation need not exceed 0.4 m^2K/W and those 0.5m^2 or less need not be insulated.

5.6.3 Piping insulation

(1) Piping shall be thermally insulated in accordance with Table 5.5. For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows:

$$T = r\left[(1 + t/r)^{k/t} - 1\right]$$

Where;

T = minimum insulation thickness, mm

r = actual outside radius of pipe, mm.

t = insulation thickness listed in Table 5.5 for applicable fluid temperature and pipe size.

K = conductivity of alternate material at mean rating temperature indicated for the applicable fluid temperature, W/(m.k)

k = the upper value of the conductivity range listed in Table 5.5 for the applicable fluid temperature

(2) The following are exempted from the requirements given in (1) above

(a) Factory installed piping within air-conditioning equipment tested and rated in accordance with the relevant standards;

(b) Piping that convey fluids having a design operating temperature range between 16 ^{0}c to 41 ^{0}C, inclusive; and

(c) Piping that convey fluids that have not been heated or cooled such that heat gain or heat loss will not increase energy usage.

Table 5.5. Minimum Pipe Insulation Thickness for Heating and Cooling Systems *

Fluid design operating temp range (^{0}C)	Insulation conductivity		Nominal pipe or tube size (mm)			
	Conductivity (W/m.K)	**Mean rating temp (^{0}C)**	**<25**	**25 to <38**	**38 to < 102**	**102 to 203 ≤**
Heating systems (steam, steam condensate and hot water)						
> 176.7	0.0461 – 0.0490	121.1	76	89	89	114
121.7 – 176.7	0.0418 – 0.0461	93.3	51	76	89	89
93.9 – 121.1	0.0389 – 0.0433	65.6	51	51	63	63
60.6 – 93.3	00361 – 0.0418	51.7	38	38	38	51
40.6 – 60.0	0.0317 - 0.0404	37.8	25	25	25	38
Cooling system (chilled water, brine and refrigerant)						
4.4 – 15.6	0.0317 – 0.0404	37.8	25	25	38	38
< 4.4	0.0317 – 0.0404	37.8	25	38	38	38

***NOTE:**
1. These thicknesses are based on energy efficiency consideration only. Issues such as water vapor permeability or surface condensation sometimes require vapor retarders or additional insulation.
2. Considerations should be given to the possibility of condensation at the inside or outside of the duct.

5.7 Electrical works

5.7.1 General requirements

All electrical works shall comply with EBCS-10.

5.7.2 Design considerations

In planning the electrical distribution system, consideration should be given to a central control of all the fans in the air handling system, such that they can be partially or completely shut down in the event of fire. A central monitoring and control system, when incorporated, can serve the same purpose.

5.7.3 Installation

(1) Wiring installation in ducts, plenum chambers and concealed spaces, used to transport supply air, return air and outdoor air requires the use of specific metallic types to minimize the products of combustion or flame spread in such areas. The use of metallic systems reduces the products of combustion and fuel contribution during a fire. Where (wiring installation penetrated fire compartmented walls, floor and ceiling, the opening shall be sealed with fire-stop material having the same rating as the compartment through which they penetrate.

(2) No wiring system shall be installed in any duct used to transport dust, loose stock or flammable vapor, or for ventilation of commercial type cooking equipment. No wiring system shall be installed in any shaft which contains such ducts.

(3) Wiring in ducts or plenum chambers shall comply with the following requirements:

(a) Wiring systems to be installed in such ducts and plenum chambers shall be of fire-rated cables, aluminum-sheathed cable, or copper-sheathed cable.

(b) Flexible metal conduit, rigid metal conduit and enclosed metal trunking are permitted in lengths not exceeding 1m to connect physically adjustable equipment and devices in these ducts and plenum chambers. The connectors used with flexible metal conduit shall effectively close any opening in the connection.

(c) Equipment and devices are permitted within such ducts or plenum chambers only if their functions are needed there.

(d) Where equipment or devices are installed in such ducts and plenum chambers and illumination is necessary to facilitate maintenance and repair, totally enclosed type fixtures can be installed in those locations.

(4) Wiring in concealed spaces shall comply with the following requirements:

(a) Wiring in concealed spaces, such as spaces above the ceiling, requires the use of fire-rated cable, aluminum-sheathed cable, or copper-sheathed cable.

(b) Rigid metal conduit, enclosed metal trunking, flexible metal conduit, liquid-tight flexible metal conduit in lengths not more than 2m, or metal-clad cables can also be used.

(c) Other electric equipment is permitted within the concealed spaces of such structures if the wiring materials, including fixtures, are suitable for the expected ambient temperature to which they will be subjected.

(5) The wiring insulation of integral fan systems, which have been specifically designed and constructed for the purpose, and the installation of motors and control equipment in air-handling ducts, where such equipment have been specifically

approved and listed by recognized authorities for the particular application, shall be deemed to comply with the requirements of this section.

5.7.4 Secondary source of power supply

(1) Apart from the supply from normal mains, a secondary source of power supply to essential services shall be provided.

- (a) Exit staircases and exit passageways;
- (b) Smoke-stop and fire fighting lobbies;
- (c) Areas of refuge within the same building;
- (d) Basement car parks;
- (e) Flammable liquid/gas storage rooms;
- (f) Emergency power generator room and engine driven fire pump room;
- (g) Car park smoke purging system; and
- (h) Powered smoke control system.

(2) The electrical circuit wiring from the supply source to the utilization points of such equipment shall be of the fire-resistant type complying with EBS-10 or suitably protected along their entire length within fire-rated ducts, or shafts.

5.7.5 Motor and motor control

(1) All motors and their control equipment as well as the associated wiring and accessories shall be suitable for their particular application and for the environment they are exposed to.

- (a) High Rupturing Capacity Fuses (HRC) or Molded Case Circuit Breakers (MCCB) with magnetic release shall be installed and capable of:
- (b) Protecting the cable connections to the motor; and
- (c) Carrying the stalled current of the motor for a period of not less than 75%of the period which such a current would cause the motor windings to fail.

(2) Any no-volt release mechanism shall be of the automatic resetting type such that on restoration of supply the motor can start automatically.

(3) Thermal overload trips shall not be permitted.

(4) Magnetic (Short circuit) trips are permitted for use in motor circuits of mechanical ventilation systems serving essential services.

5.7.6 Start-stop control

Start-stop control and visual indication of operation shall be provided in the building, at the main fire indicator board, for the mechanical ventilation systems serving the following:

(1) Exit staircase pressurization;

(2) Smoke-stop and fire fighting lobbies;

(3) Basement car parks;

(4) Car park smoke purging system; and

(5) Powered smoke control systems

SECTION 6 Operation and Maintenance

6.1 Testing and commissioning

6.1.1 General

(1) Testing and commissioning should be carried out meticulously if a satisfactory installation is to be handed over to the client. It should be ensured that these are carried out thoroughly and all results are properly documented.

(2) All equipment and components supplied may be subjected to inspection and tests during manufacture, erection/installation and after completion. No tolerances at the time of inspection shall be allowed other than those specified or permitted in the relevant approved standards, unless otherwise stated. Approval at the time of inspection shall not be construed as acceptance unless the equipment proves satisfactory in service after erection.

(3) Upon completion of installation of the system, the equipment of plants/systems are tested to check that they can function according to design & testing method equipment/system shall be in accordance with approved procedures.

(4) Each manufacturer shall provide guarantee performance for the specified duty & conditions and, where necessary, test certificates.

(5) All instruments shall be provided by the contractor or his commissioning agent, and evidence of the accuracy of the test instruments shall be provided wherever possible.

6.1.2 Preparation of Commissioning and Testing Procedure

The procedure for testing and commissioning would include but not limited to the following:

(1) Objects of the tests;

(2) Method and duration of the tests;

(3) Type and degree of accuracy of instruments to be used;

(4) The personnel carrying out the tests;

(5) The state of the plant and machinery with special reference to the cleanliness.

(6) The conditions of outdoor air as representing the required test conditions.

6.1.3 Cleaning

(1) Pre-operational chemical cleaning of water systems shall be carried out.

(2) Ductwork systems shall be cleaned by blowing out using the supply air fan. No fan shall be started until cleaning is to commence.

(3) Cleaning shall be completed before the connection of terminal units and fittings.

6.1.4 Performance tests and adjustments

(1) Appropriate sections of the plant shall be run and all necessary adjustments of valves, dampers and controls should be made to fulfill the function for which it has been designed, e.g. room temperature and humidity to be maintained, air quantity to be handled, etc. Reference can be made to an acceptable standard such as ASHRAE Standard 111.

(2) The contractor shall ensure that all performance test requirements are achieved and the plant is continuously operated for a minimum period of 24 hours before tests are witnessed.

(3) The contractor shall be responsible for the supply, fixing, connection& safe operation of sufficient temporarily artificial heat load equipment and any instrumentation necessary to demonstrate system performance & for subsequent disconnection & removal from the site.

(4) The contractor shall submit his proposals for the performance tests to the consultant or commissioning agent for approval at least six weeks before start of commissioning.

(5) For the duration of performance tests, the contractor shall ensure that all qualified commissioning and other specialist personnel are present and available at all times to make any necessary immediate adjustments & repairs.

(6) Individual room temperature shall be measured by thermometers located 1.5meters above floor level at points unaffected by the influence of draughts or direct radiation from hot or cold surfaces.

6.1.5 Tests on site of individual items of plant/system

Besides tests by manufacturers for various equipment or components, the following tests on site should be considered appropriate at the expense of the contractor.

(1) Ductwork should be checked for tightness, absence of vibration and operation of all movable fittings.

(2) Pipe work should be hydrostatically tested & the flow of fluids though a system, is correctly regulated, balanced and that it confirms to design parameters. Prior to commissioning, testing, adjusting and balancing, preliminary checks and charging of the complete system should be carried out. It is important that all water systems should have been thoroughly flushed through and hydraulically pressure tested to a minimum of 1.5 times the working pressure for a period of not less than 7 h.

(3) Insulation and the associated vapor barrier on ducts and pipes should be checked for their integrity.

(4) Air flow rate for each grille should be checked and balanced.

(5) Fans should be checked for alignment, blade angles, rotational frequency, air flow rate, sound levels and operating pressures.

(6) Pumps should be checked for alignment, rotational frequency, flow rate and pressure, and checked to comply with the required capacity.

(7) Heat transfer coils and automatic control values should be checked for water flow, pressure drops, as well as heat transfer on air-side and water-side to meet the required capacity.

