भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ: सीईडी 46/टी-16 **27 मार्च 2025**

तकनीकी समिति: भारत की राष्ट्रीय भवन निर्माण विषय समिति, सीईडी 46

प्राप्तकर्ता :

1. सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य
2. राष्ट्रीय भवन निर्माण संहिता विषय समिति, सीईडी 46 के सभी सदस्य
3. सीईडी 46 की उपसीमितयों और अन्य कार्यदल के सभी सदस्य
4. रुचि रखने वाले अन्य निकाय।

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 46 (26999) WC	**भारत की राष्ट्रीय भवन निर्माण संहिता भाग 8 भवन सेवाएँ अनुभाग 3 वायु वातानुकूलन , तापन तथा यांत्रिक संवातन** [SP7(भाग 8 अनुभाग 3) का चौथा पुनरीक्षण] (आई सी एस नंबर: 01.120: 91.040.01)

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इस पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 26 अप्रैल 2025

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा ced46@bis.gov.in पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, www.manakonline.in के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेख को अंतिम रूप दे दिया जाएगा।

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.in पर भी उपलब्ध हैं।
धन्यवाद।

भवदीय

ह/-
(द्वैपायन भद्र)
वैज्ञानिक 'ई' एवं प्रमुख (सिविल अभियांत्रिकी विभाग)

सलंग्न: उपरिलिखि

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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Website: www.bis.org.in , www.bis.gov.in

WIDE CIRCULATION DRAFT

Our Reference: CED 46/T-16 **27 March 2025**

National Building Code of India Sectional Committee, CED 46

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of the National Building Code Sectional Committee, CED 46
3. All Members of Subcommittees, Panels and Working Groups under CED 46
4. All other interests

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 46 (26999) WC	**National Building Code of India Part 8 Building Services Section 3 Air Conditioning, Heating and Mechanical Ventilation** [Fourth Revision of SP 7 (Part 8 Section 3)] (ICS No. 01.120: 91.040.01)

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 26 April 2025

Comments if any, may please be made in the enclosed format and emailed at **ced46@bis.gov.in** or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, **www.manakonline.in**.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website **www.bis.gov.in**.

Thanking you,

Yours faithfully,

Sd/-
(Dwaipayan Bhadra)
Scientist 'E' / Director and Head
(Civil Engineering Department)

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced46@bis.gov.in shall be appreciated**.

Doc. No.: CED 46 (26999) WC **BIS Letter Ref**: CED 46/T-16

Title: National Building Code of India Part 8 Building Services Section 3 Air Conditioning, Heating and Mechanical Ventilation [Fourth Revision of SP 7 (Part 8 Section 3)] (ICS No.01.120:91.040.01)

Last date of comments: **26 April 2025**

Name of the Commentator/ Organization: ________________________________

Clause/ Para/ Table/ Figure No. commented	Comments/Modified Wordings	Justification of Proposed Change

NOTE- Kindly insert more rows as necessary for each clause/table, etc

BUREAU OF INDIAN STANDARDS

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Draft Indian Standard

National Building Code of India

Part 8 Building Services

Section 3 Air Conditioning Heating and Mechanical Ventilation

[Fourth Revision of SP 7 (Part 8 Section 3)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46	**Last Date for Comments: 26 April 2025**

C O N T E N T S

National Building Code Sectional Committee, CED 46

FOREWORD

This Code (Part 8/Section 3) deals with the planning, selection, design considerations, and installation of air conditioning, heating and mechanical ventilation system for different types of building application and in towns and cities under all the climatic zones of India. It covers all aspects including the goals and objectives, basis of design, input parameters for design, guidelines for design of system, performance parameters, available system options, pre-planning considerations, range of equipment and system components, building management system, installation of the system, testing, commissioning and handing over and also operation and maintenance of the air conditioning, heating and mechanical ventilation system.

Indian construction industry is poised to add an-order-of-magnitude built foot-print in the coming years. With the advent of information technology and computers becoming part of our life-style, the requirement of air conditioning of built environment is being increasingly felt and met with. The challenge faced for this unprecedented development is the lack of material resources and natural resources like energy, water and clean air. Therefore, the selection of air conditioning and mechanical ventilation system, optimally suited for the specific type of building application and its climatic zone, becomes critical. It is necessary for the owner, designer, builder and developer to understand the provisions of this Section, and consult an air conditioning engineer at the planning stage.

Sustainable buildings movement in the country has gained tremendous momentum. The Part 11 'Approach to Sustainability' of the code, deals with all aspects of sustainable buildings, from selection of site, building design, energy and water efficient systems, use of recycled material resources, construction, third party commissioning, operation and maintenance of sustainable buildings. By following the provisions of this Section in conjunction with those given in Part 11, India will adopt sustainable buildings as the way of life, as has been the practice for centuries, prior to the onslaught of industrial revolution in India.

Computerized weather data is now available and has been included for around 145 locations across the country, covering all the five climatic zones. This data is based on the latest values obtained from India Metrological Department, Government of India.

This Section was first formulated in 1970 and was subsequently revised in 1983, 2005 and 2016. The major modifications made in 2005 version of the Code included addition of several new terms and their definitions; incorporation of a new clause on design criteria; inclusion of 'indoor air quality' as one of the factors that needed to be controlled in the conditioned space; incorporation of recommendation for independent air handling unit rooms for each floor of large and multi storeyed buildings; inclusion of inside design conditions for various applications replacing earlier Table 2 and Table 3; revision of provisions on minimum outside fresh air in the light of the then accepted international norms thus covering a wider variety and a larger number of applications;

addition of new details on temperature, humidity, vibration and noise; updation of provisions on application considerations, covering a wide variety of commercial applications, such as, offices, hotels, restaurants and computer rooms; inclusion of a new clause on statutory regulation/safety considerations; description of various system options available, under the clause on design considerations; updation of provisions on the characteristics and application of options available in piping, water distribution systems and piping layout; revision of provisions on air filters; revision of the clause on energy conservation and energy management to include concepts like energy targets, demand targets and consumption targets, the factors to be considered in system design that influence energy aspects, the need for analysis of operation of systems during various seasons of the year, and the need to incorporate energy recovery strategies. Apart from above, 'Automatic Controls' included in the 1983 version was replaced by building management system, which addressed not only the control function, but also had a telling impact on operation and maintenance as well, most importantly on the opportunities afforded to implement various energy conservation strategies; provisions on packaged air conditioners and room air conditioners were elaborated; provisions on heating were revised; provisions on symbols, units, colour code and identification of services, pipe work services, duct work services, valve labels and charts, and also on inspection, commissioning and testing were updated; and list of various parameters to be checked for performance of air handling unit, hydronic system balancing, and finally, the hand-over procedure were included.

The 2016 revision of this part introduced several important updates to align HVAC systems with modern needs and sustainable practices. It added new definitions to reflect emerging concepts and technologies and updated refrigerant guidelines to include eco-friendly options like zero-ozone-depleting and low-global-warming-potential refrigerants. Planning considerations were expanded to incorporate advanced systems such as VRF, district cooling, and hybrid central plants, supported by tools like energy modelling and solar shade analysis to optimize energy efficiency. The outdoor and indoor design conditions were updated using adaptive comfort standards and comprehensive weather data from across India. Key advancements in HVAC equipment included provisions for chilled beams, radiant floors, and geothermal systems were made. Specialized applications were addressed in greater detail, covering data centers, metro stations, and cold storage facilities critical for food security. Ventilation received a significant focus, emphasizing sustainability, demand control, and advanced fan designs. Installation practices were refined for ease of maintenance and better integration with building automation systems. The revision also standardized symbols and colour coding, introduced web-based monitoring for building management systems, and enhanced testing and commissioning protocols to ensure state-of-the-art performance

This revision of this Part 8, Section 3, of the Code focuses on improving air conditioning, heating, and ventilation systems for better efficiency and sustainability. New features include advanced refrigerants, geothermal systems, and tools for energy-saving designs. It also addresses specialized needs like data centres and metro stations. These changes help ensure better performance, lower energy use, and reduced environmental impact.

The significant changes incorporated in this revision include the following:

a) Additional details on systems like variable refrigerant flow (VRF) and inverter-based cooling for better efficiency, in **4.1.4**.

b) Added new eco-friendly refrigerants with no harm to the ozone layer and very low impact on global warming, in **5.3**.

c) Addition of modern low-energy heating and cooling solutions, including evaporative cooling, radiant cooling, and solar-assisted systems. Additionally, it provides improved guidelines for system selection, installation, and applications across residential, commercial, and industrial sectors, in **6.**

d) Inclusion of new methods for cooling and heating using the earth's natural temperature are included, in **6.4**.

e) Addition of efficient heating solutions like solar-powered systems and ground heat pumps for cold regions, in **6.5**.

f) Addition of guidelines for selecting air-conditioning and ventilation systems across various building typologies, including residential, commercial, and transport hubs, in **12.**

g) New guidelines for cold storage facilities to improve food preservation and reduce waste, in **13.2**.

h) Inclusion of enhanced guidelines for using automation systems to monitor and control building performance, in **15.2**.

j) Introduction of uniform standards for hydronic and refrigerant piping in HVAC systems to enhance performance covering material selection, sizing, installation, testing, and maintenance for efficient fluid transport, in **16.**

k) Inclusion of new procedures for testing and setting up HVAC systems to ensure they work efficiently, in **17**.

m) Introduction of comprehensive smoke mitigation guidelines for substructures, superstructures, and exit pathways, in **19.**

n) Terminology clause has been updated with new terms and definitions.

The information contained in this section is based largely on the following Indian Standards:

IS 1391	Room Air Conditioners Specification
(Part 1) : 2023	Unitary Air Conditioners (*fourth revision*)
(Part 2) : 2023	Split Air Conditioners (*fourth revision*)

IS 2379 : 2024	Colour Code for Pipeline Identification - Code of Practice (*second revision*)
IS 3315 : 2024	Direct Evaporative Air Cooler - Specification (*fourth revision*)
IS 8148 : 2018	Ducted and Package Air-Conditioners – Specification (*second revision*)
IS 7896 : 2023	Air Conditioning Outdoor Design Conditions Data for Indian Cities (Second Revision)

Assistance has also been derived from the following publications in the preparation of this Section:

Handbooks of Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)

India Model for Adaptive Comfort, CEPT University, Ahmedabad

ISO 16484-1: 2024 Building automation and control systems (BACS) – Part 1: Project specification and implementation

The provisions on natural ventilation are given in Part 8 'Building Services, Section 1 Lighting and Ventilation' of the Code.

The provisions of this Section are without prejudice to the various Acts, Rules and Regulations including *The Factories Act*, 1948 and the rules and regulations framed thereunder.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties using this Section are encouraged to investigate the possibility of applying the most recent edition of the standards.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2:2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Code Users are requested to share their inputs/comments on the draft particularly based on the changes listed above in the foreword.

Important Explanatory Note for Users of the Code

In any Part/Section of this Code, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [8-3(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part/Section, that is, IS 3615:2020 'Glossary of terms used in refrigeration and air conditioning (second revision)'.

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Draft Indian Standard

National Building Code of India

Part 8 Building Services

Section 3 Air Conditioning Heating and Mechanical Ventilation

[Fourth Revision of SP 7 (Part 8 Section 3)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46	**Last Date for Comments: 26 April 2025**

1 SCOPE

This Code (Part 8/Section 3) covers the planning, design considerations, installation, testing, commissioning and handing over and, also operation and maintenance of air conditioning, heating and mechanical ventilation systems for buildings. It also covers refrigeration for cold storages.

The provisions of this Section aim to ensure an air conditioning, heating and mechanical ventilation system which shall provide comfort by managing air temperature, humidity, indoor air quality and distribution of conditioned air for the specific use and occupancy of built space while giving due consideration to minimizing energy consumption and other resources.

The provisions on natural ventilation are covered in Part 8 'Building Services', Section 1 'Lighting and Ventilation' of the Code.

The provisions in respect of air conditioning, heating and mechanical ventilation system in sustainable buildings are covered in Part 11 ‘Approach to Sustainability’ of the Code, which shall be used in conjunction with this Section.

2 TERMINOLOGY

For the purpose of this Section the following definitions shall apply in addition to those given in the accepted standard [8-3(1)] and the following shall apply.

2.1 Air Conditioning — The process of treating air so as to control simultaneously its temperature, humidity, purity, distribution and movement and pressure to meet the requirements of the conditioned space.

2.2 Air System Balancing — Adjusting air flow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitter vanes, extractors, etc, or by using automatic control devices, such as constant-air-volume or variable-air-volume (VAV) boxes.

NOTE — Air system should be balanced in order to minimize throttling losses. For fans, its speed should be adjusted to meet design flow conditions. By creating correct air flow at fans and outlet, system performance shall be increased.

2.3 Atmospheric Pressure — The force per unit area exerted against a surface by the weight of the air above that surface. It is the pressure indicated by a barometer. Standard atmospheric pressure or standard atmosphere or barometric pressure is the pressure of 760 mm of mercury column having a density of 13.6 g/cm^3 under standard gravity of 9.8 m/sec^2 (10.332 mm of water column/101.325 kPa).

NOTE — Generally atmospheric pressure is used as a datum for indicating the system pressures in air conditioning and accordingly, pressures are mentioned above the atmospheric pressure or below the atmospheric pressure considering the atmospheric pressure to be zero. A 'U' tube manometer will indicate zero pressure when pressure measured is equal to atmospheric pressure.

2.4 Building Management System (BMS) — An energy management system relating to the overall operation of the building in which it is installed. It often has additional capabilities, such as equipment monitoring, protection of equipment against power failure, and building security. It may also be a direct digital control (DDC) system where the mode of control uses digital outputs to control processes or elements directly.

NOTE — Mechanical and electrical equipment installed in the building, such as, air conditioning, ventilation, lighting, lifts, power, pumping stations, firefighting systems, security systems are controlled and managed through BMS.

2.5 Building Energy Simulation — Use of computer models for design and optimization of building's energy performance, to compare the cost-effectiveness of energy conservation measures in the design stage as well as assessing various performance optimization measures during the operational stage.

2.6 Building Integrated Renewable Energy — Integration of renewable energy application in parts of the building envelope such as the roof, skylights, or facades.

2.7 Buildings Related Illnesses (BRI) — The diagnosable illness attributed directly to the specific air-borne building contaminants, like Legionnaire's disease, occupational asthma, etc.

NOTE — Indicators of BRI include complaints of cough, chest tightness, chills, fever and muscle aches. Occupants may need prolonged recovery times after leaving the building.

2.8 Coefficient of Performance, Compressor, Heat Pump — Ratio of the compressor heating effect (heat pump) to the rate of energy input to the shaft of the compressor, in consistent units, in a complete heat pump, under designated operating conditions.

2.9 Coefficient of Performance, Compressor, Refrigerating — Ratio of the compressor refrigerating effect to the rate of energy input to the shaft of the compressor, in consistent units, in a complete refrigerating plant, under designated operating conditions.

2.10 Coefficient of Performance (Heat Pump) — Ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete operating heat pump plant or some specific portion of that plant, under designated operating conditions.

2.11 Coefficient of Performance (Refrigerating) — Ratio of the rate of heat removal to the rate of energy input, in consistent units, for a complete refrigerating plant or some specific portion of that plant, under designated operating conditions.