(8) All control equipment and components should be calibrated and set points adjusted. Time and control sequences should also be tested.

(9) Each water chilling unit or DX unit should be checked under design conditions if practicable.

(10) All control devices, electric motors, starters, control panels, instrumentations and electrical equipment and installation shall be tested in accordance with approved standards.

6.2 Completion requirements

6.2.1 Drawings

Construction documents shall require that within 90 days after the date of system acceptance record drawings of the actual installation be provided to the building owner or the designated representative of the building owner. Record drawings shall include as a minimum the location and performance date on each pipe of equipment, general configuration of duct pipe distribution system including sizes, and the terminal air or water design flow rates.

6.2.2 Manuals

As built drawings and other documents shall be submitted after the date of system acceptance. These manuals shall be in accordance with industry accepted standards and shall include, as minimum, the following:

a) Operating manuals and maintenance manuals for each piece of equipment requiring maintenance. Required routine maintenance actions shall be clearly identified.

b) Names and addresses of at least one service agency.

c) Air-conditioning control systems maintenance and calibration information, including wiring diagrams, schematics, and control sequence descriptions. Desired or field determined set points shall be permanently recorded on control drawings at control devices or, for digital control systems, in programming comments.

d) A complete narrative of how each system is intended to operate, including suggested set points.

6.3 System Balancing

6.3.1 General requirements

All ventilation & air-conditioning systems shall be balanced in accordance with accepted engineering standards.

6.3.2 Basic Considerations

(1) The basic considerations are:

(a) To test to determine quantitative performance of equipment;

(b) To adjust to regulate for specified fluid flow rates and air patterns at terminal equipment (for example reduce fan speed, throttling etc) and

(c) To balance to proportion within distribution system (sub mains, branches and terminals) in accordance with design quantities.

(2) The objective of testing, adjusting and balancing of air conditioning, heating and Mechanical ventilation system shall be to:

(a) Verify design conformity;

(b) Establish fluid, flow rates, volume and operating pressures;

(c) Test all associated electrical panels and electrical installation for earthling continuity and earth resistance;

(d) Take electrical power readings for each motor;

(e) Establish operating sound and vibration levels;

(f) Adjust and balance to design parameters; and

(g) Record and report results as per the specified format.

6.3.3 Air System

(1) The testing, adjusting and balancing procedure shall establish the right selection and performance of the air handling units with the following results:

(a) Air-in dry-bulb and wet-bulb temperature,
(b) Air-out dry-bulb and wet-bulb temperature,
(c) Leaving air dew point temperature,
(d) Fan air volume,
(e) Fan air outlet velocity,
(f) Fan static pressure,
(g) Fan power consumption,
(h) Fan speed, and
(i) Check for zero water retention in the condensate drain pan.

(2) Both supply and return air distribution for each air handling unit and for areas served by the air handling unit shall be determined and adjusted as necessary to provide design air quantities. It shall cover balancing of air through main and branch ducts.

6.3.4 Hydronic system

(1) The hydronic system shall involve the checking and balancing of all water pumps, piping network (main and branches), heat exchange equipment like cooling and heating coils, condensers, chillers and cooling towers in order to provide design water flows.

The essential preparation work shall be done by the air conditioning contractor prior to actual testing, adjusting and balancing and shall ensure the following:

(a) Hydronic system shall be free of leaks, hydrostatically tested and shall be thoroughly cleaned, flushed and refilled.

(b) Air vent with isolation valve be provided in hydronic system.

(c) Check pumps operation for proper rotation and motor current drawn etc.

(d) Confirm that provisions for tabulation of measurements have been made.

(e) Open all shut-off valves and automatic control valves to provide full flow through coils. Set all balancing valves in the pre set position, if these values are known. If not, shut all riser balancing valves except the one intended to be balanced first.

(f) Balancing work for both chilled water system and condenser water system shall be carried out in a professional manner and test reports in the specified format shall be prepared.

6.3.5 Controls

Most of the control equipment used for air conditioning system is factory calibrated or adjusted, hence physical verification before installation shall be carried out. In addition, manufacturer's instructions should be followed for site adjustment, if any.

6.3.6 Noise and Sound Control

Measurements should be taken with a sound level meter in the following locations:`

(a) Plant rooms;

(b) Occupied rooms adjacent to plant rooms;

(c) Outside plant rooms facing air intakes and exhausts and condenser discharge, to assess possible nuisance to adjacent occupied areas;

(d) In the space served by the first grille or diffuser after a fan outlet;

(e) Spaces served by fan coil units or high velocity system terminal units (where applicable);

(f) In any space; and

(g) Air handling unit (AHU) rooms and adjoining areas

6.4 Handover Procedure

HVAC control systems shall be tested to ensure that control elements are calibrated, adjusted, and in proper working condition. Handover documentation should contain all information that the user needs to enable the installation and equipment to be efficiently and economically operated and maintained. It should also provide a record of the outcome of any site testing, balancing and regulation carried out prior to handover. Handover documentation should include the following:

6.4.1 Description of the installation, including simplified line flow and balance diagrams for the complete installation;

6.4.2 As-built installation drawings prepared by the contractor.

6.4.3 Operation and maintenance instructions for equipment, manufacturer's service maintenance manuals, manufacturer's spare parts list and spares ordering instructions;

6.4.4 Schedules of electrical equipment;

6.4.5 Schedules of mechanical equipment;

6.4.6 Copies of guarantee certificates for plant and equipment;

6.4.7 List of keys, tools and spare parts that are handed over; and

6.4.8 Manufacturer's test certificate for equipment (where required).

6.5 Maintenance

6.5.1 General

Regular and proper maintenance of equipment and systems is necessary to ensure efficient operation and to sustain long usable life.

6.5.2 Competent staff

The staff in change of maintenance planning and execution should be competent and trained.

6.5.3 Documentation

Shop drawings and operation manual of the plant, operation, manufacturers' instruction and maintenance manuals of the equipment and system; and electrical and control schematic diagrams should be made available for the maintenance team to perform its tasks.

6.5.4 Provisions for maintenance operations

There should be provisions during the design stage for:

(a) Adequate access for inspection, maintenance and repair of all component parts of the installation;

(b) Facilities for emptying the piping services;

(c) Reasonable operating space, noting that air handling unit room should not be used for maintenance work; and

(d) 600mm minimum clearance with no observation around each air handling unit.

6.5.5 Operating log sheets

Hourly and daily records of operating conditions of all major equipment (e.g refrigerating compressors, cooling tower) as well as records of all faults, breakdown and repairs shall be maintained, as required, to serve as reference for operation and planned maintenance of the plant and systems.

6.5.6 Air-conditioning Installations

(1) General

Inspect the equipment and systems such as chillers, compressors, condenser coils, chilled and condenser water pumps, water tanks, air handling units, fan coil units, all motors, chemical treatment system and the associated electrical, electronic and mechanical controls, and circuit boards to ensure satisfactory operation of the equipment and systems within designed conditions.

(2) Monthly maintenance

(a) Refrigerant compressors

(i) Inspect all refrigerant compressors and refrigerant systems including checking of refrigerant and oil levels, refrigerant filters, oil filters, transmission, controls, safety devices, joints, leaks, and suction and discharge pressures.

(ii) Check starters for abnormalities such as arcing in the starter contactors. Check and adjust tightness of terminals and connections if necessary.

(iii) Check and adjust all belt tension if applicable. Replace belt if it appears cracked or worn out.

(iv) Lubricate bearings as required.

(b) Chiller condenser

(i) Check for proper operation of chiller condenser, its associated controls and control circuits.

(ii) Check for water inlet and outlet temperatures, operating pressure, pressure drop and flow rate.

(iii) Inspect the condition of joints, stop valves, covers and seals for leaks, repair or replace if necessary.

(iv) Perform water treatment as required.

(c) Air handling unit

(i) Check for proper operation of the air handling units, its associated controls and control circuit. Repair or replace if necessary.

(ii) Check unit casing, air filters and passages around coils for any air leakage. Rectify if necessary.

(iii) Check and clean condensate drain pan, drain pipe and floor drains. Flush drain pipe with approved chemical or vacuum if necessary.

(iv) Inspect and adjust all thermostats, safety cut-outs and modulating dampers.

(v) Check routine operation of electrical components.

(vi) Check chilled water pressure drop and clean evaporator coils as required.

(vii) Check and adjust all belt tension if necessary. Replace belt if it appears cracked or worn.

(viii) Check and rectify and abnormal running noise and vibration. Replace bearings and anti-vibration rubber and springs if necessary.

(ix) Check condition of duct insulation. Repair or replace if necessary.

(x) Clean or replace filters as required.

(xi) Check and clean water strainers, if applicable.

(xii) Check for proper operation of control valves and isolating valves, rectify if required.

(xiii) Check blower fan and its bearings and housing

(xiv) Lubricate bearings as required.

(d) Fan coil units

(i) Check for proper operation of the fan coil units and associate controls. Repair or replace if necessary.

(ii) Check and clean condensate drain pan, drain pipe and floor drains. Flush drain pipe with approved chemical or vacuum if necessary.

(iii) Inspect and adjust all thermostats, safety cut-outs and modulating dampers.

(iv) Check routine operation of electrical components

(v) Check and clean evaporator coils.

(vi) Check and adjust all belt tension if necessary. Replace belt if it appears cracked or worn.

(vii) Check and rectify and abnormal running noise and vibration. Replace bearings and anti-vibration rubber and springs if necessary.

(viii) Clean the supply and return air grilles.

(ix) Clean or replace filters as required.

(x) Check and clean water strainers if applicable.

(xi) Check blower fan and its bearings and housing.

(xii) Lubricate bearings as required.

(e) Pumps

(i) Check operating pressures and flow rate to ensure the pump is operating normally.

(ii) Inspect all water pumps and seals, check for abnormal running noise and vibration. Repair if necessary.

(iii) Check condition of glands. Replace if necessary.

(iv) Check for correct alignment of the motor and pump. Rectify if necessary.

(f) Cooling towers

(i) Check for proper operation of cooling tower and associated controls and control circuits.

(ii) Check and clean the in-fills, drift eliminators, water screens, basins and sprinklers.

(iii) Check for water leakage in piping circuits due to corrosion or other reasons.

(iv) Repair or replace if necessary.

(v) Check make-up water system and cooling tower float valve operation.

(vi) Check, clean and rectify fan assembly for proper operation.

(vii) Check on chemical treatment system.

(viii) Check on tower structure and condition of tower support. To clean, wire brush, touch up and paint all rusty supports including ladder, all bolts and nuts.

(ix) Ensure tower cleanliness

(x) Ensure that water treatment conforms to standard.

(xi) Check water balancing to each cooling tower to ensure balance flow. Adjust if necessary.

(g) Motors

(i) Check motor running ampere to ensure motor is operating under normal conditions.

(ii) Check the motor casing. Lubricate motor bearings if necessary.

(iii) Check, adjust and rectify defect if necessary for circuit protective devices

(iv) Including starters, control gears and relays ancillary apparatus, bearings and moving parts, electric contactors and fuses.

(v) Check electrical circuits. Rectify loose connections or bad contacts.

(vi) Check motor drive. Adjust belt tension and pulleys if necessary. Replace belt if it appears cracked or worn.

(vii) Check and rectify and abnormal running noise and vibration. Replace bearings and anti-vibration rubber and springs if necessary.

(h) Chilled water expansion tank

Check chilled water expansion tank, float valve position and availability of make-up water supply. Clean the water expansion tank if necessary.

(2) Half-yearly maintenance

(a) Air handling units

(i) Check and balance outside air quantities.

(ii) Clean electrical contacts. Tighten all screws where necessary.

(iii) Clean, wire brush, touch up and paint all rusty parts.

(b) Fan coil units

(i) Clean electrical contacts. Tighten all screws where necessary.

(ii) Clean, wire brush, touch up and paint all rusty parts.

(iii) Check pipe insulation for deterioration and damage. Repair or replace if necessary.

(c) Pumps

Inspect and clean strainers.

(3) Annual maintenance

(a) Refrigerant compressors

(i) Pump down the machine and open up compressor assembly inspection cover to visually inspect for abnormalities and excessive wear on the gear package. Replace refrigeration filter.

(ii) Dismantle oil pump for servicing. Clean up oil pump chamber. Replace oil filters and refill with new oil.

(iii) Check and analyze the oil and refrigerant. Replace the oil and refrigerant if necessary.

(iv) Perform leak test and evacuation of systems.

(v) Test safety controls and re-calibrate them to a specific setting to ensure proper operation.

(vi) For starters; inspect and service contactor, check for abnormalities and tighten connecting parts.

(b) Chiller condenser

(i) Clean condenser tubes at regular intervals. Clearing may be carried out annually if proper water treatment is maintained.

(ii) Check and clean all strainers on condenser water pipe work.

(iii) Check if needed for ease of maintenance, automatic tube cleaning system to keep the condenser tubes from scaling and fouling.

(c) Air handling units

(i) Replace filter as required.

(ii) Test and record electrical insulation of all motors and wiring with megger.

(iii) Clean cooling coils with high pressure jet or steam and cleaning detergent.

(d) Supply and return air ducts

Inspect the supply and return air ducts for cleanliness.

(e) Fan coil units

(i) Replace filter as required.

(ii) Test and record electrical insulation of all motors and wiring with megger.

(iii) Clean cooling coils

(f) Pumps

(i) Check all associate controls. Repair or replace as required.

(ii) Dismantle pump casting and check condition of pump shafts, impellers, sleeves, bearings and castings for wear and corrosion.

(iii) Repair or replace as necessary.

(iv) Repaint the pump interior and external castings with suitable protective paint of approved color.

(v) Check grease, oil and gland packing and other parts. Replace as necessary.

(vi) Realign the pump and motor.

(g) Motors

(i) Check winding insulation by megger test. Check cable terminals and cables for damage or deterioration. Replace motor bearings, windings, and cable terminals as necessary.

(ii) Check the associate circuit protection devices, electrical starter and equipment are in good working condition. Replace contactors and other worn or defective parts as required.

(iii) Check motor bolts and nuts. Re-tighten any loose bolt and nut.

(4) Overhaul (When necessary)

Overhaul all refrigerant compressors if necessary, in accordance with the procedures and details described in the manufacturers' instruction manuals whenever available.

6.5.7 Mechanical ventilation installations

(1) General

Inspect the equipment and systems, electrical, electronic and mechanical controls, and circuit boards associated with mechanical ventilation systems to ensure satisfactory operation within designed conditions.

(2) Monthly maintenance

(a) Check motor running ampere to ensure motor is operating under normal conditions.

(b) Inspect fan blades for wear and tear. Clean fan blades as required.

(c) Check fan and motor bearings. Lubricate if necessary.

(d) Check electrical circuits. Rectify loose connections or bad contacts.

(e) Check motor drive. Adjust belt tension and pulleys if necessary. Replace belt if it appears cracked to worn.

(f) Check flexible connections and anti-vibration mountings. Replace bearings and anti-vibration rubber inserts and springs if necessary.

(g) Check for proper operation of the fan, its associated controls and control circuit. Repair or replace if necessary.

(h) Clean supply and return air grilles.

(i) Clean air filters. Replace air filters if necessary.

(3) Half-yearly maintenance

(a) Check all electrical wiring and connections, circuit protection devices and electrical starter. Rectify or replace if necessary.

(b) Clean the exhaust hood with suitable cleaning detergent.

(4) Annual maintenance

(a) Check winding insulation by megger test. Check cable terminals and cables for damage or deterioration. Replace motor bearings, windings, and cable terminals as necessary.

(b) Check the associate circuit protection devices, electrical starter and equipment are in good working condition. Replace contacts and other worn or defective parts as required.

(c) Check motor bolts and nuts. Re-tighten any loose bolt or nut.

(d) Check alignment of fan shaft with motor. Realign the fan shaft if necessary.

(e) Check fan and metal components for corrosion. Clean and repaint if necessary.

(f) Clean air passages.

ANNEX I: Climatic Design Condition

A 1.1 Climatic Design Conditions

The design conditions in this code are provided for those locations for which long-term hourly observations were available (at least 10 years of data).

Warm-season temperature and humidity conditions correspond to annual percentile values of 0.4, 1.0, and 2.5. Cold-season conditions are based on annual percentiles of 99.6 and 99.0 and 97.5. The use of annual percentiles to define the design conditions ensures that they represent the same probability of occurrence anywhere, regardless of the seasonal distribution of extreme temperature and humidity. The summary data in Table A1.1 for environmental design condition includes the following information as:

1. Station name
2. Dry-bulb temperature corresponding to 0.4%, 1.0%, and 2.5% annual cumulative frequency of occurrence and the mean coincident wet-bulb temperature (warm)
3. Wet-bulb temperature corresponding to 0.4%, 1.0%, and 2.5% annual cumulative frequency of occurrence and the mean coincident dry bulb temperature
4. Dew-point temperature corresponding to 0.4%, 1.0%, and 2.5% annual cumulative frequency of occurrence and the mean coincident dry-bulb temperature and the humidity ratio (calculated for the dew-point temperature at the standard atmospheric pressure at the elevation of the station)
5. Mean daily range, which is the mean of the difference between daily maximum and minimum dry-bulb temperatures for the warmest month (highest average dry-bulb temperature)

Values of ambient dry-bulb, dew-point, and wet-bulb temperature corresponding to the various annual percentiles represent the value that is exceeded on average by the indicated percentage of the total number of hours in a year (8760). The 0.4%, 1.0%, and 2.5% values are exceeded on average 35, 88, and 219 h per year, respectively, for the period of record. The 99.0% and 99.6% (cold) values are defined in the same way but are usually viewed as the values for which the corresponding weather element is less than the design condition for 88 and 35 h, respectively. Mean coincident values are the average of the indicated weather element occurring concurrently with the corresponding design value. These design conditions were calculated from the frequency distribution analyzed from data sets observed over several years.

Generally, the annual cumulative frequency distribution was constructed from the relative frequency distributions compiled for each month. Each individual month's data were included if they met screening criteria for completeness and unbiased distribution of missing data. Although the minimum period of record selected for this analysis was 10 years, some variation and gaps in observing programs meant that some months' data were unusable due to incompleteness.

A station's design conditions were included in this code only if there were data from at least 8 months that met the screening criteria from the period of record for each month of the year. The design conditions in this code explicitly represent the same annual probability of occurrence in any location, regardless of locations or general climatic conditions. Tables A1.1 and A1.2 represent the outdoor design condition for both cooling and heating respectively at different locations in Ethiopia where as table A1.3 shows monthly maximum and minimum temperature.

Table A1.1. Design Condition for Cooling (Maximum Temperature)

Location				Annual cumulative frequency of occurrence (%)											
				0.4				1				2.5[1]			
City/Town	**Latitude**	**Longitude**	**Elevation**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DPT (^{0}C)**	**MDR**	**DBT (^{0}C)**	**CWB**	**DPT (^{0}C)**	**MDR**	**DBT (^{0}C)**	**CWB**	**DPT (^{0}C)**	**MDR**
Adama	08^{0}55'N	38^{0}55'E	2485m	33.9	28.03	21.25	19.71	33.5	23.43	18.25	19.71	32.6	24.54	20.82	19.71
Addis Ababa	09^{0}02'N	39^{0}42'E	2355m	29	23.07	20.35	18.46	28.5	22.59	19.81	18.46	28	21.19	17.73	18.46
Assosa	10^{0}04'N	34^{0}32'E	1570m	35	22.86	14.56	22.84	34.5	21.7	14.16	22.84	34	22.94	17.02	22.84
Bahirdar	11^{0}37'N	37^{0}10'E	1800m	33	21.48	14.72	23.59	32.6	19.73	11.3	23.59	32.2	21.09	14.52	23.59
Dire Dawa	09^{0}35'N	41^{0}45'E	1200m	38.5	25.88	19.8	20.31	38	27.4	22.75	20.31	37.6	25.99	20.53	20.31
Gambella	08^{0}15'N	34^{0}34'E	514m	42.5	29.92	24.92	23.50	42	30.08	25.38	23.50	41.5	29.78	25.11	23.50
Gode	05^{0}57'N	43^{0}27'E	254m	39.6	34.78	33.13	17.89	39.2	33.94	32.1	17.89	38.7	33.33	31.44	17.89
Jijiga	09^{0}20'N	42^{0} 50'E	1609m	32.5	24.12	20.1	26.72	32.2	22.53	17.45	26.72	31.7	23.64	19.72	26.72

[1] For this standard 2.5 % Maximum temperature occurrence shall be taken.