2.12 Cooling Load — Amount of cooling per unit time required by the conditioned space or product; or heat that a cooling system shall remove from a controlled system over time.

2.13 Cooling Tower — An enclosed device, often tower like, for evaporatively cooling water by contact with air.

2.14 Dedicated Outdoor Air System (DOAS) — A unit that is used to separately condition outdoor air brought into the building for ventilation or to replace air that is being exhausted.

2.15 Demand Based Ventilation — Intelligent airflow management that adjusts outside ventilation air based on the number of occupants and the ventilation demands that those occupants create.

2.16 Design Pressure Difference — The desired pressure difference between a given space and an adjacent space measured at the boundary of the given space under a specified set of conditions, such as, that required in various spaces of hospital, clean rooms, protected space in case of smoke control operation, etc.

2.17 Dew Point Temperature — The temperature at which condensation of moisture begins when the air is cooled at same pressure.

2.18 Dry-Bulb Temperature — The temperature of the air, read on a thermometer, taken in such a way as to avoid errors due to radiation.

2.19 Duct System — A continuous passageway for the transmission of air which, in addition to the ducts, may include duct fittings, dampers, plenums, grilles and diffusers.

2.20 Economizer, Air — It consist of duct, damper and control system that allow outside air to cool the building when outside air is cooler than inside.

2.21 Economizer, Water — In this system the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat transfer or mass transfer to the environment without the use of mechanical cooling.

2.22 Effective Temperature — Combined effects of air temperature, humidity, air movement, mean radiant temperature, clothing and activity on the sensation of warmth or cold felt by the human body. Numerically equivalent to the temperature of still air producing similar thermal sensation as produced by combination of above six parameters of thermal comfort.

2.23 Energy Efficiency Ratio (EER) — Ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions.

2.24 Energy Recovery Unit — A heat exchanger assembly for transferring energy between two isolated fluid sources. The recovery system may be of air-to-air design or a closed loop hydronic system design. The system will include all necessary equipment such as fans and pumps, associated ducts or piping and all controls (operating and safety), and other custom-designed features

2.25 Evaporative Cooling — The process of evaporating part of a liquid by supplying the necessary latent heat from the sensible heat of the main bulk of the liquid which is thus cooled.

2.26 Fire Damper — The damper, normally held open, installed in an air distribution system or in a wall or floor assembly and designed to close automatically in the event of a fire in order to maintain the integrity of the fire separation.

2.27 Geothermal Heat Pump — A heating and/or cooling system utilizes the earth's crust, as heat source (in the winter) or a heat sink (in the summer) by using fluid to be pumped into the earth and circulated in order to exchange heat for the purpose of heating or cooling applications

2.28 Global Warming Potential (GWP) —The relative measure of how much a given mass of a refrigerant contributes to global warming over a given time period compared to the same mass of carbon dioxide over the same period.

NOTE —The GWP value of carbon dioxide is taken to be 1.0. The GWP value of a refrigerant is calculated over a time horizon. The time horizon shall greatly affect the numerical value of GWP. Usually the GWP values are reported over a 100 years' time horizon.

2.29 Heating Load — Heating rate required to replace heat loss from the space being controlled.

2.30 Heat Pump — A thermodynamic heating/refrigerating system to transfer heat. The condenser and evaporator may change roles to transfer heat in either direction. By receiving the flow of air or other fluid, a heat pump is used to cool or heat. Heat pumps may be the air source with heat transfer between the indoor air stream to outdoor air or water source with heat transfer between the indoor air stream and a hydronic source (ground loop, evaporative cooler, cooling tower, or domestic water).

2.31 Heat Recovery — Use of heat that would otherwise be wasted from a system or process, for example, heat-recovery chiller which uses hot waste gases as a heat source.

2.32 Hybrid Building — A building which contains both active and passive systems of heating or cooling. It requires small amount of non-renewable energy to maintain required amount of coefficient of performance (COP).

2.33 Hydronic Systems — The water systems that transfer heat to or from a conditioned space or process with hot or chilled water. The water flows through piping that connects a chiller or the water heater to suitable terminal heat transfer units located at the space or process.

2.34 Hydronic System Balancing — Adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position valves or by using automatic control devices, such as automatic flow control valves.

2.35 Indirect-Direct Cooling — The cooling which involves two stages:

a) The first stage, in which the air is made to pass through heat exchanger for sensible cooling (no direct contact of air and water), whereby the leaving air dry-bulb temperature (DBT) as well as the wet-bulb temperature (WBT) are reduced; and
b) The second stage, in which the air after the first stage is made to pass through the evaporative air-cooling (adiabatic cooling) application where water and air are in direct contact and there is simultaneous removal of sensible heat and the addition of moisture to the air giving lower DBT.

The resultant of this two-stage cooling is that the leaving air DBT is lower than ambient WBT.

NOTE — The first stage cooling is through indirect cooling. In this method, air-dry bulb and wet-bulb temperature are reduced without direct contact of air with water and through heat exchange only.

2.36 Indoor Air Quality (IAQ) — Air quality that refers to the nature of unconditioned or conditioned air that circulates throughout the space/area where one works or lives, that is, the air one breathes when indoors.

2.37 Infiltration/Exfiltration — The phenomenon of air leaking into (infiltration) or leaking out (exfiltration) out of an air-conditioned space.

2.38 Latent Heat — Change of enthalpy during a change of state, usually expressed, in kcal/kg. With pure substances, latent heat is absorbed or rejected at constant temperature at any pressure.

2.39 Latent Heat Load — Cooling load required to remove latent heat.

2.40 Mean Radiant Temperature — The uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.

2.41 Mixed Mode Building — A hybrid approach to space conditioning that uses a combination of natural ventilation and mechanical systems. These buildings utilize mechanical cooling only when and where it is necessary to supplement the natural ventilation.

2.42 Naturally Conditioned Building — A building in which the ventilation system rely on opening and closing of window of the space to maintain the thermal comfort of the space rather than mechanical systems.

2.43 Operative Temperature — A uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. It is the combined effects of the mean radiant temperature and air temperature calculated as average of the two. It is also known as dry resultant temperature or resultant temperature.

2.44 Ozone Depletion Potential (ODP)—A relative capability of a refrigerant or a gas to degrade ozone in the atmosphere as compared to trichlorofluoromethane [R-11 or Clorofluorocarbon-11(CFC-11)]. The ODP of CFC-11 is taken to be 1.0.

2.45 Passive Cooling — A building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or zero energy consumption by using natural ventilation, air cooling and shades.

2.46 Passive Heating — Passive heating uses the energy of natural source such as the sun, to keep the occupants of the building comfortable by design approach of building without the use of mechanical or electrical heating systems.

2.47 Plenum — An air compartment connected to one or more distributing ducts.

2.48 Positive Ventilation — The supply of outside air by means of a mechanical device, such as a fan.

2.49 Psychrometric Chart — A chart graphically representing the thermodynamic properties of moist air.

2.50 Recirculated Air — The return air that has been passed through the conditioning apparatus before being re-supplied to the space.

2.51 Refrigerant — The fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects heat at a higher temperature and a higher pressure of the fluid, usually involving changes of state of the fluid.

2.52 Relative Humidity — Ratio of the partial pressure of actual water vapour in the air as compared to the partial pressure of maximum amount of water that may be contained at its dry-bulb temperature.

NOTE — When the air is saturated, dry-bulb, wet-bulb and dew point temperatures are all equal, and the relative humidity is 100 percent.

2.53 Return Air — Air returned from conditioned or refrigerated space.

2.54 Sensible Heat — Heat which is associated with a change in temperature; in contrast to a heat interchange in which a change of state (latent heat) occurs.

2.55 Sensible Cooling — The process of removing sensible heat (lowering the dry-bulb temperature) from the air passing through it under specified conditions of operation.

2.56 Shade Factor — The ratio of instantaneous heat gain through the fenestration with shading device to that through the fenestration.

2.57 Sick Building Syndrome (SBS) — A term used to describe the presence of acute non-specific symptoms in the majority of people, caused by working in buildings with an adverse indoor environment.

NOTE — SBS could be a cluster of complex irritative symptoms like irritation of the eyes, blocked nose and throat, headaches, dizziness, lethargy, fatigue irritation, wheezing, sinusitis, congestion, skin rash, sensory discomfort from odours, nausea, etc. These symptoms are usually short-lived and experienced immediately after exposure; and may disappear when one leaves the building.

2.58 Smoke Barrier — A continuous membrane, either vertical or horizontal, such as a wall, floor, or ceiling assembly, that is designed and constructed to restrict the movement of smoke in conjunction with a smoke control system.

2.59 Smoke Damper — A damper similar to fire damper, however, having provision to close automatically on sensing presence of smoke in air distribution system or in conditioned space.

2.60 Smoke Management — A smoke control method that utilizes natural or mechanical systems to maintain a tenable environment for the means of egress from a large-volume space or to control and reduce the migration of smoke between the area on fire and communicating spaces.

2.61 Stack Effect — The vertical airflow within buildings caused by the temperature-created density differences between the building interior and exterior or between two interior spaces.

2.62 Static Pressure — The normal force per unit area that would be exerted by a moving fluid on a small body immersed in it if the body were carried along with the fluid. Practically, it is the normal force per unit area at a small hole in a wall of the duct through which the fluid flows (piezometer) or on the surface of a stationary tube at a point where the disturbances, created by inserting the tube. It is supposed that the thermodynamic properties of a moving fluid depend on static pressure in exactly the same manner as those of the same fluid at test depend upon its uniform hydrostatic pressure.

2.63 Supply Air — The air that has been passed through the conditioning apparatus and taken through the duct system and distributed in the conditioned space.

2.64 Terminal Devices— Devices fixed in the air-conditioned space for distribution of conditioned supply air and return of air such as, supply and return air grilles and diffusers.

2.65 Thermal Adaptation — The gradual diminution of the people's response to repeated environmental stimulation and subsumes all processes which building occupants undergo in order to improve the fit of the indoor climate.

2.66 Thermal Comfort – That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

2.67 Thermal Insulation Material — A material used over the conducting material to retard the flow of heat energy in the form of heat loss or gain to facilitate the temperature control as the process and prevent permeability of moist vapour and reduces condensation on cold surfaces.

2.68 Thermal Energy Storage — Storage of thermal energy, sensible, latent or combination thereof for use in central system for air conditioning or refrigeration. It uses a primary source of refrigeration for cooling and stored thermal energy for reuse at peak demand or for backup as planned.

2.69 Velocity Pressure — The pressure exerted by movement of air which makes the air to travel to longer distance in ducts. This pressure is always in the direction of flow.

2.70 Variable Refrigerant Flow (VRF) System — A heating and/or cooling system in which the flow of the refrigerant shall be varied according to the load.

2.71 Water Hardness — The hardness in water represented by the sum of calcium and magnesium salts in water, which may also include aluminium, iron, manganese, zinc, etc.

2.72 Water Treatment — The treatment of water circulating in a hydronic system, so that it shall be used without creating undue corrosion or scaling to the piping systems and other deleterious effects.

2.73 Wet-Bulb Temperature — The temperature at which liquid or solid water, by evaporating into air, shall bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature is the temperature indicated by a wet-bulb thermometer constructed and used according to specifications.

2.74 Definitions / terminology reference to refrigerants – Refer to the accepted standard [8-3(9)] for all the definitions. In addition, below are some definitions.

2.74.1 *Glide* – The difference in the dew and bubble point of a zeotropic refrigerant at constant pressure.

2.74.2 *Occupational Exposure Limit (OEL)* – The threshold amount of time-weighted average (TWA) concentration a normal 8-hour shift and a 40-hour workweek to which nearly all workers shall be repeatedly exposed without any adverse effects.

3 BASIS OF DESIGN

3.1 Planning and design considerations

In any building, clear definition of design considerations holds the key for a good HVAC system. This includes, appropriate system selection, system sizing, layout and location planning, planning for operation, maintenance and controls as explained in following pages.

3.2 Fundamental Planning Requirements

The objective of installing air conditioning, heating and mechanical ventilation in buildings shall be to provide comfortable conditions without compromising on health and safety of occupants. Air conditioning, heating and mechanical ventilation installation shall aim at controlling the following factors in the building:

a) Thermal Comfort
b) Air quality, Air quantity and Air movement,
c) Sound and vibration,
d) through meeting the minimum energy efficiency levels,
e) ensuring electrical and
f) fire safety requirements. This shall be done

3.2.1 All plans, design, drawings, specifications and data for air conditioning, heating and mechanical ventilation systems of all buildings and serving all occupancies within the scope of the Code, shall be supplied to the Authority, where called for (*see* Part 2 'Administration' of the Code).

3.2.2 The plans, design and drawings for air conditioning, heating and mechanical ventilation (HVAC) systems shall include all details and data necessary for detailed load calculation through computer simulation such as:

a) Building name, type and location, address;
b) Owners' name;
c) HVAC designers' name;
d) Use of building;
e) Building orientation: north direction on plans and design drawings;
f) General plans, dimensions and height of all rooms in SI unit;
g) Intended use of internal spaces;
h) Detail or description of wall construction, including insulation and finish;
j) detail or description of roof, ceiling and floor construction, including insulation and finish;
k) Detail or description of windows and outside doors, including sizes, thermal properties, weather stripping, chajjas or projections;
m) Internal load, such as people, equipment, computer/server load and lighting load;
n) Layout showing the location, size and components of the hvac equipment being installed;
p) Information regarding air distribution system;
q) Information on air and water systems and their flow rates and pressure drops;
r) Information regarding location, size and accessibility of shafts;
s) Information regarding type and location of dampers (both volume control and fire/smoke dampers) used in air conditioning system, such as, whether motorized or manually operated and rating;
t) Location and grade of the required fire separations;

u) Water treatment and softening arrangement;
v) Information on presence of any chemical fumes or gases and
w) HVAC automation design, description and Piping and Instrumentation (generally referred to as P&I drawing) drawing.

3.3 Fundamental Design Requirements

The following guidelines address critical factors such as load calculations, system adjustments for off-peak hours, and specialized needs for various applications, ensuring optimal performance and energy conservation across diverse scenarios.

3.3.1 Heat Load Calculation shall take into account the following factors:

a) Recommended indoor temperature, relative humidity, air velocity, mean radiant temperature, clothing, activity and IAQ parameters;
b) Outside and indoor design conditions as specified;
c) Details of building construction and orientation of exposures of building components;
d) Fenestration area, thermal properties and shading factors;
e) Occupancy: Number of people and their schedule of activities;
f) Ventilation: Requirement for fresh air;
g) Infiltration, air leakage;
h) Internal load: Equipment, computer/server and lighting;
j) Effective volume; and
k) Occupancy, lighting and equipment schedule.

3.3.2 The design of air conditioning, heating and mechanical ventilation system and its associated controls shall also consider the following:

a) Application,
b) Permissible control limits,
c) Fire safety,
d) Opportunities for heat recovery, condensate drain recovery,
e) Energy efficiency,
f) Filtration standard,
g) Hours of use,
h) Suitable diversity factor based on usage,
j) Outdoor and indoor air quality.

3.3.3 Due consideration shall be given to air conditioning load encountered during off-peak hours including night, weekend, holidays. The system shall be designed for the maximum operational efficiency to achieve lowest annual energy consumption. Consideration shall be given to the anticipated future changes (permanent or temporary) in building load. the system shall be designed for maximum operational efficiency is achieved throughout.

3.3.4 The air conditioning system for Special applications like hospitals, operating theatres, computer rooms, data centres and telecommunication rooms, clean rooms, laboratories, libraries, museums, art galleries, sound recording studios, etc shall be designed as per specific requirement.

3.3.5 Computer based hourly load calculation and energy simulation tools should be used for HVAC equipment sizing and to identify effect of various energy conservation measures on energy consumption.

3.3.6 An uncertainty analysis should be carried out Based on the input parameter accuracy level. The system design should be determined by the uncertainty analysis considering the parameters like variation in climatic conditions, material properties, usage pattern, internal loads over design or under design of the should be avoided.

3.3.7 The system sizing shall be based upon outdoor and indoor design conditions, considering a safety factor, together with capacity deration due to local conditions as well as aging of equipment. Performance maps of major equipment at different climatic conditions and loads should be considered for accessing their suitability, sufficiency and energy efficiency.

3.4 System Layout and space planning

Each type of HVAC system has peculiar space and layout requirement. Major requirements for planning an efficient and serviceable layout are explained below:

3.4.1 *Equipment Room for Central Air Conditioning Plant*

These guidelines address the provisions of Equipment Room for Central Air Conditioning Plant

3.4.1.1 This room shall be located preferably within the building being air conditioned and closer to external wall for facilitating ventilation and equipment movement. The equipment may also be installed in a separate service block which should also be located as close as possible to the load/building being conditioned. The clear headroom below soffit of beam should be minimum 4.5 m for larger capacity chillers (500 TR and above) and minimum 3.6 m for smaller plants.

3.4.1.2 The floors of the equipment rooms should be compacted and finished. For floor loading, the air conditioning engineer should be consulted (*see* also Part 6 ‘Structural Design, Section 1 Loads, Forces and Effects’ of the Code).

3.4.1.3 Supporting of pipe within plant room spaces should be normally from the floor. However, outside plant room areas, structural provisions shall be made for supporting the water pipes from the floor/ceiling slabs. All floor and ceiling supports shall be isolated from the structure to prevent vibration transmission.

3.4.1.4 Equipment rooms, wherever necessary, shall have provision for mechanical ventilation. In hot and dry climate, evaporative air cooling shall be considered to maintain plant room temperature.

3.4.1.5 Plant machinery in the plant room shall be placed on levelled plain/reinforced cement concrete foundation block and provided with anti-vibratory supports or alternatively on inertia bases. Supports for appliances shall be designed and constructed to sustain vertical and horizontal loads within the stress limitations specified in the Part 6 'Structural Design' of the Code. All foundations should be protected from damage by providing epoxy coated angle nosing. Seismic restraints requirement should also be considered (*see* also **12.6.4**).

3.4.1.6 Appropriate sound insulation and noise control measures shall be taken in plant room space as per Part 8 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of the Code. Acoustic treatment as may be required shall be provided in plant room space in accordance with **12.1.9** to prevent noise transmission to adjacent occupied areas.

3.4.1.7 In case air conditioning plant room is located in basement, equipment movement route shall be planned to facilitate future replacement and maintenance. Service ramps or hatch in ground floor slab should be provided in such cases. Fire egress and emergency battery backup lighting shall be provided for the plant room operator.

3.4.1.8 Floor drain channels or dedicated drain pipes in slope shall be provided within plant room space for effective disposal of waste water, if necessary, by automatic level-controlled sump pumps. Fresh water connection may also be provided in the air conditioning plant room.

3.4.1.9 Thermal Energy Storage should be used for limiting maximum demand, by controlling peak electricity load through reduction of chiller capacity, and by taking advantage of high system efficiency during low ambient conditions. Thermal storage will also help in reducing operating cost by using differential time-of-the day power tariff, where applicable. In case of central plant designed with thermal energy storage, its location shall be decided in consultation with the air conditioning engineer. For roof top installations, structural provision shall take into account load coming on the building/structure due to the same. For open area surface installation, horizontal or vertical system options shall be considered and approach ladders for manholes provided. Buried installation shall take into account loads due to movement of vehicles above the area. Provision for adequate expansion tank and its connection to thermal storage tanks shall be made.

3.4.2 *Equipment Room for Air Handling Units and Package Units*

These guidelines ensure optimal placement, safety, and functionality of equipment rooms for air handling and package units within the building's HVAC system.

3.4.2.1 This shall be located as centrally as possible to the conditioned area and contiguous to the corridors or other service areas for carrying air ducts in ceiling spaces.

3.4.2.2 In case of special and high-rise buildings, air handling units shall be provided in accordance with Fire and Life Safety considerations, separately given in this Code. Air handling unit rooms should preferably be located vertically one above the other.

3.4.2.3 Provision shall be made for the entry of outdoor ventilation air into air handling unit room. For energy conservation, it is desirable to install mechanism for modulating the outdoor air quantity based on demand.

3.4.2.4 Exterior openings for outdoor air intake and also exhaust outlets shall have louvers with rain protection profile, volume control damper, pre-filter and bird screen.

3.4.2.5 In all cases, outdoor air intakes shall be located to avoid contamination from exhaust outlets and pollution sources in concentration higher than normal in the building locality. The separation distance between fresh air intake and any exhaust outlets shall minimum 8 meters.

3.4.2.6 Exhaust air from any dwelling unit shall not be circulated/ingress directly or indirectly to any other dwelling unit, to public corridor or into public stairway.

3.4.2.7 All air handling rooms should have floor drains. The trap in floor drain shall provide a water seal between the air-conditioned space and the drain line.

3.4.2.8 Supply/return air duct serving other areas shall not be taken through fire exits.

3.4.2.9 Waterproofing of air handling unit rooms shall be carried out to prevent damage to floor below.

3.4.2.10 The floors should be finished smooth. For floor loading, the air conditioning engineer should be consulted (*see* also Part 6 'Structural Design, Section 1 Loads, Forces and Effects' of the Code).

3.4.2.11 Structural design should avoid beam obstruction to the passage of supply and return air ducts. Adequate ceiling space should be made available outside the air handling unit room to permit installation of supply and return air ducts and fire/smoke dampers at compartment wall crossings.

3.4.2.12 Appropriate sound insulation and noise control measures shall be taken in air handling unit rooms, if located in close proximity to occupied areas, as per Part 8 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of the Code. The air handling unit rooms shall be acoustically treated in accordance with the noise control requirements if located in close proximity to occupied areas.

3.4.2.13 Access door to air handling unit room shall be single/double leaf type, air tight, opening outwards and should have a sill to prevent flooding of adjacent occupied areas. It is desired that access panels in air-conditioned spaces should be provided with tight sealing, gaskets and self-closing devices for air conditioning to be effective.

3.4.2.14 It should be possible to isolate the air handling unit room in case of fire. The door shall be fire resistant (*see* Part 4 'Fire and Life Safety' of the Code) and fire/ smoke dampers shall be provided in supply/return air duct at air handling unit room wall crossings. Annular space between the duct and the wall should be fire sealed using appropriate fire resistance rated material.

3.4.2.15 Fire isolation shall be provided for vertical fresh air duct, connecting several floors.

3.4.2.16 It is desirable that individual air handling unit should be installed for each fire compartment, alternately, fire barrier should be provided at each fire separation for air handling units serving more than one compartment.

3.4.3 Pipe Shafts

These guidelines address the placement, safety, and accessibility requirements for pipe shafts to ensure effective distribution and maintenance of building services.

3.4.3.1 The shafts carrying chilled water pipes should be located adjacent to air handling unit room or within the room.

3.4.3.2 Shaft carrying condensing water pipes to cooling towers located on terrace should be vertically aligned.

3.4.3.3 All shafts shall be provided with fire barrier at floor crossings following the fire safety requirements.

3.4.3.4 Access to shaft shall be provided at every level, if there is any serviceable component in the shaft. In case of tall buildings, care shall be taken for expansion/contraction of pipes while planning the supports.

3.4.4 Supply Air Ducts and Return Air Ducts

These guidelines ensure efficient and safe design of supply and return air ducts, focusing on airflow distribution, energy conservation, and compliance with safety standards.

3.4.4.1 The duct supports shall be designed to handle the load and also to take into account seismic considerations. The support material should be galvanized steel/aluminium and facilitate ease of installation at site using alternatives such as fully threaded rod/angle section/wire support systems using stud anchors provided in the ceiling slab from drilled holes without damaging the slab or structural member.

3.4.4.2 If false ceiling is provided, the supports for the duct and the false ceiling, shall be independent. Collars for grilles and diffusers shall be taken out only after false ceiling/boxing framework is done and frames for fixing grilles and diffusers have been installed. Flexible ducts may be used for making the final connections.

3.4.4.3 Where a duct penetrates the masonry wall, it shall either be suitably covered on the outside to isolate it from masonry, or an air gap shall be left around it to prevent vibration transmission. Further, where a duct passes through a fire resisting compartment/barrier, the annular space shall be sealed with fire sealant to prevent smoke transmission as per relevant clauses of this code.

3.4.5 Cooling Tower

These guidelines focus on the efficient design, placement, and maintenance of cooling towers to optimize cooling performance, minimize energy use, and ensure safe operation.

3.4.5.1 Cooling towers are used to dissipate heat from water cooled refrigeration, air conditioning and industrial process systems to the atmosphere. Cooling is achieved by evaporating a small proportion of recirculating water into outdoor air stream. Cooling towers shall be installed at a place where free flow of ambient air is available.

3.4.5.2 Range of a cooling tower is defined as temperature difference between the entering and leaving water. Approach of the cooling tower is the difference between leaving water temperature and the ambient air wet-bulb temperature.

3.4.5.3 Selection of Cooling Tower:

Following factors shall be considered for selection of cooling tower:

a) Design wet-bulb temperature and approach of cooling tower. The designer shall endeavour for reducing the approach for maximizing the energy conservation potential;
b) Height limitation and aesthetic requirement;
c) Location of cooling tower considering possibility of easy drain back from the system;
d) d) Placement with regard to adjacent walls, windows and other buildings, and effects on these from any water carried over by the air stream;
e) Vibration and noise levels, particularly during silent hours;
f) Material of construction for the tower;
g) Direction and flow of prevailing wind;
h) Quality of water used for make-up;
j) Maintenance and service space availability; and
k) Ambient air quality.

3.4.5.4 The recommended floor area requirement for various types of cooling tower is as given below:

a) Natural draft: 0.15 to 0.20 m^2 /3.516 kW cooling tower
b) Mechanical draft: 0.07 to 0.10 m^2 /3.516 kW cooling tower

3.4.5.5 Structural provision for the cooling tower shall be taken into account while designing the building. Vibration isolation shall be an important consideration in structural design.

3.4.5.6 Special care should be taken in design where noise transmitted to the adjoining building shall be of serious concern. Special vibration control and sound attenuation devices may be required in that case. Appropriate sound insulation and noise control measures shall be taken in such cases in accordance with relevant requirements of this code.

3.4.5.7 Certain amount of water is lost from circulating water in the cooling tower, as given below:

a) *Evaporation loss* – It is usually about 1 percent of the rate of water circulation.
b) *Drift loss* – The drift loss shall be below 0.1 percent of rate of water circulation.
c) *Blow-down/bleed-off* – The amount of blowdown shall be below 0.8 percent of the total water circulation. If simple blow-down is inadequate to control scale formation, chemicals may be added to inhibit corrosion and limit microbiological growth. Provision shall be made to make-up for the loss of circulating water.

3.4.5.8 Provision for make-up water tank to the cooling tower shall be made. Make-up water tank to the cooling tower shall be separate from the tank serving drinking water. Makeup water should be sourced from treated water from sewage treatment, waste water treatment plant, or from rain water harvesting. Make-up water having contaminants or hardness, which shall adversely affect the refrigeration plant life, shall be treated. Treated water where hardness as ppm of $CaCO_3$ is reduced to 50 ppm or below is recommended for air conditioning applications. Water with pH value less than 5 shall also need to be treated.

3.4.5.9 Cooling tower should be so located as to eliminate nuisance from drift to adjoining structures.

3.4.6 *Building Envelope* – The envelope of the building including wall, roof and fenestration shall be planned as per Part 11 'Approach to Sustainability' of the Code.

3.4.7 *Fire Safety* – For fire safety in case of special and high-rise buildings, provisions of Part 4 'Fire and Life Safety' of the Code shall be applicable.

3.4.8 *Sound Insulation and Noise Control* – Sound insulation and noise control measures for HVAC system shall be in accordance with Part 8 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of the Code.

3.4.9 *Energy Conservation* – Designers shall aim for energy efficiency in buildings with the right blend of passive and active design strategies in accordance with Part 11 'Approach to Sustainability' of the Code, so as to minimise the energy use while ensuring comfort.

3.5 Outside design conditions

The outdoor design conditions shall be considered in accordance with IS 7896. Table 1 presents design conditions taken from this standard as ready reference. For cities not included in this table, it is recommended that extrapolation may be done, from the data of the nearby listed city, but keeping into consideration the specific topographical and climatic conditions of the concerned location. Values of ambient dry-bulb temperatures and wet-bulb temperatures, against the various annual percentiles, represent the value that is exceeded on average by the indicated percentage of the total number of hours. The 0.4 percent, 1.0 percent, 2.0 percent values are exceeded on average 35 h, 88 h and 175 h respectively in a year. The 99.0 percent and 99.6 percent values are defined in the same way but are usually reckoned as the values for which the corresponding weather elements are less than the design conditions of 88 h and 35 h, respectively.

Mean coincidental values are the average of the indicated weather element occurring concurrently with the corresponding design value. After the calculation of design dry-bulb temperatures, the program locates the values of corresponding wet-bulb temperatures from the database for that particular station, the average of these values is computed, which are then called mean of coincidental wet-bulb temperature. In the same way, design wet-bulb temperatures and coincidental dry-bulb temperatures are evaluated.

The design values of 0.4 percent, 1.0 percent and 2.0 percent annual cumulative frequency of occurrence may be selected depending upon application of air conditioning system. For normal comfort conditions, values under 1.0 percent column should be used for cooling loads and 99 percent column for heating loads. For critical applications, values under 0.4 percent column should be used for cooling loads and 99.6 percent column for heating loads.