Mekelle	13^{0}33'N	39^{0}30'E	2084m	30	27.97	27.18	18.95	29.8	27.48	26.57	18.95	29.4	27.28	26.44	18.95
Semera	11^{0}30'N	41^{0} 12'E	633m	44.5	28.71	21.81	25.85	44	28.62	21.99	25.85	43.8	31.65	27.1	25.85

Table A1.2. Outdoor Design Condition for Heating

Location				Annual cumulative frequency of occurrence (%)					
				99.6		99		97.5	
City/Town	**Latitude**	**Longitude**	**Elevation**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DBT (^{0}C)**	**CWB (^{0}C)**	**DBT (^{0}C)**	**CWB (^{0}C)**
Adama	08055'N	38055'E	2485m	6	2.52	7.7	5.19	9.4	6.7
Addis Ababa	09002'N	39042'E	2355m	4.5	0.66	5	1.57	5.6	2.09
Assosa	10004'N	34032'E	1570m	8.4	4.92	9	5.62	10	5.4
Bahirdar	11037'N	37010'E	1800m	3.5	0.54	4.1	1.33	5	2.77
Dire Dawa	09035'N	41045'E	1200m	11.1	8.14	12	9.32	12.8	9.9
Gambella	08015'N	34034'E	514m	17	14.99	17.5	15.51	18.5	16.3
Gode	05057'N	43027'E	254m	17.3	14.11	18.5	14.5	19.6	16.29
Jijiga	09020'N	420 50'E	1609m	1	-0.16	2	0.2	3.5	1.84
Mekelle	13033'N	39030'E	2084m	5	2.9	6	3.9	7.3	5.3
Semera	11030'N	410 12'E	633m	13.5	11.82	14.5	11.16	15.3	13.38

DBT= Dry Bulb Temperature

CWB = Coincident Wet Bulb Temperature

Table A1.3. Monthly Maximum and Minimum Temperature Values for Different Locations

		Location									
Month		**Adama**	**Addis Ababa**	**Assosa**	**Bahirdar**	**Dire Dawa**	**Gambella**	**Gode**	**Jijiga**	**Mekelle**	**Semera**
January	Max. DBT (^{0}C)	30.1	26.67	33.28	29.53	31.91	40.90	37.70	30.25	26.16	34.62
	Min. DBT (^{0}C)	7.61	4.87	9.60	4.55	11.71	17.50	18.12	2.91	5.44	14.66
	MDR (^{0}C)	22.45	21.8	23.68	24.98	20.20	23.40	19.58	27.34	20.72	19.96
February	Max. DBT (^{0}C)	32.09	28.13	34.07	30.92	34.71	42.20	38.53	31.95	27.91	37.13
	Min. DBT (^{0}C)	10.11	6.27	10.93	6.26	12.17	18.60	19.32	3.85	6.99	15.86
	MDR (^{0}C)	21.98	21.86	23.14	24.66	22.54	23.60	19.21	28.11	20.92	21.27
March	Max. DBT (^{0}C)	32.71	28.62	34.53	32.16	36.65	43.00	39.29	32.44	28.42	40.30
	Min. DBT (^{0}C)	10.92	7.54	11.69	7.66	14.07	19.50	21.40	5.72	8.11	16.73

	MDR (^{0}C)	21.79	21.08	22.84	24.49	22.58	23.50	17.89	26.72	20.31	23.57
April	Max. DBT (^{0}C)	32.5	28.39	33.85	32.39	37.12	42.20	39.34	32.14	28.73	41.90
	Min. DBT (^{0}C)	12.42	9.55	13.17	8.80	16.42	21.20	21.64	8.60	9.65	18.30
	MDR (^{0}C)	20.08	18.84	20.68	23.59	20.70	21.00	17.70	23.54	19.08	23.60
May	Max. DBT (^{0}C)	33.38	28.46	32.29	31.89	38.17	39.50	36.97	31.74	29.66	43.84
	Min. DBT (^{0}C)	13.67	10.00	13.22	11.45	17.86	20.90	21.70	10.03	11.26	23.60
	MDR (^{0}C)	19.71	18.46	19.07	20.44	20.31	18.60	15.27	21.71	18.40	20.24
June	Max. DBT (^{0}C)	32.68	27.11	28.21	29.99	38.05	38.02	36.48	30.93	29.97	45.25
	Min. DBT (^{0}C)	12.99	9.60	14.15	12.06	17.60	19.90	22.67	11.98	11.02	22.35
	MDR (^{0}C)	19.69	17.51	14.06	17.93	20.45	18.12	13.81	18.95	18.95	22.90
July	Max. DBT (^{0}C)	29.54	24.36	26.59	26.67	36.85	36.50	35.56	30.36	27.06	45.55
	Min.	13.81	9.49	13.80	11.87	16.89	20.10	22.11	13.56	10.96	19.70

	DBT (^{0}C)										
	MDR (^{0}C)	15.73	14.87	12.79	14.80	19.96	16.40	13.44	16.80	16.10	25.85
August	Max. DBT (^{0}C)	28.47	23.61	27.25	26.48	35.84	35.43	36.09	30.02	25.52	42.68
	Min. DBT (^{0}C)	13.61	9.54	13.70	12.01	16.92	19.30	22.04	12.78	11.10	18.48
	MDR (^{0}C)	14.86	14.07	13.55	14.46	18.92	16.13	14.04	17.24	14.42	24.20
September	Max. DBT (^{0}C)	29.46	24.2444	27.74	26.92	35.69	36.07	37.16	30.58	26.36	42.93
	Min. DBT (^{0}C)	12.29	8.92	13.70	11.07	16.64	20.30	22.46	11.03	9.20	19.80
	MDR (^{0}C)	17.17	15.3222	14.04	15.85	19.04	15.77	14.70	19.55	17.16	23.13
October	Max. DBT (^{0}C)	29.7	25.8	28.77	27.95	35.53	37.67	37.36	30.09	26.19	40.25
	Min. DBT (^{0}C)	9.83	6.92	11.80	9.85	14.63	20.30	21.18	5.83	7.02	18.20
	MDR (^{0}C)	19.87	18.8778	16.97	18.10	20.90	17.37	16.18	24.26	19.17	22.05
November	Max. DBT (^{0}C)	29.22	25.19	30.03	28.53	33.84	38.33	36.51	29.88	25.40	37.65

	Min. DBT (^{0}C)	9.31	4.26	9.98	5.27	12.44	18.17	18.60	3.11	6.99	17.20
	MDR (^{0}C)	19.91	20.93	20.05	23.26	21.40	20.17	17.91	26.76	18.41	20.45
December	Max. DBT (^{0}C)	28.7	25.7	31.25	28.59	31.78	38.73	36.78	30.26	25.23	35.20
	Min. DBT (^{0}C)	8.02	5.37	9.26	4.44	12.21	17.63	18.40	2.84	5.76	17.20
	MDR (^{0}C)	20.68	20.3333	21.99	24.14	19.56	21.10	18.38	27.42	19.46	18.00
Annual	Max. DBT (^{0}C)	33.38	28.5	34.53	32.39	38.17	43.00	39.29	32.44	29.97	45.55
	Min. DBT (^{0}C)	13.67	10.00	11.69	8.80	17.86	19.50	21.40	5.72	11.02	19.70
	MDR (^{0}C)	19.71	18.46	22.84	23.59	20.31	23.50	17.89	26.72	18.95	25.85

ANNEX II. COOLING AND HEATING LOAD CALCULATION METHOD

A2.1 Heat Flow Rates

In air-conditioning systems design, four related heat flow rates, each of which varies with time, must be differentiated: space heat gain, space cooling/ heating load, space heat extraction rate, and cooling coil load.

A2.1.1. Space Heat Gain

This instantaneous rate of heat gain is the rate at which heat enters into and/or is generated within a space. Heat gain is classified by the mode in which it enters the space and whether it is a sensible or latent gain. The mode of entry includes:

- Solar radiation through transparent surfaces;
- Heat conduction through exterior walls and roofs;
- Heat conduction through ceilings, floors, and interior partitions;
- Heat generated in the space by occupants, lights, and appliances;
- Energy transfer as a result of ventilation and infiltration of outdoor air; and
- Miscellaneous heat gains.

Sensible heat is added directly to the conditioned space by conduction, convection, and/or radiation. Latent heat gain occurs when moisture is added to the space (e.g., from vapor emitted by occupants and equipment). To maintain a constant humidity ratio, water vapor must condense on the cooling apparatus and be removed at a rate equal to the rate it is added to the space. The amount of energy required to offset the latent heat gain essentially equals the product of the rate of condensation and the latent heat of condensation. In selecting cooling apparatus, it is necessary to distinguish between sensible and latent heat gain. Every cooling apparatus has a maximum sensible heat removal capacity and a maximum latent heat removal capacity for particular operating conditions.

A2.1.2. Space Cooling Load

This is the rate at which heat must be removed from the space to maintain a constant space air temperature. The sum of all space instantaneous heat gains at any given time does not necessarily (or even frequently) equal the cooling load for the space at that same time. Radiant energy must first be absorbed by the surfaces that enclose the space (walls, floor, and ceiling) and the objects in the space (furniture, etc.). When these surfaces and objects become warmer than the surrounding air, some of their heat is transferred to the air by convection. The composite heat storage capacity of these surfaces and objects determines the rate at which their respective surface temperatures increase for a given radiant input and thus governs the relationship between the radiant portion of heat gain and its corresponding part of the space cooling load. The thermal storage effect is critically important in differentiating between instantaneous heat gain for a given space and its cooling load at that moment. Predicting the nature and magnitude of this phenomenon in order to estimate a realistic cooling load for a particular combination of circumstances has long been a subject of interest to design engineers.

A2.1.3. Space Heat Extraction Rate

The rate at which heat is removed from the conditioned space equals the space cooling load only if the room air temperature is held constant. Along with the intermittent operation of the cooling equipment, the control system characteristics usually permit a minor cyclic variation or swing in room temperature. Therefore, a proper simulation of the control system gives a more realistic value of energy removal over a fixed period than using the values of the space cooling load.

A2.1.4. Cooling Coil Load

The rate at which energy is removed at the cooling coil that serves one or more conditioned spaces equals the sum of the instantaneous space cooling loads (or space heat extraction rate if it is assumed that the space temperature does not vary) for all the spaces served by the coil, plus any external loads. Such external loads include fan heat gain, duct heat gain, and outdoor air heat and moisture brought into the cooling equipment to satisfy the ventilation requirement.