Table 1 Summary for Outdoor Design Conditions
(*Clause* 3.5)

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
1)	**Agartala**	10.8	11.6	35.2	25	34.5	25	33.8	27	28.5	33	28.1	32	27.8	32
2)	**Agra**	4.6	6.1	42.1	21	40.8	22	39.8	22	28.7	31	28.3	30	28	31
3)	**Ahmedabad**	12.3	13.2	42.7	25	41.7	22	41	22	30.2	35	29.3	34	28.4	33
4)	**Aizawl**	10.5	11.3	30.5	20	29.5	21	28.9	21	24.8	27	24.5	26	24.1	27
5)	**Ajmer**	4.8	5.6	41.5	22	40.7	21	39.4	21	25.2	34	24.9	34	24.7	33
6)	**Akola**	12.4	13.9	43.1	23	42.2	21	41.4	22	26.9	33	26.5	32	26.2	31
7)	**Aligarh**	3.9	5.3	42.9	23	41.8	23	40.4	24	28.3	33	27.9	34	27.6	33
8)	**Allahabad**	9.8	10.6	43.1	23	41.7	23	40.3	23	28.7	32	28.3	33	28	32
9)	**Amaravati**	19.2	19.8	42	27	39.7	27	38.1	26	28.4	33	28.2	32	27.8	33
10)	**Amritsar**	3	4.5	42	23	41	23	39	23	29.2	32	28.6	32	28.2	31
11)	**Anantapur**	16.9	18.1	40	24	39.5	24	38.7	23	26.3	35	25.8	33	25.5	34
12)	**Aurangabad**	11.8	12.9	40.1	23	39.3	22	38.3	22	26.8	34	26	32	25.5	31
13)	**Balasore**	12.9	13.9	36.8	26	35.5	26	34.6	27	28.8	33	28.4	33	28.1	33
14)	**Bareilly**	6.4	7.2	39.6	23	38.7	26	37.7	25	29.2	34	28.8	33	28.4	33
15)	**Barmer**	10.6	11.5	43.2	23	42	22	40.4	24	28.3	36	27.9	35	27.5	34

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
16)	**Belgaum**	13.5	14.6	36.7	19	35.5	18	34.2	19	24.1	29	23.7	29	23.4	28
17)	**Bengaluru**	15.6	16.2	34.1	21	33.4	20	32.7	19	23.5	29	23.1	29	22.8	28
18)	**Bhagalpur**	13.1	13.8	38.3	22	36.8	25	35	27	29.3	34	28.9	33	28.7	32
19)	**Bhavnagar**	12	12.8	42.4	25	41.3	27	39.8	25	28.4	30	28.1	32	27.8	32
20)	**Bhilai**	12.7	14	42.6	23	41.7	24	40.4	23	26.8	31	26.5	32	26.2	31
21)	**Bhopal**	9	10.2	42	21	40.7	25	39.5	21	26	30	25.7	30	25.3	29
22)	**Bhubaneswar**	14.1	15.1	38.9	27	37.8	27	36.7	26	30.1	35	29.5	33	29.1	33
23)	**Bhuj**	12.4	13.3	40.5	23	39.5	24	38.3	23	28.1	36	27.6	33	27.3	33
24)	**Biharsharif**	7.8	8.7	40.1	24	38.7	24	37.6	24	28.4	31	28	32	27.7	31
25)	**Bikaner**	7.6	9.1	44.8	22	43.3	23	41.9	23	27.6	34	27.2	32	26.8	33
26)	**Bilaspur**	11.8	13	43.2	22	42.3	23	41.3	23	26.9	31	26.6	31	26.4	31
27)	**Chandigarh**	2.8	4	43	22	40.8	20	39.2	18	27.2	33	26.8	32	26.5	32
28)	**Chennai**	20.5	21	39	26	38	26	37	26	28.5	34	28.1	34	27.8	35
29)	**Chitradurga**	16.2	16.9	37.4	21	36.5	21	35.6	20	23.8	27	23.5	26	23.2	26
30)	**Coimbatore**	18.6	19.5	36.5	23	35.8	24	34.9	24	25.4	33	25.1	31	24.9	29
31)	**Cuddalore**	20.1	20.8	37.9	26	37.1	26	36.1	27	29	33	28.7	33	28.3	34
32)	**Dahod**	8.6	9.8	41.1	20	40.4	23	39.3	21	27	30	26.5	32	25.7	33

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
33)	**Daltonganj**	8.8	9.9	43.3	24	42	25	41	24	28.1	32	27.7	31	27.5	32
34)	**Davanagere**	16.9	17.7	37.4	21	36.5	21	35.7	21	24.2	29	23.8	29	23.5	29
35)	**Dehradun**	5.8	6.6	37.7	22	36.2	23	34.5	22	27	30	26.5	30	26.2	30
36)	**Dhanbad**	8	9.3	41.5	23	40.5	22	39.7	22	27.4	32	27	32	26.7	31
37)	**Dharmsala**	3.7	4.7	32.1	20	31.1	21	30.2	18	23.7	28	23.4	26	22.9	25
38)	**Dibrugarh**	10.2	11	35	28	34	27	33.2	27	29.2	34	28.6	33	28.1	32
39)	**Diu**	10.5	11.4	35.9	24	34.6	23	33.6	22	25.1	30	24.8	29	24.6	29
40)	**Erode**	18.3	18.9	40.3	23	39.3	23	38.3	24	26.5	31	25.8	30	25.4	31
41)	**Etawah**	3.8	5.3	44.2	24	43.1	25	42	25	28.9	36	28.2	37	27.6	34
42)	**Ganganagar**	4.6	6.1	44.2	22	42.7	26	40.8	25	29.1	35	28.7	34	28.4	35
43)	**Gangtok**	1.4	2.3	23.1	19	22.7	18	22.3	19	19.8	22	19.6	22	19.4	22
44)	**Gaya**	7	9	43.3	20	41.8	23	40.2	21	28.5	33	28	33	27.7	32
45)	**Gorakhpur**	8.5	9.6	40.7	23	38.9	23	37.7	22	28.1	32	27.8	33	27.5	33
46)	**Gulbarga**	19.4	20.4	41.5	24	40.6	25	39.8	25	27.4	36	27	34	26.6	35
47)	**Guna**	8.5	10	42.8	22	41.9	22	40.9	22	27	33	26.7	31	26.4	32
48)	**Guntur**	16.6	17.7	41.1	25	39.6	25	38.5	25	28.6	31	28.3	31	28.1	31
49)	**Guwahati**	11.2	12.1	35.4	27	34.5	29	33.9	27	29.2	34	28.9	33	28.6	33

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
50)	**Gwalior**	4.9	5.7	43.2	24	42.2	24	40.9	23	28.5	34	28.2	35	27.8	33
51)	**Hissar**	4.1	5.1	43.8	25	42.6	24	41.2	23	29	37	28.7	34	28.3	33
52)	**Honavar**	18.8	19.8	34.3	24	33.6	24	33.1	25	27.8	32	27.4	32	27.2	31
53)	**Hubballi**	12.5	13.2	41.8	24	40.7	23	39.4	24	26	26	25.5	29	25.2	30
54)	**Hyderabad**	15.3	16.3	41	22	39.6	22	38.4	24	25.4	34	25	31	24.7	31
55)	**Imphal**	4.9	5.9	32	21	31.3	23	30.7	23	25.7	31	25.2	30	24.8	29
56)	**Indore**	10.4	11.3	39.9	19	38.9	21	37.9	21	25.6	31	25.1	29	24.8	29
57)	**Itanagar**	8.8	9.7	35.2	29	34.3	29	33.4	29	29.8	34	29.5	34	29.1	32
58)	**Jabalpur**	8.4	9.8	41.6	20	40.7	20	39.5	20	26.3	30	25.9	31	25.6	30
59)	**Jagdalpur**	9.6	11.1	39.2	20	38.1	23	37	23	26.6	36	25.9	32	25.5	31
60)	**Jaipur**	8.4	9.3	42.4	20	41	21	40	21	27.6	33	27.2	31	26.9	32
61)	**Jaisalmer**	8.3	9.3	44.3	24	42.8	23	41.7	25	28.1	38	27.6	34	27.2	36
62)	**Jalandhar**	4.3	5.5	43.7	21	42.4	21	40.7	21	25.6	33	25	36	24.6	33
63)	**Jammu**	4.8	5.8	41.9	21	40.1	20	38.9	21	28.6	32	27.9	30	27.4	32
64)	**Jamnagar**	7.9	8.9	38.7	24	37.5	23	36.5	24	27.7	30	27.5	31	27.3	32
65)	**Jamshedpur**	9.8	10.7	41.4	23	39.8	23	38.2	24	27.6	33	27.3	33	27	32
66)	**Jhansi**	6.1	7	44.9	24	43.7	22	42.8	22	27.6	34	27.1	31	26.9	33

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
67)	**Jharsuguda**	11	12	42	24	40.8	24	39.5	23	27.8	31	27.4	32	27.1	31
68)	**Jodhpur**	9	10.4	42.1	22	40.7	23	39.8	23	27.9	33	27.4	34	27	32
69)	**Jorhat**	8.5	9.2	33.1	27	32.6	26	31.6	27	27.7	31	27.5	30	27.2	30
70)	**Kakinada**	18.1	19.4	42.2	26	39.4	25	37.3	28	29.2	35	28.8	33	28.4	34
71)	**Kalingapatam**	15.8	17.6	35.3	29	34.6	29	34	28	29.7	34	29.5	33	29.1	33
72)	**Kannur**	20.6	21.2	36.4	24	35.6	24	34.9	24	26.8	30	26.5	31	26.3	30
73)	**Kanpur**	6.4	7.2	43.4	23	42	23	40.9	23	28.5	34	28.2	34	28	33
74)	**Karaikal**	21.8	22.7	37	26	36.2	26	35.3	26	29.1	34	28.9	34	28.4	32
75)	**Karimnagar**	13.4	14.7	42.7	24	41.9	26	40.7	25	28.2	37	27.6	34	27.2	35
76)	**Karnal**	4.7	5.6	40.8	22	39.7	24	38.4	22	27.8	33	27.3	31	26.9	32
77)	**Karwar**	20.6	21.6	35.9	27	35.4	26	34.9	26	29.6	34	29.2	34	28.8	33
78)	**Kavaratti**	23.3	24	33.8	28	33.4	27	32.9	27	28.6	33	28.2	33	27.9	32
79)	**Kochi**	22.8	23.2	32.9	26	32.6	26	32.3	26	27.6	32	27.3	31	27.1	31
80)	**Kodaikanal**	7	7.7	24.4	15	23.4	14	22.6	14	15.8	22	15.4	22	15.1	21
81)	**Kohima**	5.9	6.8	27.1	20	26.3	21	25.6	20	21.6	23	21.3	24	21.1	24
82)	**Kolhapur**	19.4	20.3	35.6	20	35.1	20	34.5	20	27.4	28	26.6	27	25.5	29
83)	**Kolkata**	12	13	37	28	36.3	28	35.7	28	29.6	33	29.2	34	28.8	34

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
84)	**Kollam**	21.8	22.3	34.2	25	33	23	32.4	23	26.8	30	26.6	30	26.4	29
85)	**Kota**	10	11.2	43.5	21	42.3	21	41	22	27.1	32	26.8	31	26.5	31
86)	**Kozhikode**	22.6	23.1	34.8	29	34.3	28	33.9	27	29.2	34	28.9	33	28.6	33
87)	**Kurnool**	17.1	18	41.1	22	40.1	24	39.2	24	26.1	32	25.8	34	25.5	33
88)	**Leh**	-20.7	-19	26.6	10	25.8	11	24.8	11	14	23	13.5	21	12.9	20
89)	**Lucknow**	6.7	8	42	23	41	23	40	24	29.4	34	29	36	28.6	34
90)	**Ludhiana**	2.6	3.6	40.7	22	39.3	24	38.1	22	28.1	30	27.6	32	27.2	32
91)	**Machilipatnam**	20.4	20.9	40.3	28	38.7	27	37.1	27	29.7	36	29.3	36	28.8	34
92)	**Madurai**	18.1	18.8	40.9	24	39.6	25	38.8	25	28.1	32	27.4	32	27	32
93)	**Mangaluru**	21.3	22	34.2	24	33.7	25	33.3	25	27	33	26.7	31	26.5	30
94)	**Minicoy**	23.9	24.4	33.3	28	32.9	28	32.5	28	28.7	32	28.3	32	28.1	32
95)	**Moradabad**	5.2	6.6	42.1	23	40.7	24	39.4	25	28.8	35	28.3	33	27.8	33
96)	**Mumbai**	19	20.2	35	23	34.7	24	33.9	23	27.9	31	27.7	31	27.3	31
97)	**Muzaffarpur**	8.5	9.3	38.9	25	37.9	26	36.8	27	29.5	35	29.2	34	28.9	32
98)	**Mysuru**	14.6	15.1	36.7	21	35.5	22	34.4	22	24	25	23.6	29	23.2	27
99)	**Nagappattinam**	22.7	23.2	36.9	26	36.2	26	35.4	27	29.1	32	28.9	32	28.6	32
100)	**Nagpur**	12	13	44	22	43	22	42	22	27.5	31	27.1	29	26.7	31

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
101)	**Nashik**	9.5	10.1	37.3	19	36.5	20	35.6	19	26.3	28	25	27	24.3	27
102)	**Nellore**	21	21.6	41	28	39.6	27	38.4	28	28.8	36	28.5	38	28.2	35
103)	**New-Delhi**	5	6.5	43.6	21	42.6	22	41	23	28.2	36	27.8	35	27.5	30
104)	**Nizamabad**	15.4	16.6	43.3	24	41.9	24	40.3	23	26.2	30	25.9	30	25.6	31
105)	**Ongole**	21.5	21.8	41.9	27	39.2	26	37.7	27	28.7	36	28.3	36	27.8	34
106)	**Panaji**	19.8	20.5	34.1	26	33.8	27	33.3	26	28.2	33	27.9	32	27.6	32
107)	**Pasighat**	11	11.9	34.1	26	33.3	27	32.4	26	27.7	32	27.3	31	27	31
108)	**Patiala**	6.2	7	42.2	26	40.4	24	38.8	25	29.4	34	29	34	28.6	33
109)	**Patna**	7	8.2	41	24	39.6	26	37.7	23	28.6	33	28.3	33	28	32
110)	**Pendra-road**	9	10.2	39.7	21	38.7	21	37.6	23	26.2	31	25.7	30	25.3	29
111)	**Port-Blair**	22.1	22.9	33.1	27	32	27	31.3	26	27.5	32	27.2	31	26.9	30
112)	**Pune**	10.2	11.2	38.7	19	37.5	20	36.3	19	24.6	30	24	30	23.8	29
113)	**Raipur**	13.1	14.2	42.1	24	41.1	23	40	24	27.1	31	26.8	32	26.5	31
114)	**Rajkot**	12	13	41.3	21	39.9	23	38.9	24	27.4	29	27	30	26.7	31
115)	**Ranchi**	8.9	10	38.9	20	37.7	20	36.3	20	25.9	30	25.4	29	25.2	29
116)	**Ratnagiri**	17.9	18.6	34.1	22	33.7	24	33.1	23	27.1	31	26.9	30	26.7	30
117)	**Raxaul**	8.3	9.3	38.6	25	36.3	26	34.8	25	29	32	28.6	32	28.3	32

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
118)	**Roorkee**	4.4	5.3	40.4	24	39.1	23	37.9	23	27.9	32	27.4	31	27.2	32
119)	**Sagar**	8.1	9.5	41.9	24	41.1	23	40	21	26.5	37	25.9	33	25.5	30
120)	**Saharanpur**	4.2	4.9	43.2	22	42	23	40.7	24	28.5	33	28.2	33	27.9	34
121)	**Salem**	17.5	18.2	39.9	24	39.1	22	38.1	23	25.6	30	25.2	31	25	30
122)	**Sangli**	7.8	8.5	40.1	20	38.9	19	37.8	18	24.5	27	24.2	27	23.9	28
123)	**Satna**	7.6	8.6	43.4	23	42.2	22	40.5	23	27.5	33	27	31	26.7	30
124)	**Shillong**	3.3	4.3	26.1	21	25.5	21	24.9	20	21.5	24	21.1	24	20.9	24
125)	**Shivamogga**	13.7	14.7	39	21	38	20	36.9	20	24	29	23.8	29	23.6	28
126)	**Siliguri**	8.6	9.6	36.3	30	35	28	33.9	28	30.8	32	30	31	29.1	32
127)	**Silvassa**	9	10.6	36.8	22	35.4	18	34.6	20	25.7	29	25.4	29	25	28
128)	**Solapur**	15.2	16.4	40.7	21	39.9	22	39.1	21	26.1	34	25.5	34	25.1	34
129)	**Srinagar**	-3.7	-2.4	31	20	29.9	20	28.9	20	22.4	30	21.9	28	21.3	26
130)	**Surat**	13.3	14.7	37.5	22	36.1	23	35.1	24	28.4	31	28.1	31	27.8	30
131)	**Tezpur**	11.2	12.1	34.5	29	33.8	26	33.1	27	29	32	28.6	32	28.2	32
132)	**Thanjavur**	18.8	19.8	41.5	26	40.5	25	39.3	25	27.4	35	27.1	32	26.9	31
133)	**Thiruvananthapuram**	22.5	23	34.3	26	33.6	25	33.1	26	27.8	32	27.4	31	27.2	32
134)	**Thoothukudi**	20.2	21	39.2	25	38.4	25	37.6	26	27.8	32	27.5	31	27.2	31

SL No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
135)	**Thrissur**	19.3	20.3	37.8	26	36.1	27	34.8	25	28.8	31	28.6	32	28.2	31
136)	**Tiruchrapalli**	20	20.7	39	26	38.4	26	37.8	26	27.1	35	26.8	34	26.5	34
137)	**Tirunelveli**	20.3	21	41.8	24	40.3	25	39.1	24	26.5	30	26.2	30	26	31
138)	**Tiruppur**	16.4	17	31.9	20	30.8	20	29.9	18	21.9	25	21.6	24	21.4	24
139)	**Tumakuru**	14.7	15.5	37.8	19	36.4	20	35.2	18	22.3	30	21.9	30	21.5	28
140)	**Udaipur**	6.5	8.4	40.7	22	39.9	20	38.6	21	26.2	31	25.9	30	25.6	31
141)	**Varanasi**	8	9.9	43	24	42	24	41	24	28.7	35	28.4	33	27.9	33
142)	**Vellore**	15.9	16.7	42.1	23	40.3	23	38.8	22	25.6	29	25.3	31	25.1	30
143)	**Veraval**	15.5	16.5	35.2	22	34	26	33.2	28	28.8	33	28.5	32	28.3	32
144)	**Vishakhapatnam**	20	21.2	34	27	33.4	27	33	28	29.3	32	28.8	32	28.4	32
145)	**Warangai**	13.8	14.6	43.9	23	42.9	23	41.6	23	27.5	32	27.2	32	26.9	31

3.6 Inside Design and Operating Conditions

One of the primary objectives of designing indoor environment is to ensure thermal comfort and indoor air quality of all occupants. Air conditioning, heating and mechanical ventilation (HVAC) system is employed to achieve thermal comfort inside building, when means to achieve the same only through building design is limited.

According to the internationally accepted definition, thermal comfort is that state of mind which expresses satisfaction with the indoor environment. The above definition clearly highlights the importance of both the psychological (mental) and physiological (physical) factors in determining acceptable thermal comfort conditions. The following five environmental parameters are important for thermal comfort and indoor air quality while designing the HVAC system because these are directly controllable by an HVAC system:

a) Air temperature (ºC),
b) Radiant temperature (ºC),
c) Air speed (m/s), and
d) Relative humidity (percent).
e) Indoor air quality

In addition to the above five environmental parameters, there are two personal or behavioural parameters that also affect thermal comfort but are not controllable by the HVAC system and they are:

1) Activity rate (W/m^2), and
2) Clothing insulation ($m^2.K/W$).

There are number of secondary parameters also which are important to define thermal comfort conditions such as, radiative temperature asymmetry, temperature gradient, and draught rate.

Air conditioning systems for interior spaces intended for human occupancy shall be sized for not more than 26°C for cooling and for not less than 18°C for heating at occupied level.

HVAC systems should also be designed to control the humidity. Relative humidity in occupied spaces should not fall below 30 percent and should not exceed 70 percent. Adequate measures should be provided in system design itself for keeping it in the prescribed range including humidification and dehumidification as needed.

Air velocity control should be used to facilitate thermal adaptation as well as to save energy as described in the adaptive thermal comfort section below. However, air velocity should not exceed 1.5 m/s at the work plane to avoid discomfort due to draft and fluttering of papers etc.

While the system sizing needs to be done for design conditions mentioned above, the systems should be provided with features that facilitate thermal adaptation to be practiced by occupants. Buildings should provide users and facility managers to control air velocity in spaces and around individuals so that higher temperature set point shall be kept for saving energy. Buildings should provide spaces to control the set point individually as the temperature at which set point is to be kept varies as per the change in outdoor conditions over the time.

In conditioned buildings, the values for quality of thermal environment parameters for representative occupant of a space shall be as specified in Table 2 below.

Table 2 Conditions for Thermal Comfort
(*Clause* 3.6)

Sl No.	Air velocity	Weather condition	Level of activity	Reference table or Threshold Values
(1)	(2)	(3)	(4)	(5)
i)	Up to 0.2m/s	Summer / winter	Met value ≤ 1.2	Table 3
ii)	Above 0.2m/s	Summer / winter	Met value ≤ 1.2	Table 3 + Fig. 1 or Table 4
iii)	-	Summer	-	Relative humidity: 30 to 70 percent

Table 3 Acceptable Range of Operative Temperature with Air Velocity up to 0.2 m/s
(*Table* 2)

Sl No.	Level of Activity	Operative Temperature (°C)	
		Summer (Cooling season) ~0.5 clo	Winter (Heating season) ~1.0 clo
(1)	(2)	(3)	(4)
i)	Met >1 and up to 1.2	23.0 ± 3.0	19.0 ± 4.0
ii)	Met ≤1.0	24.5 ± 2.5	22.0 ± 3.0

NOTE – At still air condition, operative temperature is the average of air temperature and mean radiant temperature. For details ISHRAE IEQ Standard 10001 can be referred.

High air velocity shall give opportunity of keeping higher air temperature without compromising thermal comfort. However, it is also suggested to keep under consideration noise and other effect of high indoor air velocity.

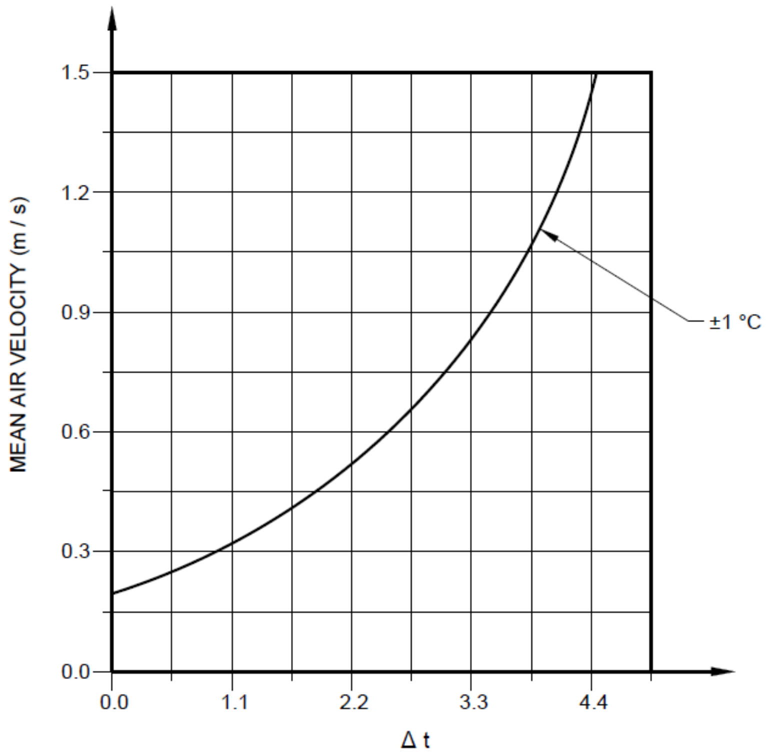


FIG. 1 REQUIRED AIR SPEED TO OFFSET INCREASED OPERATIVE TEMPERATURE (IN CELSIUS)

3.6.1 *Designing for Using Adaptive Thermal Comfort in Operation*

Design based on use of an adaptive thermal comfort model during operation of building plays a major role in reducing energy use whilst maintaining the comfort, productivity and well-being of occupants. This approach recognizes that people's thermal comfort needs depend on their past and present context and that these needs vary with the outdoor environmental conditions of their location. For more details, refer Part 8 'Building Services Section 1 Lighting and Natural Ventilation' of this Code.

3.6.1.1 *Path A*

This Section deals with predominantly dry bulb temperature (DBT) and mean radiant temperature (MRT) based adaptive thermal comfort model which differentiates the thermal response of occupants in air conditioned and mixed-mode buildings. For more details, refer Part 8 'Building Services Section 1 Lighting and Natural Ventilation' of this Code.

3.6.1.2 *Path B*

Since in many buildings, especially where microclimatic interventions or where occupants from wide range of ambient/indoor conditions (outside of the period of occupancy in the building in consideration) are likely to be present, it may be difficult to determine their running mean monthly outdoor temperature and they are likely to display different order of thermal adaptation. This alternate path for estimation of thermal comfort is through calculation of standard effective temperature (SET) using the look up Tables 4 and 5, given below provided option for determining set of indoor conditions that are likely to provide thermal comfort.

The recommended range of SET for Indian conditions over all types of buildings is 23.5ºC to 25.5ºC, with 80 percent acceptability. The term SET includes combined effect of all five parameters that govern thermal comfort, including various adaptive actions such as air velocity, adjusting clothing, adjusting temperature set point, adjusting activity level, and humidity. Same method shall be used in unconditioned buildings as well for assessment of thermal comfort.

The desired value of SET shall be achieved at different values of air temperatures depending upon the values of other parameters. This Table 4 and 5 shall also be used in designing radiant cooling systems, personalised air conditioning system etc.

Table 4 Calculated Standard Effective Temperature for Adaptive Thermal Comfort

(*Clause* 3.6.1.2 and *Table* 2)