A2.2 Load Calculation Methods

There are different cooling and heating load calculation methods in practice. Among these, the heat balance (HB) and Radiant time series methods are the dominant ways of analyzing transient load condition. The preferable one of the two methods is the heat balance (HB) method. The calculation procedures and scientific principles are explained in equation format. These equations are coded in a generic computer program and linked to a user interface program to allow input and output in either SI units or imperial units.

The radiant time series (RTS) method, which is a simplified method directly related to and derived from the HB calculation procedure.

The transfer function method (TFM), for example, required many calculation steps. Also, this method was originally designed for energy analysis with emphasis on daily, monthly, and annual energy use and, thus, was more oriented to average hourly cooling loads than peak design loads.

The total equivalent temperature differential method with time averaging (TETD/TA) has been a highly reliable—if subjective— method of load estimating since its initial presentation in the 1967 ASHRAE Handbook—Fundamentals. Originally conceived as a manual method of calculation, it proved suitable only as a computer application because of the need to calculate an extended profile of hourly heat gain values from which the radiant components had to be averaged over a time perceived to represent the general mass of the building involved. Because this perception of thermal storage characteristics of a given building was almost entirely subjective, with little specific information for the user to judge variations, the TETD/TA method's primary usefulness has always been to the experienced engineer.

The cooling load temperature differential method with solar cooling load factors (CLTD/CLF) was an attempt to simplify the two-step TFM and TETD/TA methods into a single-step technique that allowed proceeding directly from raw data to cooling load without the intermediate conversion of radiant heat gain to cooling load.

A series of factors were taken from cooling load calculation results (produced by more sophisticated methods) as “equivalent temperature differences” for use in traditional conduction ($Q = UA\Delta T$) equations. The results, however, are approximate cooling load values rather than simple heat gain values. This method uses tabulated results from transfer function method solutions for common building construction. Calculation is based on:

$$Q = UACLTD$$

Where;

U = Overall heat transfer coefficient

A = Net Surface area

Based on standard recommendations and accuracy of the process, the heat balance (HB) or equivalent methods (Transfer function method, Radiant Time Series) are the appropriate procedure to be used in Ethiopian building code practice. Accordingly; the theoretical and mathematical description of heat balance method is discussed here under in order to make the procedure understandable by the reader during application of the heat balance method using software packages.

A2.3 Heat Balance Method of Cooling Load Calculation

The estimation of cooling load for a space involves calculating a surface-by-surface conductive, convective, and radiative heat balance for each room surface and a convective heat balance for the room air.

A2.3.1 General Zone for Load Calculation

The heat balance procedure is tailored to a single thermal zone. The definition of a thermal zone depends on how the fixed temperature is going to be controlled. If air is circulated through an entire building or an entire floor in such a way that it is uniformly well stirred, the entire building or floor could be considered a thermal zone. On the other hand, if each room has a different control scheme, each room may need to be considered as a separate thermal zone. The framework needs to be flexible enough to accommodate any zone arrangement, but the heat balance aspect of the procedure also requires that a complete zone be described.

This zone consists of four walls, a roof or ceiling, a floor, and a "thermal mass surface". Each wall and the roof can include a window (or skylight in the case of the roof). This makes a total of 12 surfaces, any of which may have zero area if it is not present in the zone to be modeled.

The heat balance processes for this general zone are formulated for a 24 h steady-periodic condition. The variables of the problem are the inside and outside temperatures of the 12 surfaces plus either the HVAC system energy required to maintain a specified air temperature or the air temperature, if the system capacity is specified. This makes a total of 25 x 24 or 600 variables. While it is possible to set up the problem for a simultaneous solution of these variables, the relatively weak coupling of the problem from one hour to the next permits a double iterative approach. One iteration is through all the surfaces in each hour, and the other iteration is through the 24 h of a day. This procedure automatically reconciles the nonlinear aspects of the surface radiative exchange and the other heat flux terms.

A2.3.2 Heat Balance Equations

The primary variables in the heat balance for the general zone are the 12 inside face temperatures and the 12 outside face temperatures at each of the 24 h, assigning i as the surface index and j as the hour index, or, in the case of CTFs, the sequence index. Then, the primary variables are:

$T_{so_{i,j}}$ = Outside face temperature, i = 1, 2, …12; j = 1,2,…24

$T_{so_{i,j}}$ = Inside face temperature, i = 1, 2, …12; j = 1,2,…24

The general expression for 12 equations applicable in each time step solved for T_{so} is given as:

$$T_{soi,j} = \left(\sum_{k=1}^{nz} T_{si_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{soi,j-k} Z_{i,k} - \sum_{k=1}^{nq} \Phi_{i,k} \dot{q}_{ko_{i,j-k}} + \dot{q}_{\alpha sol_{i,j}} + \dot{q}_{LWR_{i,j}} + T_{si_{i,j}} Y_{i,o} + T_{o_j} h_{co_{i,j}} \right) \Big/ \left(Z_{i,o} + h_{co_{i,j}} \right) \tag{1}$$

For inside temperature case,

$$T_{si_{i,j}} = \frac{\left(T_{si_{i,j}} Y_{i,o} + \sum_{k=1}^{nz} T_{so_{i,j-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{so_{i,J-k}} Y_{i,k} - \sum_{k=1}^{nz} T_{sI_{i,J-K}} Z_{i,k} - \sum_{k=1}^{nq} \Phi_{i,k} \dot{q}_{ki_{i,j-k}} + T_{aj} h_{ci_j} + \dot{q}_{LWX} + \dot{q}_{SW} + \dot{q}_{sol^e} T_{si_{i,j}} Y_{i,o} + T_{o_j} h_{co_{i,j}} \right)}{\left(Z_{i,o} + h_{ci_{i,j}} \right)} \quad \text{....(2)}$$

Where;

T_O = outside air temperature

T_a = zone air temperature

h_{co} = outside convection coefficient, introduced by using $\dot{q}_{conv} = h_{co}(T_o - T_{so})$

A2.3.3 Elements of Heat Balance Model

Within the framework of the heat balance method assumptions, the heat balance model can be viewed as four distinct processes:

- Outside face heat balance
- Wall conduction process
- Inside face heat balance
- Air heat balance

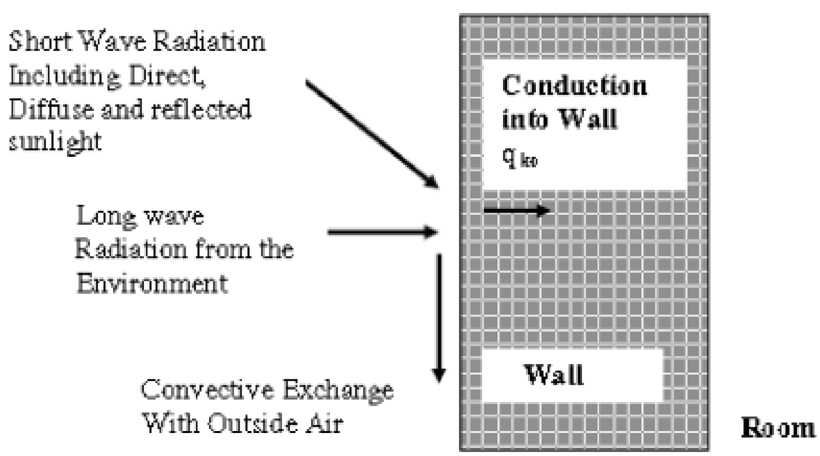

Figure A2.1 Heat balance at outside surface of wall

A2.3.3.1. Outside Face Heat Balance

The heat balance on the outside face of each surface is

$$\dot{q}_{\alpha sol} = \dot{q}_{LWR} + \dot{q}_{conv} - \dot{q}_{ko} = 0 \quad (3)$$

Where;

$\dot{q}_{\alpha sol}$ = absorbed direct and diffuse solar radiation flux flow rate, W/m^2

$\dot{q}_{LWR}$ = net long-wave radiation flux exchange with air and surroundings, W/m^2

$\dot{q}_{conv}$ = convective exchange flux flow rate with outside air, W/m^2

$\dot{q}_{ko}$ = conductive flux flow rate into wall, W/m^2

All terms are positive for net flux to the face except the conduction term, which is traditionally taken to be positive in the direction from outside to inside the wall.

A2.3.3.2. Wall Conduction Process

Because it links the outside and inside heat balances, the wall conduction process regulates the time dependence of the cooling load. For the heat balance procedure presented here, the wall conduction process is formulated using conduction transfer functions (CTFs), which relate conductive heat fluxes to the current and past surface temperatures and the past heat fluxes. The general form for the inside heat flux is

$$\dot{q}_{ki}(t) = -Z_0 T_{si,\theta} - \sum_{j=1}^{nz} Z_j T_{si,\theta-j\delta} + Y_0 T_{so,\theta} + \sum_{j=1}^{nz} Y_j T_{si,\theta-j\delta} + \sum_{j=1}^{nq} \Phi_j \dot{q}_{ki,\theta-j\delta} \quad (4)$$

For the outside heat flux, the form is:

$$\dot{q}_{ko}(t) = -Y_0 T_{si,\theta} - \sum_{j=1}^{nz} Y_j T_{si,\theta-j\delta} + X_0 T_{so,\theta} + \sum_{j=1}^{nz} X_j T_{so,\theta-j\delta} + \sum_{j=1}^{nq} \Phi_j \dot{q}_{ko,\theta-j\delta} \quad (5)$$

Where;

X_J = outside conduction transfer function (CTF), j = 0, 1 …………………..nz

Y_J = cross conduction transfer function, j = 0, 1 ……………………………..nz

Z_J = inside conduction transfer function, j = 0, 1 ……………………………..nz

Φ_J = flux conduction transfer function, j = 1, 2 ………………..……………nq

θ = time

δ = time step

T_{si} = inside face temperature, ^{0}C

T_{so} = outside face temperature, ^{0}C

$\dot{q}_{ki}$ = conductive heat flux flow rate on inside face, W/m^2

$\dot{q}_{ko}$ = conductive heat flux flow rate on outside face, W/m^2

The subscript following the comma indicates the time period for the quantity in terms of the time step. Also, the first terms in the series have been separated from the rest in order to facilitate solving for the current temperature in the solution scheme. The two summation limits nz and nq depend on wall construction and depend somewhat on the scheme used for calculating the CTFs. If nq = 0, the CTFs are generally referred to as response factors, but then theoretically nz is infinite. The values for nz and nq are generally set to minimize the amount of computation.