Standard Effective Temperature for Activity level 1 Met (office work type activity) and Clothing 1.0 Clo (Winter clothing)																																									
AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
14	20	16.1	13.9	12.8	12.1	17	14.6	13.5	12.7	18	15.4	14.1	13.4	19	16.2	14.8	14	19.9	16.9	15.5	14.6	20.9	17.7	16.2	15.3	21.9	18.5	16.9	15.9	23	19.3	17.7	16.6	24	20.2	18.4	17.3	24.9	21	19.1	17.9
	40	16.2	14	13	12.3	17.2	14.8	13.6	12.9	18.1	15.5	14.3	13.5	19.1	16.3	15	14.2	20.1	17.1	15.7	14.8	21.1	17.9	16.4	15.4	22.1	18.7	17.1	16.1	23.1	19.5	17.8	16.7	24.1	20.3	18.5	17.4	25	21.1	19.3	18.1
	60	16.4	14.2	13.1	12.4	17.3	14.9	13.8	13.1	18.3	15.7	14.5	13.7	19.2	16.5	15.2	14.3	20.2	17.2	15.8	15	21.2	18	16.5	15.6	22.2	18.8	17.3	16.2	23.2	19.6	18	16.9	24.3	20.5	18.7	17.6	25.2	21.3	19.4	18.2
	80	16.5	14.3	13.3	12.6	17.4	15.1	13.9	13.2	18.4	15.8	14.6	13.9	19.4	16.6	15.3	14.5	20.3	17.4	16	15.1	21.3	18.2	16.7	15.8	22.3	19	17.4	16.4	23.4	19.8	18.1	17.1	24.4	20.6	18.9	17.7	25.4	21.4	19.6	18.4
16	20	17	15.1	14.2	13.7	17.9	15.9	14.9	14.3	18.9	16.6	15.6	14.9	19.8	17.4	16.2	15.5	20.8	18.2	16.9	16.1	21.8	18.9	17.6	16.8	22.8	19.7	18.3	17.4	23.8	20.5	19	18.1	24.7	21.4	19.8	18.7	25.6	22.2	20.5	19.4
	40	17.2	15.3	14.4	13.9	18.1	16	15.1	14.5	19	16.8	15.7	15.1	20	17.6	16.4	15.7	21	18.3	17.1	16.3	22	19.1	17.8	17	23	19.9	18.5	17.6	24	20.7	19.2	18.3	24.9	21.5	19.9	18.9	25.8	22.4	20.7	19.6
	60	17.3	15.5	14.6	14	18.2	16.2	15.3	14.7	19.2	17	15.9	15.3	20.1	17.7	16.6	15.9	21.1	18.5	17.3	16.5	22.1	19.3	18	17.2	23.1	20.1	18.7	17.8	24.1	20.9	19.4	18.4	25.1	21.7	20.1	19.1	26.1	22.5	20.8	19.8
	80	17.5	15.6	14.8	14.2	18.4	16.4	15.4	14.8	19.3	17.1	16.1	15.5	20.3	17.9	16.8	16.1	21.3	18.7	17.5	16.7	22.3	19.5	18.2	17.3	23.3	20.3	18.9	18	24.3	21.1	19.6	18.6	25.4	21.9	20.3	19.3	26.4	22.7	21	19.9
18	20	17.9	16.4	15.7	15.2	18.8	17.1	16.3	15.8	19.8	17.8	17	16.4	20.7	18.6	17.6	17	21.7	19.4	18.3	17.7	22.7	20.2	19	18.3	23.7	20.9	19.7	18.9	24.6	21.8	20.4	19.6	25.4	22.6	21.1	20.2	26.3	23.4	21.8	20.9
	40	18.1	16.5	15.9	15.4	19	17.3	16.5	16	19.9	18	17.2	16.6	20.9	18.8	17.8	17.2	21.9	19.6	18.5	17.9	22.9	20.4	19.2	18.5	23.9	21.1	19.9	19.1	24.8	21.9	20.6	19.8	25.7	22.8	21.3	20.4	26.6	23.6	22	21.1
	60	18.2	16.7	16.1	15.6	19.2	17.5	16.7	16.2	20.1	18.2	17.4	16.8	21.1	19	18.1	17.4	22	19.8	18.7	18.1	23	20.5	19.4	18.7	24.1	21.3	20.1	19.3	25	22.1	20.8	20	26	23	21.5	20.6	26.9	23.8	22.2	21.3
	80	18.4	16.9	16.3	15.8	19.3	17.7	16.9	16.4	20.3	18.4	17.6	17	21.2	19.2	18.3	17.7	22.2	20	18.9	18.3	23.2	20.7	19.6	18.9	24.3	21.5	20.3	19.5	25.4	22.3	21	20.2	26.4	23.1	21.7	20.8	27.4	24	22.4	21.5
20	20	18.8	17.6	17.1	16.7	19.7	18.3	17.7	17.3	20.6	19.1	18.4	17.9	21.6	19.8	19	18.5	22.6	20.6	19.7	19.1	23.6	21.4	20.4	19.8	24.5	22.2	21.1	20.4	25.3	23	21.8	21	26.1	23.8	22.5	21.7	27	24.4	23.2	22.3
	40	19	17.8	17.3	17	19.9	18.6	17.9	17.6	20.8	19.3	18.6	18.2	21.8	20.1	19.3	18.8	22.8	20.8	19.9	19.4	23.8	21.6	20.6	20	24.7	22.4	21.3	20.6	25.6	23.2	22	21.3	26.5	23.9	22.7	21.9	27.3	24.6	23.4	22.5
	60	19.2	18	17.5	17.2	20.1	18.8	18.2	17.8	21	19.5	18.8	18.4	22	20.3	19.5	19	23	21	20.2	19.6	24	21.8	20.8	20.2	25	22.6	21.5	20.9	26	23.4	22.2	21.5	26.9	24.1	22.9	22.1	27.8	24.9	23.6	22.8
	80	19.4	18.3	17.8	17.5	20.3	19	18.4	18	21.2	19.7	19.1	18.6	22.2	20.5	19.7	19.2	23.2	21.3	20.4	19.8	24.3	22	21.1	20.5	25.4	22.8	21.8	21.1	26.4	23.6	22.4	21.7	27.4	24.4	23.1	22.3	28.4	25.2	23.8	23
22	20	19.7	18.8	18.5	18.3	20.6	19.6	19.1	18.8	21.5	20.3	19.8	19.4	22.5	21	20.4	20	23.5	21.8	21.1	20.6	24.3	22.6	21.8	21.2	25.2	23.4	22.4	21.9	26	24	23.1	22.5	26.8	24.7	23.8	23.1	27.6	25.3	24.3	23.7
	40	19.9	19.1	18.7	18.5	20.8	19.8	19.4	19.1	21.8	20.5	20	19.7	22.7	21.3	20.7	20.3	23.7	22.1	21.3	20.9	24.6	22.8	22	21.5	25.5	23.6	22.7	22.1	26.4	24.3	23.4	22.7	27.3	24.9	24	23.4	28.1	25.6	24.6	23.9
	60	20.1	19.3	19	18.8	21	20.1	19.6	19.4	22	20.8	20.3	20	22.9	21.5	20.9	20.5	24	22.3	21.6	21.1	25	23.1	22.3	21.8	26	23.8	22.9	22.4	26.9	24.6	23.6	23	27.9	25.3	24.3	23.6	28.8	26	24.9	24.2
	80	20.3	19.6	19.3	19.1	21.3	20.3	19.9	19.6	22.2	21	20.5	20.2	23.2	21.8	21.2	20.8	24.4	22.6	21.8	21.4	25.5	23.3	22.5	22	26.6	24.2	23.2	22.6	27.6	25	23.9	23.2	28.6	25.8	24.6	23.9	29.6	26.6	25.3	24.5
24	20	20.6	20.1	19.9	19.8	21.5	20.8	20.5	20.3	22.4	21.5	21.1	20.9	23.4	22.3	21.8	21.5	24.3	23	22.4	22.1	25.1	23.7	23.1	22.7	25.9	24.4	23.8	23.3	26.7	25	24.3	23.9	27.5	25.6	24.8	24.3	28.3	26.2	25.3	24.8
	40	20.8	20.3	20.2	20.1	21.7	21.1	20.8	20.6	22.7	21.8	21.4	21.2	23.6	22.5	22.1	21.8	24.6	23.3	22.7	22.4	25.5	24	23.4	23	26.4	24.7	24	23.6	27.3	25.3	24.6	24.1	28.1	26	25.1	24.6	28.9	26.6	25.7	25.1
	60	21.1	20.6	20.5	20.4	22	21.4	21.1	20.9	22.9	22.1	21.7	21.5	24	22.8	22.4	22.1	25	23.6	23	22.7	26	24.3	23.7	23.3	27	25.1	24.3	23.8	28	25.8	24.9	24.4	28.9	26.5	25.6	25	29.8	27.2	26.2	25.6
	80	21.3	20.9	20.7	20.6	22.3	21.6	21.4	21.2	23.3	22.4	22	21.8	24.5	23.1	22.7	22.4	25.7	24	23.3	23	26.8	24.9	24.1	23.6	27.9	25.7	24.8	24.3	28.9	26.5	25.5	24.9	29.9	27.3	26.2	25.6	30.8	28.1	26.9	26.2
26	20	21.5	21.3	21.3	21.3	22.4	22	21.9	21.8	23.3	22.7	22.5	22.4	24.2	23.5	23.2	23	25	24.1	23.7	23.5	25.8	24.7	24.2	24	26.6	25.3	24.8	24.5	27.4	25.9	25.3	24.9	28.2	26.5	25.8	25.4	29	27.1	26.3	25.9
	40	21.7	21.6	21.6	21.6	22.7	22.3	22.2	22.1	23.6	23.1	22.8	22.7	24.6	23.7	23.5	23.3	25.5	24.4	24	23.8	26.4	25.1	24.6	24.3	27.3	25.7	25.2	24.8	28.1	26.4	25.7	25.3	29	27	26.3	25.8	29.8	27.7	26.8	26.3
	60	22	21.9	21.9	21.9	23	22.6	22.5	22.5	24.1	23.4	23.2	23	25.1	24.2	23.8	23.6	26.2	24.9	24.5	24.2	27.2	25.7	25.1	24.8	28.1	26.4	25.7	25.3	29.1	27.1	26.4	25.9	29.9	27.8	27	26.5	30.8	28.5	27.6	27
	80	22.3	22.2	22.2	22.2	23.5	23	22.9	22.8	24.8	23.9	23.6	23.5	26	24.8	24.4	24.1	27.2	25.7	25.1	24.8	28.3	26.5	25.9	25.5	29.3	27.4	26.6	26.1	30.3	28.2	27.3	26.8	31.3	28.9	28	27.4	32.2	29.7	28.7	28
28	20	22.4	22.5	22.6	22.7	23.3	23.2	23.3	23.3	24.1	23.8	23.8	23.7	25	24.4	24.3	24.2	25.8	25	24.8	24.6	26.6	25.6	25.3	25.1	27.4	26.2	25.8	25.5	28.1	26.8	26.3	26	28.9	27.3	26.8	26.4	29.7	27.9	27.3	26.9
	40	22.7	22.9	23	23.1	23.7	23.6	23.6	23.6	24.6	24.2	24.1	24.1	25.5	24.9	24.7	24.6	26.4	25.6	25.3	25.1	27.3	26.2	25.8	25.6	28.2	26.8	26.4	26.1	29	27.5	26.9	26.6	29.8	28.1	27.5	27.1	30.6	28.7	28	27.6
	60	23.1	23.3	23.4	23.5	24.2	24.1	24.1	24.1	25.3	24.8	24.7	24.7	26.4	25.6	25.4	25.2	27.4	26.4	26	25.8	28.4	27.1	26.6	26.4	29.3	27.8	27.2	26.9	30.2	28.5	27.9	27.5	31.1	29.2	28.5	28	31.9	29.9	29.1	28.6

Standard Effective Temperature for Activity level 1 Met (office work type activity) and Clothing 1.0 Clo (Winter clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
	80	23.8	24	24.1	24.2	25.2	25	24.9	24.9	26.5	25.9	25.7	25.6	27.8	26.8	26.5	26.3	28.9	27.6	27.2	27	30	28.5	27.9	27.6	31	29.3	28.6	28.2	32	30	29.3	28.9	32.9	30.8	30	29.5	33.7	31.5	30.6	30.1
30	20	23.3	23.6	23.8	24	24.1	24.2	24.3	24.4	24.9	24.8	24.8	24.8	25.8	25.4	25.3	25.3	26.6	26	25.8	25.7	27.3	26.5	26.3	26.2	28.1	27.1	26.8	26.6	28.9	27.7	27.3	27	29.6	28.2	27.7	27.5	30.3	28.8	28.2	27.9
	40	23.7	24.1	24.3	24.5	24.7	24.8	24.9	25	25.6	25.4	25.4	25.4	26.5	26.1	26	25.9	27.4	26.7	26.5	26.4	28.3	27.4	27.1	26.9	29.2	28	27.6	27.4	30	28.6	28.1	27.9	30.8	29.2	28.7	28.4	31.5	29.8	29.2	28.8
	60	24.5	24.9	25.1	25.3	25.6	25.7	25.8	25.9	26.7	26.4	26.4	26.4	27.8	27.2	27	27	28.8	27.9	27.7	27.5	29.8	28.6	28.3	28.1	30.7	29.3	28.9	28.6	31.5	30	29.5	29.2	32.4	30.7	30	29.7	33.2	31.3	30.6	30.2
	80	25.9	26.4	26.6	26.8	27.3	27.3	27.4	27.5	28.7	28.2	28.2	28.1	29.9	29.1	28.9	28.8	31	29.9	29.6	29.4	32	30.7	30.3	30	33	31.5	30.9	30.6	33.9	32.2	31.6	31.2	34.7	32.9	32.2	31.8	35.5	33.5	32.8	32.3
32	20	24.1	24.6	24.9	25.1	24.9	25.2	25.4	25.5	25.7	25.8	25.9	25.9	26.5	26.3	26.3	26.4	27.3	26.9	26.8	26.8	28.1	27.5	27.3	27.2	28.8	28	27.8	27.6	29.6	28.6	28.2	28.1	30.3	29.1	28.7	28.5	31	29.6	29.2	28.9
	40	24.8	25.4	25.7	25.9	25.8	26	26.2	26.4	26.7	26.7	26.8	26.9	27.6	27.3	27.3	27.3	28.5	28	27.8	27.8	29.3	28.6	28.4	28.3	30.2	29.2	28.9	28.7	31	29.8	29.4	29.2	31.7	30.4	29.9	29.7	32.5	30.9	30.4	30.1
	60	26.1	26.7	27	27.3	27.2	27.5	27.7	27.8	28.3	28.2	28.3	28.4	29.4	28.9	28.9	28.9	30.3	29.7	29.5	29.4	31.3	30.3	30.1	30	32.2	31	30.7	30.5	33	31.6	31.2	31	33.8	32.3	31.8	31.5	34.5	32.9	32.3	32
	80	28.7	29.3	29.7	29.9	30.1	30.2	30.4	30.5	31.4	31.1	31.1	31.2	32.5	31.9	31.8	31.8	33.5	32.6	32.4	32.3	34.5	33.4	33	32.9	35.3	34	33.6	33.4	35.6	34.7	34.2	33.9	36.1	35.3	34.7	34.4	36.7	35.3	34.7	34.9

Standard Effective Temperature for Activity level 1 Met (office work type activity) and Clothing 0.5 Clo (Summer clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
14	20	11	7.2	5.3	4	12.1	8.2	6.2	4.9	13.3	9.1	7.1	5.7	14.4	10.1	8	6.5	15.6	11.1	8.9	7.4	16.8	12.2	9.8	8.3	18	13.2	10.7	9.1	19.2	14.2	11.7	10	20.4	15.2	12.6	10.9	21.6	16.3	13.6	11.8
	40	11.1	7.4	5.5	4.3	12.3	8.4	6.4	5.1	13.4	9.4	7.3	5.9	14.6	10.3	8.2	6.8	15.8	11.3	9.1	7.6	17	12.4	10	8.5	18.1	13.4	11	9.4	19.3	14.4	11.9	10.2	20.5	15.4	12.8	11.1	21.7	16.5	13.8	12
	60	11.3	7.6	5.8	4.5	12.4	8.6	6.6	5.4	13.6	9.6	7.5	6.2	14.8	10.6	8.4	7	15.9	11.6	9.3	7.9	17.1	12.6	10.3	8.7	18.3	13.6	11.2	9.6	19.5	14.6	12.1	10.5	20.7	15.6	13.1	11.3	21.9	16.7	14	12.2
	80	11.5	7.8	6	4.8	12.6	8.8	6.9	5.6	13.8	9.8	7.8	6.4	14.9	10.8	8.7	7.3	16.1	11.8	9.6	8.1	17.3	12.8	10.5	9	18.4	13.8	11.4	9.8	19.6	14.8	12.3	10.7	20.8	15.8	13.3	11.6	22	16.9	14.2	12.5
16	20	12.1	8.8	7.2	6.1	13.2	9.8	8.1	6.9	14.3	10.7	8.9	7.8	15.5	11.7	9.8	8.6	16.7	12.7	10.7	9.4	17.8	13.7	11.6	10.3	19	14.7	12.6	11.1	20.2	15.7	13.5	12	21.4	16.7	14.4	12.9	22.6	17.7	15.3	13.7
	40	12.2	9	7.5	6.4	13.4	10	8.3	7.2	14.5	11	9.2	8	15.7	11.9	10.1	8.9	16.8	12.9	11	9.7	18	13.9	11.9	10.5	19.2	14.9	12.8	11.4	20.4	15.9	13.7	12.2	21.5	17	14.7	13.1	22.7	18	15.6	14
	60	12.4	9.3	7.7	6.7	13.6	10.2	8.6	7.5	14.7	11.2	9.5	8.3	15.9	12.2	10.3	9.1	17	13.2	11.2	10	18.2	14.2	12.1	10.8	19.3	15.2	13.1	11.7	20.5	16.2	14	12.5	21.7	17.2	14.9	13.4	22.9	18.2	15.8	14.2
	80	12.6	9.5	8	7	13.7	10.5	8.8	7.8	14.9	11.4	9.7	8.6	16	12.4	10.6	9.4	17.2	13.4	11.5	10.2	18.3	14.4	12.4	11.1	19.5	15.4	13.3	11.9	20.7	16.4	14.2	12.8	21.9	17.4	15.1	13.6	23	18.4	16.1	14.5
18	20	13.1	10.4	9.1	8.2	14.3	11.3	9.9	9	15.4	12.3	10.8	9.8	16.5	13.3	11.7	10.6	17.7	14.3	12.6	11.4	18.8	15.2	13.4	12.3	20	16.2	14.3	13.1	21.2	17.2	15.2	13.9	22.3	18.2	16.2	14.8	23.5	19.2	17.1	15.6
	40	13.3	10.7	9.4	8.5	14.5	11.6	10.2	9.3	15.6	12.6	11.1	10.1	16.7	13.5	12	10.9	17.9	14.5	12.8	11.7	19	15.5	13.7	12.6	20.2	16.5	14.6	13.4	21.4	17.5	15.5	14.2	22.5	18.4	16.4	15.1	23.7	19.4	17.3	15.9
	60	13.6	10.9	9.7	8.8	14.7	11.9	10.5	9.6	15.8	12.8	11.4	10.4	16.9	13.8	12.2	11.2	18.1	14.8	13.1	12	19.2	15.7	14	12.9	20.4	16.7	14.9	13.7	21.6	17.7	15.8	14.5	22.7	18.7	16.7	15.4	23.9	19.7	17.6	16.2
	80	13.8	11.2	9.9	9.1	14.9	12.2	10.8	9.9	16	13.1	11.7	10.7	17.1	14.1	12.5	11.5	18.3	15	13.4	12.3	19.4	16	14.3	13.2	20.6	17	15.2	14	21.7	17.9	16.1	14.8	22.9	18.9	17	15.6	24	19.9	17.8	16.5
20	20	14.2	12	10.9	10.2	15.3	12.9	11.8	11	16.4	13.9	12.6	11.8	17.6	14.8	13.5	12.6	18.7	15.8	14.3	13.4	19.9	16.7	15.2	14.2	21	17.7	16.1	15	22.2	18.7	17	15.9	23.3	19.6	17.9	16.7	24.3	20.6	18.7	17.5
	40	14.4	12.3	11.3	10.6	15.6	13.2	12.1	11.4	16.7	14.2	12.9	12.2	17.8	15.1	13.8	12.9	18.9	16.1	14.7	13.7	20.1	17	15.5	14.6	21.2	18	16.4	15.4	22.4	18.9	17.3	16.2	23.5	19.9	18.1	17	24.5	20.8	19	17.8
	60	14.7	12.6	11.6	10.9	15.8	13.5	12.4	11.7	16.9	14.5	13.3	12.5	18	15.4	14.1	13.3	19.2	16.3	15	14.1	20.3	17.3	15.8	14.9	21.4	18.2	16.7	15.7	22.6	19.2	17.6	16.5	23.7	20.1	18.4	17.3	24.8	21.1	19.3	18.1
	80	14.9	12.9	11.9	11.3	16	13.8	12.7	12	17.1	14.8	13.6	12.8	18.3	15.7	14.4	13.6	19.4	16.6	15.3	14.4	20.5	17.6	16.1	15.2	21.6	18.5	17	16	22.8	19.5	17.9	16.8	23.9	20.4	18.7	17.6	25.1	21.3	19.6	18.4
22	20	15.3	13.6	12.8	12.3	16.4	14.5	13.6	13	17.5	15.4	14.4	13.8	18.6	16.3	15.3	14.6	19.7	17.3	16.1	15.4	20.9	18.2	17	16.1	22	19.2	17.8	16.9	23.1	20.1	18.7	17.7	24.2	21	19.5	18.5	25.1	22	20.3	19.3
	40	15.5	13.9	13.1	12.6	16.6	14.8	14	13.4	17.7	15.7	14.8	14.2	18.9	16.7	15.6	14.9	20	17.6	16.5	15.7	21.1	18.5	17.3	16.5	22.2	19.5	18.1	17.3	23.4	20.4	19	18.1	24.4	21.3	19.8	18.8	25.3	22.2	20.6	19.6
	60	15.8	14.2	13.5	13	16.9	15.1	14.3	13.8	18	16.1	15.1	14.5	19.1	17	16	15.3	20.2	17.9	16.8	16.1	21.3	18.8	17.6	16.9	22.5	19.7	18.5	17.6	23.6	20.7	19.3	18.4	24.7	21.6	20.1	19.2	25.7	22.5	20.9	19.9
	80	16.1	14.6	13.9	13.4	17.2	15.5	14.7	14.2	18.3	16.4	15.5	14.9	19.4	17.3	16.3	15.7	20.5	18.2	17.1	16.4	21.6	19.1	18	17.2	22.7	20	18.8	18	23.9	20.9	19.6	18.7	25	21.9	20.4	19.5	26.2	22.8	21.2	20.2

Standard Effective Temperature for Activity level 1 Met (office work type activity) and Clothing 0.5 Clo (Summer clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
24	20	16.3	15.1	14.6	14.2	17.4	16	15.4	15	18.5	16.9	16.2	15.7	19.6	17.8	17	16.5	20.7	18.7	17.8	17.2	21.9	19.7	18.6	18	23	20.6	19.5	18.8	24	21.5	20.3	19.5	24.9	22.4	21.1	20.3	25.8	23.3	21.9	21
	40	16.6	15.5	15	14.7	17.7	16.4	15.8	15.4	18.8	17.3	16.6	16.1	19.9	18.2	17.4	16.9	21	19.1	18.2	17.6	22.1	20	19	18.4	23.2	20.9	19.8	19.1	24.2	21.8	20.6	19.9	25.2	22.7	21.4	20.6	26.2	23.6	22.2	21.3
	60	16.9	15.9	15.4	15.1	18	16.7	16.2	15.8	19.1	17.6	17	16.5	20.2	18.5	17.8	17.3	21.3	19.4	18.6	18	22.4	20.3	19.4	18.7	23.5	21.2	20.2	19.5	24.6	22.1	20.9	20.2	25.7	23	21.7	20.9	26.7	23.8	22.5	21.7
	80	17.2	16.2	15.8	15.5	18.3	17.1	16.6	16.2	19.4	18	17.3	16.9	20.5	18.9	18.1	17.7	21.6	19.7	18.9	18.4	22.7	20.6	19.7	19.1	23.8	21.5	20.5	19.8	25.1	22.4	21.3	20.6	26.3	23.3	22	21.3	27.4	24.1	22.8	22
26	20	17.4	16.6	16.4	16.2	18.5	17.5	17.1	16.9	19.6	18.4	17.9	17.6	20.6	19.3	18.7	18.3	21.7	20.2	19.5	19.1	22.8	21.1	20.3	19.8	23.9	21.9	21	20.5	24.8	22.8	21.8	21.2	25.6	23.7	22.6	21.9	26.5	24.3	23.4	22.6
	40	17.7	17.1	16.8	16.6	18.8	17.9	17.6	17.3	19.9	18.8	18.3	18	21	19.7	19.1	18.8	22	20.5	19.9	19.5	23.1	21.4	20.6	20.2	24.2	22.3	21.4	20.9	25.1	23.1	22.2	21.6	26.1	23.9	22.9	22.3	27.1	24.6	23.7	23
	60	18	17.4	17.2	17.1	19.1	18.3	18	17.8	20.2	19.2	18.7	18.5	21.3	20	19.5	19.2	22.3	20.9	20.3	19.9	23.4	21.8	21	20.6	24.6	22.6	21.8	21.3	25.7	23.4	22.5	21.9	26.7	24.2	23.3	22.6	27.8	25	23.9	23.3
	80	18.4	17.8	17.6	17.5	19.4	18.7	18.4	18.2	20.5	19.5	19.1	18.9	21.6	20.4	19.9	19.6	22.6	21.2	20.6	20.2	23.9	22.1	21.4	20.9	25.2	22.9	22.1	21.6	26.5	23.8	22.9	22.3	27.7	24.8	23.6	23	28.8	25.7	24.4	23.6
28	20	18.4	18.1	18.1	18	19.5	19	18.8	18.7	20.6	19.8	19.6	19.4	21.7	20.7	20.3	20.1	22.7	21.6	21.1	20.8	23.8	22.4	21.8	21.5	24.6	23.2	22.6	22.1	25.5	24	23.3	22.8	26.4	24.6	23.9	23.5	27.2	25.2	24.5	24
	40	18.8	18.6	18.5	18.5	19.9	19.4	19.3	19.2	20.9	20.3	20	19.9	22	21.1	20.7	20.5	23.1	21.9	21.5	21.2	24.1	22.8	22.2	21.9	25.1	23.6	22.9	22.5	26.1	24.3	23.6	23.2	27	25	24.2	23.8	27.9	25.7	24.8	24.3
	60	19.2	19	19	19	20.2	19.8	19.7	19.6	21.3	20.7	20.4	20.3	22.3	21.5	21.2	21	23.4	22.3	21.9	21.6	24.6	23.1	22.6	22.3	25.8	24	23.3	22.9	26.9	24.8	24	23.5	27.9	25.6	24.7	24.1	28.9	26.4	25.4	24.8
	80	19.5	19.4	19.4	19.4	20.6	20.2	20.1	20.1	21.6	21.1	20.8	20.7	22.7	21.9	21.6	21.4	24.1	22.7	22.3	22	25.5	23.6	23	22.6	26.8	24.6	23.8	23.3	28.1	25.6	24.6	24.1	29.3	26.5	25.4	24.8	30.4	27.4	26.2	25.5
30	20	19.5	19.6	19.7	19.8	20.5	20.4	20.4	20.5	21.6	21.3	21.2	21.1	22.6	22.1	21.9	21.8	23.7	22.9	22.6	22.4	24.5	23.6	23.3	23.1	25.4	24.3	23.9	23.6	26.3	24.9	24.4	24.1	27.1	25.5	24.9	24.6	28	26.1	25.5	25.1
	40	19.9	20.1	20.2	20.3	20.9	20.9	20.9	21	22	21.7	21.6	21.6	23	22.5	22.3	22.2	24	23.3	23	22.8	25.1	24	23.6	23.4	26.1	24.7	24.2	24	27	25.4	24.8	24.5	28	26.1	25.4	25	28.9	26.8	26	25.6
	60	20.3	20.5	20.7	20.8	21.3	21.3	21.4	21.4	22.3	22.1	22.1	22	23.5	22.9	22.7	22.6	24.7	23.7	23.4	23.2	25.9	24.6	24.1	23.9	27.1	25.4	24.8	24.5	28.2	26.2	25.5	25.1	29.2	27	26.2	25.8	30.2	27.8	26.9	26.4
	80	20.7	21	21.1	21.2	21.7	21.8	21.8	21.9	22.7	22.5	22.5	22.5	24.4	23.6	23.3	23.1	26	24.7	24.2	24	27.4	25.7	25.1	24.8	28.8	26.7	26	25.5	30	27.7	26.8	26.3	31.2	28.6	27.6	27	32.3	29.4	28.4	27.7
32	20	20.5	21	21.3	21.5	21.5	21.8	22	22.1	22.6	22.6	22.7	22.7	23.6	23.4	23.3	23.3	24.5	24	23.8	23.8	25.3	24.6	24.4	24.2	26.2	25.2	24.9	24.7	27.1	25.8	25.4	25.2	27.9	26.4	25.9	25.6	28.7	27	26.4	26.1
	40	21	21.5	21.8	22	22	22.3	22.5	22.6	23	23.1	23.1	23.2	24.1	23.8	23.7	23.7	25.1	24.5	24.3	24.2	26.1	25.2	24.9	24.8	27.1	25.9	25.5	25.3	28	26.6	26.1	25.8	29	27.3	26.7	26.3	29.9	27.9	27.3	26.9
	60	21.4	22	22.3	22.5	22.4	22.7	22.9	23.1	23.6	23.6	23.7	23.7	25	24.5	24.4	24.4	26.2	25.4	25.1	25	27.4	26.2	25.9	25.7	28.6	27	26.5	26.3	29.6	27.8	27.2	26.9	30.7	28.6	27.9	27.5	31.6	29.4	28.6	28.1
	80	21.8	22.4	22.9	23.3	23.1	23.7	24	24.2	25.1	25	25	25.1	26.9	26.2	26	25.9	28.5	27.3	26.9	26.7	29.9	28.3	27.8	27.5	31.2	29.3	28.6	28.2	32.4	30.2	29.4	29	33.5	31.1	30.2	29.7	34.5	31.9	30.9	30.3

NOTE – AT: Dry bulb temperature of indoor air, AV: Air velocity around occupant, MET: Metabolic rate, Clo: Thermal resistance due to clothing, MRT: Mean radiant temperature

Table 5 Minimum Ventilation Rates in Breathing Zone (*See* Notes 1 to 5)
(*Clause* 3.6.1.2)

(This table is not valid in isolation; it shall be used in conjunction with the accompanying notes.)

Sl. No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**		**Area Outdoor Air Rate, R_a**		**Notes**	**Default Values**			**Air[1)] Class**
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	**Correctional facilities:**									
a)	Cell	5	2.5	0.12	0.6		25	10	4.9	2
b)	Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
c)	Guard Stations	5	2.5	0.06	0.3		15	9	4.5	1
d)	Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
ii)	**Educational facilities:**									
a)	Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
b)	Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
c)	Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4	1
d)	Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1

Sl. No.	Occupancy Category	People Outdoor Air Rate, R_p		Area Outdoor Air Rate, R_a		Notes	Default Values: Occupant Density (*see* Note 4)	Default Values: Combined Outdoor Air Rate (*see* Note 4)		Air[1)] Class
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
e)	Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
f)	Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
g)	Art classroom	10	5	0.18	0.9		20	19	9.5	2
h)	Science laboratories	10	5	0.18	0.9		25	17	8.6	2
j)	University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
k)	Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
m)	Computer lab	10	5	0.12	0.6		25	15	7.4	1
n)	Media centre	10	5	0.12	0.6	*See* Note 6	25	15	7.4	1
p)	Music/theatre/dance	10	5	0.06	0.3		35	12	5.9	1
q)	Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
iii)	**Food and beverage service:**									
a)	Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
b)	Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
c)	Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2

Sl. No.	Occupancy Category	People Outdoor Air Rate, R_p		Area Outdoor Air Rate, R_a		Notes	Default Values: Occupant Density (*see* Note 4)	Default Values: Combined Outdoor Air Rate (*see* Note 4)		Air[1)] Class
		cfm/person	l/s.person	cfm/ft²	l/s.m²		Persons per 1 000 ft² or per 100 m²	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
iv)	**General:**									
a)	Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
b)	Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
c)	Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
d)	Corridors	-	-	0.06	0.3		-	-	-	1
e)	Storage rooms	-	-	0.12	0.6	*See* Note 7	-	-	-	1
v)	**Hotels, motels, resorts, dormitories:**									
a)	Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
b)	Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
c)	Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
d)	Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
e)	Lobbies/pre-function	7.5	3.8	0.06	0.3		30	10	4.8	1
f)	Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

Sl. No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**		**Area Outdoor Air Rate, R_a**		**Notes**	**Default Values**			**Air[1)] Class**
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
vi)	**Office buildings:**									
a)	Office space	5	2.5	0.06	0.3		5	17	8.5	1
b)	Reception Areas	5	2.5	0.06	0.3		30	7	3.5	1
c)	Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
d)	Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
vii)	**Miscellaneous spaces:**									
a)	Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
b)	Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
c)	Electrical equipment rooms	-	-	0.06	0.3	*See* Note 7	-	-	-	1
d)	Elevator machine rooms	-	-	0.12	0.6	*See* Note 7	-	-	-	1
e)	Pharmacy (preparation area)	5	2.5	0.18	0.9		10	23	11.5	2
f)	Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
g)	Shipping/receiving	-	-	0.12	0.6	*See* Note 7	-	-	-	1

Sl. No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**		**Area Outdoor Air Rate, R_a**		**Notes**	**Default Values**			**Air[1)] Class**
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
h)	Telephone closets	-	-	0.00	0.0		-	-	-	1
j)	Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
k)	Warehouses	-	-	0.06	0.3	*See* Note 7	-	-	-	2
viii)	**Public assembly spaces:**									
a)	Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
b)	Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
c)	Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
d)	Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
e)	Libraries	5	2.5	0.12	0.6		10	17	8.5	1
f)	Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
g)	Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
h)	Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
ix)	**Residential:**									
a)	Dwelling unit	5	2.5	0.06	0.3	*See* Notes 8 and 9	*See* Note 8	-	-	1

Sl. No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**		**Area Outdoor Air Rate, R_a**		**Notes**	**Default Values**			**Air[1)] Class**
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
b)	Common corridors	-	-	0.06	0.3	-	-	-	-	1
x)	**Retail:**									
a)	Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
b)	Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
c)	Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
d)	Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
e)	Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
f)	Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
g)	Coin-operated laundries	7.5	3.8	0.06	0.3		20	11	5.3	2
xi)	**Sports and entertainment:**									
a)	Sports arena (play area)	-	-	0.30	1.5	*See* Note 10	-	-	-	1
b)	Gym, stadium (play area)	-	-	0.30	1.5		30	-	-	2
c)	Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
d)	Swimming (pool and deck)	-	-	0.48	2.4	*See* Note 11	-	-	-	2

Sl. No.	Occupancy Category	People Outdoor Air Rate, R_p		Area Outdoor Air Rate, R_a		Notes	Default Values: Occupant Density (*see* Note 4)	Default Values: Combined Outdoor Air Rate (*see* Note 4)		Air[1)] Class
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
e)	Disco/dance floors	20	10	0.06	0.3		100	21	10.3	1
f)	Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
g)	Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
h)	Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
j)	Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
k)	Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
m)	Stages, studios	10	5	0.06	0.3	*See* Note 12	70	11	5.4	1

[1)] Air Class Characteristic

1 Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odour.