A2.3.3.3. Inside Face Heat Balance

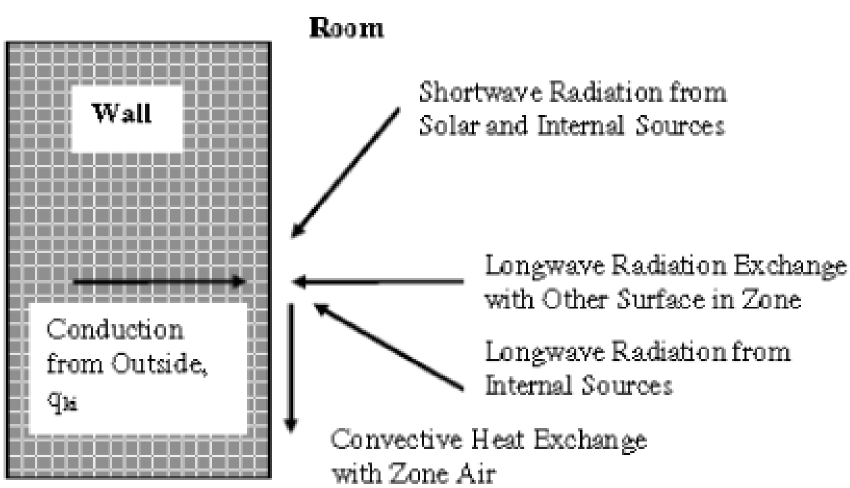

Figure A2.2 Heat balance at inside surface of wall

The heart of the heat balance method is the internal heat balance involving the inside faces of the zone surfaces. This heat balance has many heat transfer components, and they are all coupled. Both long-wave (LW) and short-wave (SW) radiation are important, as well as wall conduction and convection to the air. The inside face heat balance for each surface can be written as follows:

$$\dot{q}_{LWX} + \dot{q}_{SW} + \dot{q}_{LWS} + \dot{q}_{ki} + \dot{q}_{sol} + \dot{q}_{conv} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where;

$\dot{q}_{LWX}$ = net long-wave radiant flux exchange between zone surfaces, W/m^2

$\dot{q}_{SW}$ = net short-wave radiation flux flow rate to surface from lights, W/m^2

$\dot{q}_{LWS}$ = long-wave radiation flux flow rate from equipment in zone, W/m^2

$\dot{q}_{ki}$ = conductive flux flow rate through the wall, W/m^2

$\dot{q}_{sol}$ = transmitted solar radiative flux flow rate absorbed at surface, W/m^2

$\dot{q}_{conv}$ = convective heat flux flow rate to zone air, W/m^2

A2.3.3.4. Air Heat Balance

In heat balance formulations aimed at determining cooling loads, the capacitance of the air in the zone is neglected and the air heat balance is done as a quasi-steady balance in each time period. Four factors contribute to the air heat balance:

$$\dot{Q}_{conv} + \dot{Q}_{CE} + \dot{Q}_{IV} + \dot{Q}_{sys} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where;

$\dot{Q}_{conv}$ = convective heat transfer rate from surfaces, W

$\dot{Q}_{CE}$ = convective parts of the internal loads, W

$\dot{Q}_{IV}$ = sensible load due to infiltration and ventilation air, W

$\dot{Q}_{sys}$ = heat transfer rate to/from the HVAC system, W

The system cooling load is given by the following expression:

$$\dot{Q}_{sysj} = \sum_{i=1}^{12} A_i h_{ci} \left(T_{si_{i,j}} - T_{aj} \right) + \dot{Q}_{CE} + \dot{Q}_{IV}$$

Where;

$\dot{Q}_{sysj}$ = Cooling load, j = 1,….24

A2.4 Cooling Load Principles and Components

The variables affecting cooling load calculations are numerous, often difficult to define precisely, and always intricately interrelated. Many cooling load components vary in magnitude over a wide range during a 24 h period. In general, the load on an air-conditioning system can be divided into the following sections:

- Sensible Transmission through glass.
- Solar Gain through glass.
- Internal Heat gains
- Heat gain through walls.
- Heat gain through roof.
- Ventilation and/ or infiltration gains.

The heat gain through the glass windows is divided into two parts since there is a heat gain due to temperature difference between outside and inside and another gain due to solar radiation shining through windows. Heat gains through solid ground floors are minimal and can be neglected.

A2.4.1. Sensible Transmission Through Glass

This is the Solar Gain due to differences between inside and outside temperatures. In very warm locations, this can be quite significant. This gain only applies to materials of negligible thermal capacity i.e. glass.

$$\dot{Q}_g = A_g U_g (T_O - T_r) \quad \text{.............................} \quad (8)$$

Where;

$\dot{Q}_g$ = Sensible heat gain through glass (W)

A_g = Surface area of glass (m^2)

U_g = 'U' value for glass (W/m^2 °C)

T_o = outside air temperature (°C)

T_r = room air temperature (°C)

A2.4.2. Solar Gain Through Windows

This gain is when the sun shines through windows. The cooling loads per meter squared window area have been tabulated in standards for various; locations, times, dates and orientations. These figures are then multiplied by correction factors for; shading and air node correction factor.

$$\dot{Q}_{sg} = (S.\dot{q}_{sg}.A_g) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where;

$\dot{Q}_{sg}$ = Actual cooling load (W)

$\dot{q}_{sg}$ = Tabulated cooling load (W/m^2)

S = Mean solar gain factor

A_g = Area of glass (m^2)

A2.4.3. Internal Heat Gains

These gains are from occupants, lights, equipment and machinery, as detailed below.

Table A1.4. Typical Heat Gain Values

Conditions	Typical building	Sensible Heat Gain (Watts)	Latent Heat Gain (Watts)
Seated very light work	Offices, hotels, apartments	70	45
Moderate office work	Offices, hotels, apartments	75	55
Standing, light work; walking	Department store, retail store	75	55
Walking standing	Bank	75	70
Sedentary work	Restaurant	80	80
Light bench work	Factory	80	140
Athletics	Gymnasium	210	315

Loads from, Lighting (Average power density from light fixtures), Electrical equipment (PC's and Monitors , Laser Printers and Photocopiers , Electric Motors ,Lift Motors) , Cooking equipment can be calculated based on ASHRAE Fundamentals Load calculation principles.

Hence total latent heat load is found from;

$\dot{Q}_{int} = HeatfromOccupants + HeatfromLighting + HeatfromElectricalEquipment + HeatfromCooking$ …(.10)

A2.4.4. Heat Gain Through Walls

This is the unsteady-state heat flow through a wall due to the varying intensity of solar radiation on the outer surface.

Sol-Air Temperature

In the calculation of this heat flow use is made of the concept of sol-air temperature, which is defined as the value of the outside air temperature which would, in the absence of all radiation exchanges, give the same rate of heat flow into the outer surface of the wall as the actual combination of temperature difference and radiation exchanges.

$$T_{eo} = T_a + \left(\frac{\alpha . I \cos a . \cos n + \alpha I_S}{h_{so}} \right) \qquad (11)$$

Where;

T_{eo} = sol-air Temperature (°C)

T_a = outside air temperature (°C)

α = absorption coefficient of surface

I = intensity of direct solar radiation on a surface at right angles to the rays of the sun. (W/m^2)

a = solar altitude (degrees)

n = wall-solar azimuth angle (degrees)

I_s = intensity of scattered radiation normal to a surface (W/m^2)

h_{so} = external surface heat transfer coefficient (W/m$^{2\circ}$C)

Heat Trasnsfer to the oustide surface of the wall

$$\dot{Q}_{wo} = A.h_o (T_{eo} - T_{wo}) \qquad (12)$$

Where;

$\dot{Q}_{wo} =$ Heat transfer rate to the wall

$A =$ Area of wall (m^2)

$h_o =$ Outside convective film coeffcient (W/m^2 °C)

$T_{wo} =$ Outside wall temperature (°C)

The heat flow through a wall is complicated by the presence of thermal capacity, so that some of the heat passing through it is stored, being released at a later time. Thick heavy walls with a high thermal capacity will damp temperature swings considerably, whereas thin light walls with a small thermal capacity will have little damping effect, and fluctuations in outside surface temperature will be apparent almost immediately.

Heat gain from inside the wall surface

$$\dot{Q} = A.U(T_{wi} - T_r) \qquad (13)$$

Where;

$\dot{Q} =$ Heat gain from wall

$A =$ area of wall (m^2)

$h_i =$ Inide convective film coeffcient (W/m^2 °C)

$T_{wi} =$ Inside wall temperature (°C)

$T_r =$ Room temperature.

A2.4.5. Heat Gain Through Roof

The heat gain through a roof i similar to the rooml as shown below.

A2.4.6. Ventilation and/or Infiltration Gains

Heat load is found from;

$$\dot{Q}_{si} = \frac{n.V.(T_o - T_r)}{3} \qquad (14)$$

Where;

$\dot{Q}_{si}$ = Sensible heat gain (W)

n = number of air changes per hour (h^{-1})

V = volume of room (m^3)

T_o = outside air temperature (°C)

T_r = room air temperature (°C)

Infiltration gains should be added to the room heat gains. Recommended infiltration rates are 1/2 air change per hour for most air-conditioning cases. Ventilation or fresh air supply loads can be added to either the room or central plant loads but should only be accounted for once.

A2.4.7. Latent Gains

Latent heat gains are calculated so that the Total heat gain can be determined to complete a psychrometric chart.

Total heat gain = Sensible heat gain + Latent heat gains

Latent heat gains are required to size Chillers. Latent heat gains are comprised of latent gain from occupants and from natural infiltration fresh air. Latent heat gains from occupants can be obtained from standrads. The following formula gives the infiltration latent heat gain.

$$\dot{Q}_{li} = 0.8.n.V.(m_{so} - m_{sr}) \ldots\ldots\ldots\ldots \quad (15)$$

Where;

$\dot{Q}_{lj}$ = Infiltration latent heat gain (W)

n = Number of air changes per hour (h^{-1})

V = Room volume (m^3)

m_{so} = Moisture content of outside air (g/kg d.a.) from psychrometric chart.

m_{sr} = Moisture content of room air (g/kg d.a.) from psychrometric chart.

In the majority of cases, by far the greatest external fluctuating component is the solar heat gain through the windows.Therefore, it will be this gain which determines when the total heat gain to the room is a maximum. Heat gains may be calculated and displayed in table form as shown below.

Table A1.5. Summary Format for Cooling load Components

Heat Gain from	Watts	%
1. Sensible transmission through glass		
2. Solar gain through glass		
3. Internal		
4. External walls		
5. Roof		
6. Ventilation		
Total		100%
Heat gain per m^2 floor area =		
Heat gain per m^3 space =		

A2.4.8. Total Room Load From Heat Gains

$$\dot{Q}_{total} = \dot{Q}_{g} + \dot{Q}_{sg} + \dot{Q}_{\text{int}} + \dot{Q}_{wall} + \dot{Q}_{Roof} + \dot{Q}_{SI} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

A2.5 General Cooling and Heating Load Calculation Procedures

A2.5.1. Space Cooling Load

To calculate a space cooling load, detailed building design information and weather data at selected design conditions are required. Generally, the following steps should be followed.

A2.5.1.1. Building Characteristics

Obtain characteristics of the building. Building materials, component size, external surface colors, and shape are usually determined from building plans and specifications.

A2.5.1.2. Configuration

Determine building location, orientation, and external shading from building plans and specifications. Shading from adjacent buildings can be determined by a site plan or by visiting the proposed site but should be carefully evaluated as to its probable permanence before it is included in the calculation. The possibility of abnormally high ground-reflected solar radiation (i.e., from adjacent water, sand, or parking lots) or solar load from adjacent reflective buildings should not be overlooked.

A2.5.1.3. Outdoor Design Conditions

Obtain appropriate weather data, and select outdoor design conditions. For outdoor design conditions for a number of locations in Ethiopia, see table 1. Note; however, that these values for the design dry-bulb and mean coincident wet-bulb temperatures may vary considerably from data traditionally used in various areas. Use judgment to ensure that results are consistent with expectations.

A2.5.1.4. Indoor Design Conditions

Select indoor design conditions, such as indoor dry-bulb temperature, indoor wet-bulb temperature, and ventilation rate from ASHRAE handbook recommendations. Include permissible variations and control limits.

A2.5.1.5. Operating Schedules

Obtain a proposed schedule of lighting, occupancy, internal equipment, appliances, and processes that contribute to the internal thermal load. Determine the probability that the cooling equipment will be operated continuously or shut off during unoccupied periods (e.g., nights and/or weekends).

A2.5.1.6. Additional Considerations

The proper design and sizing of all-air or air-and-water central air-conditioning systems require more than calculation of the cooling load in the space to be conditioned. The type of air-conditioning system, fan energy, fan location, duct heat loss and gain, duct leakage, heat extraction lighting systems, and type of return air system all affect system load and component sizing. Adequate system design and component sizing require that system performance be analyzed as a series of psychometric processes.

A2.5.2. Space Heating Load

To calculate a design heating load, prepare the following information about building design and weather data at design conditions.

a) Select outdoor design weather conditions: temperature, wind direction, and wind speed.

b) Select the indoor air temperature to be maintained in each space during design weather conditions.

c) Temperatures in adjacent unheated spaces, attached garages, and attics can be estimated at the outdoor ambient temperature.

d) Select or compute heat transfer coefficients for outside walls and glass; for inside walls, non basement floors, and ceilings if these are next to unheated spaces; and for the roof if it is next to heated spaces.

e) Determine the net area of outside wall, glass, and roof next to heated spaces, as well as any cold walls, floors, or ceilings next to unheated spaces. These determinations can be made from building plans or from the actual building, using inside dimensions.

f) Compute transmission heat losses for each kind of wall, glass, floor, ceiling, and roof in the building by multiplying the heat transfer coefficient in each case by the area of the surface and the temperature difference between indoor air and outdoor air or adjacent lower temperature spaces.

g) Compute heat losses from basement or grade-level slab floors.

h) Select unit values, and compute the energy associated with infiltration of cold air around outside doors, windows, porous building materials, and other openings. These unit values depend on the kind or width of crack, wind speed, and the temperature difference between indoor and outdoor air. An alternative method is to use air changes.

i) When positive ventilation using outdoor air is provided by an air-heating or air-conditioning unit, the energy required to warm the outdoor air to the space temperature must be provided by the unit. The principle for calculation of this load component is identical to that for infiltration. If mechanical exhaust from the space is provided in an amount equal to the outdoor air drawn in by the unit, the unit must also provide for natural infiltration losses. If no mechanical exhaust is used and the outdoor air supply equals or exceeds the amount of natural infiltration that can occur without ventilation, some reduction in infiltration may occur.

j) The sum of the coincidental transmission losses or heat transmitted through the confining walls, floor, ceiling, glass, and other surfaces, plus the energy associated with cold air entering by infiltration or the ventilation air required to replace mechanical exhaust, represents the total heating load.

k) Include the pickup loads that may be required in intermittently heated buildings using night thermostat setback. Pickup loads frequently require an increase in heating equipment capacity to bring the temperature of structure, air, and material contents to the specified temperature.

ANNEX III. Duct Work Design

A3.1. Pressure Drop in a Duct

Pressure drop in ducts is given in general by Darcy-Weisbach equation as follows.

$$\Delta p = \rho \frac{fL}{D} \frac{\mathrm{v}^2}{2}$$

Where;

Δp = Pressure drop (Pa)

ρ = Density of air

v = Air velocity (m/s)
D = Duct equivalent diameter
f = Friction factor determined from moody diagram depending on Reynold's number and relative roughness of the duct
L = Duct length

When a duct has rectangular section of size a by b, the equivalent diameter is determined by

$$D = 1.3 \frac{(ab)^{0.625}}{(a+b)^{0.25}}$$

Reynold's number is given as:

$$\mathrm{Re} = \frac{\rho V D}{\mu}$$

ρ = Density of air
D = Duct equivalent diameter
V = Air velocity (m/s)
μ = Dynamic viscosity of air

The friction factor of a duct is read from moody diagram or determined by Colebrook formula in iterative way as function of Reynold's number and relative roughness of duct $\frac{\in}{D}$,

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\in}{3.7D} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

Where;

$\in$ = Duct surface roughness

D = Equivalent diameter of duct

f = Friction factor

Re = Reynold's Number

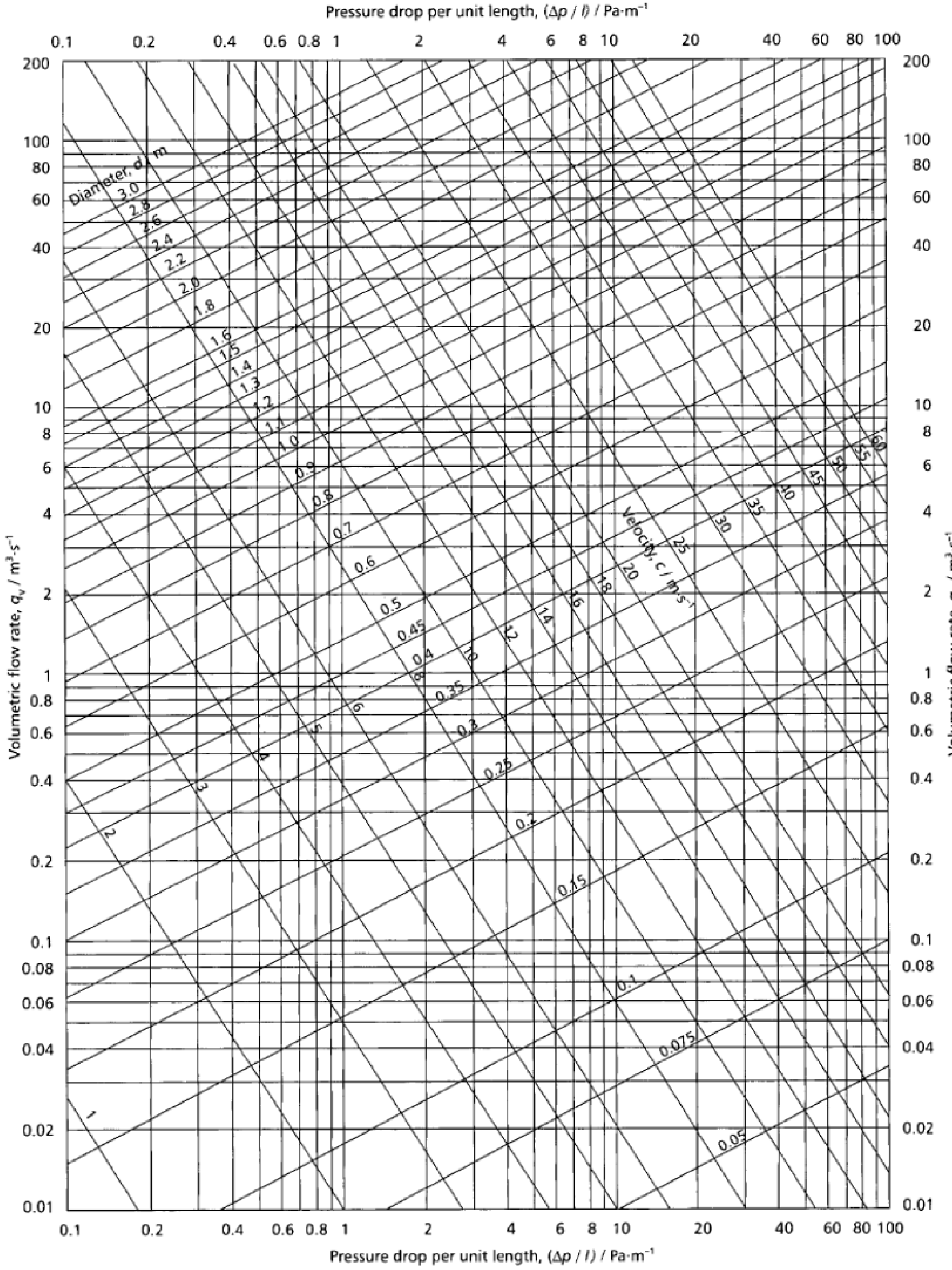

Figure A3.1. Duct Sizing Diagram

To facilitate duct design using Colebrook formula and Darcy-Weisbach equations plots of constant diameter and velocity lines were made on volume flow rate versus pressure drop diagram. The diagram facilitates determination of equivalent diameter for specified volume flow rate and pressure drop per meter length.

A3.2. Duct Sizing and Pressure Drop Calculation

For conventional ductwork the equal friction method is recommend to be used. In this method, the average pressure or resistance to flow per unit length is kept at a constant.

Resistance per unit length can be selected as below.

- Quiet - Pressure drop 0.4 Pa/m.
- Commercial - Pressure drop 0.6 Pa/m.
- Industrial - Pressure drop 0.8 Pa/m.

However, 1.0 Pa/m is recommended for pressure drop calculation for straight duct for accounting deviation from actual case. The design procedure can be summarizes as follows

1. Choose a rate of pressure drop and keep this constant for the whole system.
2. Size ductwork using duct sizing chart or duct sizing programs if the volume flow rate of air is known. This will give the duct equivalent diameter.
3. Determine the equivalent size of rectangular duct if required by calculation, using tables or duct sizing programs and round.
4. Calculate the actual air velocity from:

$$V = \frac{Q}{A}$$

Where;

V = Air velocity (m/s)

Q = volume flow rate (m^3/s)

A = Cross sectional area of duct (m^2)

5. Determine pressure drop in straight duct assuming pressure drop of about 1pa/m.
6. Determine fittings pressure loss as follows.

   a) Determine the velocity pressure factors (C) for the fittings) in each section of ductwork as given in ASHRAE fittings database.

b) Determine the velocity pressure (dynamic pressure) by calculation or using the following formula.

$$p_d = \frac{\rho v^2}{2}$$

Where;

p_d = velocity pressure (Pa)

ρ = Density of air

v = Air velocity (m/s)

c) Read the duct loss coefficient (C factors) for fitting from data given in the following sections or ASHRAE database and multiply C factors with velocity pressure (p_d) to determine pressure drop across the fitting.

$$\Delta p = C_i \frac{\rho v^2}{2}$$

Where;

C = Pressure loss factor for a fitting

$\Delta p_i (pa)$ = Pressure drop across fitting

7. Read pressure drop across filters, dampers, grills, sound attenuators etc from catalogues

8. Determine total pressure drop in each duct section consisting of pressure loss in straight duct and pressure loss for fittings and air distribution and control devices in that section.

$$\Delta p_j = \Delta p_{s.duct,j} + \sum_{i=1} C_i \frac{\rho v^2}{2} + \Delta p_{acess.,j}$$

9. Determine total pressure drop in the duct system by summing up the pressure drops in the sections using excel sheet similar to table A3.2

$$\Delta ptotal = \sum_{i=1}^{n} \Delta p_{j_i}$$

Table A3.1. Dimension of Equivalent Rectangular Duct to a Circular Duct of Given Diameter

Lgth Adj.[b]	Length One Side of Rectangular Duct (a), mm																			
	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800	900
	Circular Duct Diameter, mm																			
100	109																			
125	122	137																		
150	133	150	164																	
175	143	161	177	191																
200	152	172	189	204	219															
225	161	181	200	216	232	246														
250	169	190	210	228	244	259	273													
275	176	199	220	238	256	272	287	301												
300	183	207	229	248	266	283	299	314	328											
350	195	222	245	267	286	305	322	339	354	383										
400	207	235	260	283	305	325	343	361	378	409	437									
450	217	247	274	299	321	343	363	382	400	433	464	492								
500	227	258	287	313	337	360	381	401	420	455	488	518	547							
550	236	269	299	326	352	375	398	419	439	477	511	543	573	601						
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656					
650	253	289	321	351	378	404	429	452	474	515	553	589	622	653	683	711				
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765			
750	268	306	341	373	402	430	457	482	506	550	592	630	666	700	732	763	792	820		
800	275	314	350	383	414	442	470	496	520	567	609	649	687	722	755	787	818	847	875	
900	289	330	367	402	435	465	494	522	548	597	643	686	726	763	799	833	866	897	927	984
1000	301	344	384	420	454	486	517	546	574	626	674	719	762	802	840	876	911	944	976	1037
1100	313	358	399	437	473	506	538	569	598	652	703	751	795	838	878	916	953	988	1022	1086
1200	324	370	413	453	490	525	558	590	620	677	731	780	827	872	914	954	993	1030	1066	1133
1300	334	382	426	468	506	543	577	610	642	701	757	808	857	904	948	990	1031	1069	1107	1177
1400	344	394	439	482	522	559	595	629	662	724	781	835	886	934	980	1024	1066	1107	1146	1220
1500	353	404	452	495	536	575	612	648	681	745	805	860	913	963	1011	1057	1100	1143	1183	1260
1600	362	415	463	508	551	591	629	665	700	766	827	885	939	991	1041	1088	1133	1177	1219	1298
1700	371	425	475	521	564	605	644	682	718	785	849	908	964	1018	1069	1118	1164	1209	1253	1335
1800	379	434	485	533	577	619	660	698	735	804	869	930	988	1043	1096	1146	1195	1241	1286	1371
1900	387	444	496	544	590	663	674	713	751	823	889	952	1012	1068	1122	1174	1224	1271	1318	1405
2000	395	453	506	555	602	646	688	728	767	840	908	973	1034	1092	1147	1200	1252	1301	1348	1438
2100	402	461	516	566	614	659	702	743	782	857	927	993	1055	1115	1172	1226	1279	1329	1378	1470
2200	410	470	525	577	625	671	715	757	797	874	945	1013	1076	1137	1195	1251	1305	1356	1406	1501
2300	417	478	534	587	636	683	728	771	812	890	963	1031	1097	1159	1218	1275	1330	1383	1434	1532
2400	424	486	543	597	647	695	740	784	826	905	980	1050	1116	1180	1241	1299	1355	1409	1461	1561
2500	430	494	552	606	658	706	753	797	840	920	996	1068	1136	1200	1262	1322	1379	1434	1488	1589
2600	437	501	560	616	668	717	764	810	853	935	1012	1085	1154	1220	1283	1344	1402	1459	1513	1617
2700	443	509	569	625	678	728	776	822	866	950	1028	1102	1173	1240	1304	1366	1425	1483	1538	1644
2800	450	516	577	634	688	738	787	834	879	964	1043	1119	1190	1259	1324	1387	1447	1506	1562	1670
2900	456	523	585	643	697	749	798	845	891	977	1058	1135	1208	1277	1344	1408	1469	1529	1586	1696

Lgth Adj.[b]	Length One Side of Rectangular Duct (a), mm																			
	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
	Circular Duct Diameter, mm																			
1000	1093																			
1100	1146	1202																		
1200	1196	1256	1312																	
1300	1244	1306	1365	1421																
1400	1289	1354	1416	1475	1530															
1500	1332	1400	1464	1526	1584	1640														
1600	1373	1444	1511	1574	1635	1693	1749													
1700	1413	1486	1555	1621	1684	1745	1803	1858												
1800	1451	1527	1598	1667	1732	1794	1854	1912	1968											
1900	1488	1566	1640	1710	1778	1842	1904	1964	2021	2077										
2000	1523	1604	1680	1753	1822	1889	1952	2014	2073	2131	2186									
2100	1558	1640	1719	1793	1865	1933	1999	2063	2124	2183	2240	2296								
2200	1591	1676	1756	1833	1906	1977	2044	2110	2173	2233	2292	2350	2405							
2300	1623	1710	1793	1871	1947	2019	2088	2155	2220	2283	2343	2402	2459	2514						
2400	1655	1744	1828	1909	1986	2060	2131	2200	2266	2330	2393	2453	2511	2568	2624					
2500	1685	1776	1862	1945	2024	2100	2173	2243	2311	2377	2441	2502	2562	2621	2678	2733				
2600	1715	1808	1896	1980	2061	2139	2213	2285	2355	2422	2487	2551	2612	2672	2730	2787	2842			
2700	1744	1839	1929	2015	2097	2177	2253	2327	2398	2466	2533	2598	2661	2722	2782	2840	2896	2952		
2800	1772	1869	1961	2048	2133	2214	2292	2367	2439	2510	2578	2644	2708	2771	2832	2891	2949	3006	3061	
2900	1800	1898	1992	2081	2167	2250	2329	2406	2480	2552	2621	2689	2755	2819	2881	2941	3001	3058	3115	3170

Table A3.2. Duct Sizing Sheet

Duct Sizing Table											
1	2	3	4	5	6	7	8	9	10	11	12
Section	Length (m)	Flow Rate (m^3/s)	Pressure drop per meter (Pa/m)	Duct Size (mm)	Velocity (m/s)	Velocity Pressure (Pa)	Fittings pressure loss factor (C)	Pressure Loss		Section Total Pressure Loss (Pa)	Cumulative Pressure Loss (Pa)
								Fittings (Pa)	Straight Duct (Pa)		
A											
B											
C											
D											
E											
F											
G											
H											
	System Total Pressure Drop										

A3.3. Duct Leakage

The specific duct leakage shall be calculated as follows by assuming leakage class (C_L) according duct type and construction from the following table to determine the leakage that shall be added.

$$Q = \frac{1000C_L}{\Delta P_s^{0.65}}$$

Where;

Q = leakage rate, L/s per m^2

C_L = Leakage class, mL/s at 1 Pa

$\Delta P_s^{0.65}$ = Static pressure drop in the duct

Table A3.3. Approximate Values of Duct leakage Class (ASHRAE)

	Sealed Duct		**Unsealed Duct**	
Duct type	**C_L Class**	**Leakage Rate at 250 Pa L/(s. m^2)**	**C_L Class**	**Leakage Rate at 250 Pa L/(s. m^2)**
Metal				
Round & flat oval	4	0.14	42	1.5
Rectangular <500 Pa	17	0.62	68	2.5
>500 Pa and	8	0.29	68	2.5
< 2500 Pa				
Flexible				
Aluminium	11	0.4	42	1.5
Non-metal	17	0.62	30	1.5
Fibrous glass				
Round	4	0.14		

Rectangular	8	0.29

A3.4. Duct Work Sectional Losses

Common duct fitting database is given in this section. The fittings are numbered (coded) as shown in the following table.

Table A3.4. System for Coding of Duct Fittings and Accessories

Fitting Function	Geometry	Category	Sequential Number
S: Supply	D: Round	1. Entry 2. Exit	1,2,3...n
E: Exhaust/ Return	R: Rectangular	3. Elbows 4. Transition	
C: Common (Supply/Return)	F: Flat oval	5. Junction 6. Obstruction	
		7. Fan system interaction	
		8. Duct mounted equipment	
		9. Dampers	
		10. Hoods	