2 Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odours. Class 2 air also includes air that is not necessarily harmful or objectionable but that is inappropriate for transfer or recirculation to spaces used for different purposes.

3 Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odour.

4 Air with highly objectionable fumes or gases or with potentially dangerous particles, bio aerosols, or gases, at concentrations high enough to be considered harmful.

NOTES

1 The rates in this table are based on all other applicable requirements being met.

2 This table applies to no-smoking areas only. Rates for smoking-permitted spaces shall be determined using other methods.

3 Volumetric airflow rates are based on an air density of 1.2 kg of dry air/m^3, which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 21°C. Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 Actual occupant density should be considered, the default occupant density shall be used only when actual occupant density is not known. Default combined outdoor air (per person) rate is based on the default occupant density.

Sl. No.	Occupancy Category	People Outdoor Air Rate, R_p		Area Outdoor Air Rate, R_a		Notes	Default Values			Air[1)] Class
							Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)		
		cfm/person	l/s.person	cfm/ft^2	l/s.m^2		Persons per 1 000 ft^2 or per 100 m^2	cfm/person	l/s.person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

5 If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.
6 For high school and college libraries, use values shown for public assembly spaces- libraries.
7 The prescribed value may not be sufficient when stored materials include those having potentially harmful emissions.
8 Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
9 Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.
10 When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.
11 The prescribed value does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.
12 The prescribed value does not include special exhaust for stage effects, for example, dry ice vapours, smoke.

3.6.2 *Designing for Air Quality*

The HVAC system shall be designed with adequate filtration for achieving following levels of indoor pollutants:

The threshold values for IAQ pollutants will be as mentioned in as per the table 6 provided below. The buildings / indoor spaces will be classified as Class A, B and C where Class A refers to aspirational, Class B refers to acceptable and Class C refers to minimum acceptable.

Table 6 Threshold Values for IAQ Pollutants
(*Clause* 3.6.2)

Sl no.	Pollutants	Units	Classification		
			A	B	C
(1)	(2)	(3)	(4)	(5)	(6)
i)	CO_2	ppm	ambient + 350	ambient + 500	ambient + 700
ii)	$PM_{2.5}$	ug/m^3	<15	<25	<25
iii)	PM_{10}	ug/m^3	<50	<100	<100
iv)	O_3	ug/m^3	<50	<100	-
v)	TVOC (equivalent to isobutylene)	ug/m^3	<200	<400	<500
vi)	CH_2O	ug/m^3	<30	<100	-
vii)	SO_2	ug/m^3	<40	<80	-
viii)	NO_2	ug/m^3	<40	<80	-
ix)	CO	ppm	<2	<9	<9

3.6.3 *Designing for Background Noise Control and Vibration*

The background noise and vibration created by air distribution through the HVAC system, combined with noise from equipment and outdoor sources of noise and vibration may causes significant disturbance to building users. Adoption of measures for adhering to indoor noise limits and vibration control should be ensured in the design of equipment, their foundation, supports and air distribution system.

4 HVAC SYSTEM TYPES

HVAC system requirements for the design, construction, installation, operation, replacement, repair, alteration, maintenance and end of life of mechanical cooling systems. It encourages the adoption of products designed with recyclability, reusability, and remanufacturing in mind, aiming to minimize waste, reduce environmental impacts, and promote resource efficiency throughout the entire lifecycle of the systems.

Following points to be considered for selection of cooling systems:

a) Safeguard people from illness, injury or loss (including loss of amenity) due to the failure of air-conditioning installation;
b) Ensure that air-conditioning installation is suitable;
c) Conserve water and energy;
d) Safeguard the environment;
e) Safeguard public and private infrastructure; and
f) Ensure that air-conditioning installation is designed and is capable of being maintained so that throughout its serviceable life it will continue to satisfy Objectives (a) to (e).

Mechanical services, plant and equipment that are used for cooling, heating and/or ventilation of a building shall be adequate for the purpose meeting the basis of design. A building's HVAC system installation and maintenance shall support energy efficient outcomes and minimise any adverse impact on building occupants or occupants of adjoining places, the network utility operator's infrastructure, property and the environment.

Compliance with the requirement shall be verified either:

a) By satisfying the required criteria when tested in accordance with a specified test method endorsed by a recognised certification body; or
b) By calculation and certification by persons or organisations with recognised credentials in the testing of ventilation and air conditioning systems.

4.1 General

Systems for air conditioning may be broadly grouped as air-to-air, air-to-water, and liquid-to-liquid type. Suitability of system type shall not be generalized; hence it shall need to be building specific decision, considering initial cost, efficiency, maintenance, effect on building aesthetics, sound level, service life and other factors. Lower operating cost, central maintenance and control shall be of primary considerations.

It may be noted that central systems often require a higher initial cost than distributed systems but often result in annual energy savings. They also have a potential of reducing the total installed capacity by using load diversity. Over the life cycle, the centralized cooling systems usually prove to be more cost-effective when the total building load exceeds 350 kW (approximately 100 TR), depending on climate and patterns of occupancy use.

When low initial cost and simplicity are primary concerns, designers may select zone-by-zone distributed systems, incorporating either cooling or both heating and cooling facility. This approach shall normally be used for smaller buildings, however, larger buildings with multiple tenancy may also consider this as an option.

NOTES

1 Distributed systems, also known as unitary systems, individually consists of fan, cooling coil, compressor and outdoor condenser. Examples of distributed systems include unitary air conditioners, packaged rooftop air conditioners, variable refrigerant flows (VRFs), heat pumps, as well as refrigerant-based split-system fan-coil units (single or multi-unit).

2 Water-source heat pumps (WSHPs) are also considered as distributed systems in which the compressor is located close to the occupied space, but they are collectively served by a centralized water system with auxiliary heat rejection devices.

Comparative advantages, disadvantages and constraints of each option should be carefully evaluated before zeroing down to final HVAC system selection. Table 7 lists out various system characteristics of different HVAC systems; it may be used as a guiding tool for system selection.

Table 7 HVAC System Analysis and Selection Matrix
(*Clause* 4.1)

Sl no.	**System Characteristics**	**Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)**	**Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)**	**Variable Speed Multi or Modular Systems (VRF)**	**Central Systems**
(1)	(2)	(3)	(4)	(5)	(6)
i)	Temperature	No uniform and effective control	Minimal uniform and effective control possible	Reasonably uniform and effective control possible	Uniform and effective control possible
ii)	Humidity	Effective control not possible	Effective control not possible	Effective control not possible	Effective control possible
iii)	Space Pressure	Effective control not possible	Effective control not possible	Effective control not possible	Effective control possible
iv)	Capacity Requirements	Capacity to suit zone peak, No diversity	Capacity to suit zone peak, No diversity	Capacity to suit zone peak, Limited diversity shall be considered	Allows the design engineer to consider HVAC diversity factors that reduce installed equipment capacity
v)	Redundancy	Does not have the benefit of back-up or standby equipment	Does not have the benefit of back-up or standby equipment	It has the benefit of partial back-up or standby equipment	Back-up or standby equipment shall easily be accommodated
vi)	Facility Management	Allows minimal provision to maximize performance using good facility management	Allows minimal provision to maximize performance using good facility management	Limited possibilities to maximize performance using good facility management	Allows maximize performance using good facility management

Sl no.	System Characteristics	Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)	Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)	Variable Speed Multi or Modular Systems (VRF)	Central Systems
(1)	(2)	(3)	(4)	(5)	(6)
		techniques in operation	techniques in operation	techniques in operation	techniques in operation
vii)	Spatial Requirements	No plant/ equipment room required. Compromises building elevation	No plant/ equipment room required. Compromises building elevation	No plant/ equipment room required. Outside units shall be located on roof or on adjacent ground. Very small depth but larger linear length (based on number of modular outdoor units) for shaft is required for refrigerant piping.	Equipment rooms/ spaces and accessible shaft required for chilled water piping
viii)	Electric Supply	Distributed electric supply required	Distributed electric supply required	Zone wise distributed electric supply required	Minimal distribution cost by centralised supply near the substation
ix)	First Cost	Minimum first cost	First cost marginally higher than fixed speed system	Moderate first cost but marginally higher than variable speed unitary product	Even with HVAC diversity, a central system may be of a bit higher or similar cost as a decentralized HVAC system

Sl no.	**System Characteristics**	**Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)**	**Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)**	**Variable Speed Multi or Modular Systems (VRF)**	**Central Systems**
(1)	(2)	(3)	(4)	(5)	(6)
x)	Operating Cost	Higher operating cost Strategic scheduling of multiple pieces of equipment shall save marginal operating cost. But equipment less efficient	Strategic scheduling of multiple pieces of equipment shall save reasonable operating cost. Higher peak energy requirement	Strategic scheduling of equipment shall save operating cost better than unitary product. Higher peak energy requirement	More energy-efficient primary equipment and multiple pieces of HVAC equipment allow staging of operation to match building loads while maximizing operational efficiency
xi)	Maintenance Cost	Comparatively less maintenance cost	Maintenance cost marginally higher than fixed speed	Maintenance cost higher than both fixed and variable speed unitary system but less than central system	Comparatively higher since centralised equipment room requires operator with no access to occupant workspace, but with fewer pieces of HVAC equipment to service
xii)	Reliability	Reliable equipment but low service life	Reliable equipment but low service life	Reliable equipment but moderate service life	Reliable equipment with much longer service life
xiii)	Flexibility	Has to be placed at fixed locations	Has to be placed at fixed locations	Can be placed at distributed locations	Flexibility available in terms of alternative locations
xiv)	Level of Control	Limited control level available	Limited control level available	Moderate control level available	Close control level available
xv)	Noise and Vibration	Noise and vibration within/adjacent to occupied spaces	It is generally available in split system only for which noise and	Noise and vibration on roof terrace or ground away	Noise and vibration away from occupied spaces

Sl no.	System Characteristics	Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)	Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)	Variable Speed Multi or Modular Systems (VRF)	Central Systems
(1)	(2)	(3)	(4)	(5)	(6)
		for unitary window type air conditioners which is substantially reduced in case of split system	vibration is substantially reduced in occupied and adjacent spaces as compared to a window type air conditioner	from occupied spaces, however the same shall be reduced with good installation practices	
xvi)	Constructability	Multiple and similar-in-size equipment makes standardization a construction feature	Multiple and similar-in-size equipment makes standardization a construction feature	Multiple and similar equipment makes standardization a construction feature	Require more coordinated installation with added benefit of consolidated primary equipment in a central location.

4.1.1 *Window Air Conditioners*

Window Air Conditioners, as the name itself suggests, are usually fitted in a window or a recess created in a wall of a building. These are unitary direct expansion (DX) systems, having all the components packaged in a single box. The front side is designed to deliver the conditioned air to the connected space, and rear side shall be exposed to ambient for easy discharge of heat without any direct adverse effect on anyone else.

4.1.1.1 *Suitability*

Window air conditioners are suitable for residences, office cabin, general office area, and similar applications, where rigid comfort conditions are not required to be maintained.

4.1.1.2 *Limitations*

a) *Sound level* – Noise level of window air conditioner inside the conditioned room presents a serious problem due to close proximity of compressor to the occupied space.

   The noise level of window air conditioner shall be in accordance with the levels specified in Table 5 of accepted standard [8-3(4)].

b) *Fresh air for ventilation* – Most window air conditioners have a very small opening for entry of outdoor air for ventilation. As a result, the conditioned space, especially if occupied by more than 2-3 persons, may have higher levels of CO_2, as compared to centralised system.

c) *Location* – Window air conditioner shall be mounted preferably at the window sill level on an external wall, where hot air from air-cooled condenser shall be discharged to the outdoor space without causing inconvenience to others. There should not be any obstruction for the inlet air to, nor for discharge air from, the condenser.

While deciding location of the window air conditioner, care shall be taken to ensure that the condensate drain water is piped to the ground level and does not drip in open space, causing nuisance.

Window air conditioner shall not be used for special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired, nor in applications where high amount of fresh air is desired for ventilation. It shall also not be used for areas that require close control of both the indoor temperature and relative humidity.

For detailed information regarding constructional and performance requirements and methods for establishing ratings of unitary (window) air conditioners, reference shall be made to the accepted standard [8-3(4)] and [8-3(10)].

4.1.1.3 For detailed information regarding constructional and performance requirements and methods for establishing rating of window type room air conditioners, reference shall be made to the accepted Indian standards.

4.1.2 *Split Air Conditioner*

Split air conditioners comprise of an indoor unit and an outdoor unit. Depending on its type, the Indoor unit may be mounted on either on floor, on wall, or at the roof. The outdoor unit consisting of compressor, heat exchanger, fan and motor; is installed in a separate independent cabinet. The indoor unit is an air handling system, designed primarily to provide conditioned air to an enclosed space, room or zone (conditioned space). It includes a prime source of refrigeration for cooling and dehumidification/ heating and means for the circulation and filtering of air.

Various types of split air conditioners may be categorized based on type of compressor for outdoor unit and air-distribution for indoor unit, as below:

a) *Outdoor unit with variable speed compressor* – Also called an inverter AC or variable speed AC, works on part load depending on the demand for the conditioned space. This often uses a variable-frequency drive to control the frequency and thereby the speed of the compressor motor.
b) *Outdoor unit with fixed speed compressor*
c) *Free-blow indoor unit* – It could be high wall mounted, ceiling suspended cassette (exposed type), or floor-mounted.

d) *Indoor unit (ceiling suspended)* – It is mounted in the ceiling void and provided with a duct collar and grille. This is commonly used in the vestibule of a hotel room.
e) *Ducted indoor unit* – It is generally mounted in ceiling void and requires duct work for air distribution.

4.1.2.1 *Suitability*

Split Air conditioners are suitable for wide range of applications including residence, small office, club, restaurant, showroom, departmental store and others except for locations having high occupancy and requirement of high ventilation rates.

4.1.2.2 *Operating parameters*

In general, nominal capacity of the split air conditioner are rated as per accepted standard [8-3(5)] for an ambient temperature of 35°C. Split ACs gets de-rated at higher ambient temperature (above 35°C) in summer months, in most Indian cities, and locations where for significant duration ambient temperature is likely to be above 35°C, information related to capacity deration and reduction in energy efficiency shall be the basis of system sizing.

At locations having high voltage fluctuation and inferior power quality, a voltage stabilizer shall be required to get stabilized rated voltage as per specifications defined by manufacturer. For 3 phase unit, it is recommended to use phase reversal protection device in power supply to the outdoor unit.

4.1.2.3 *Location*

Split air conditioner indoor units are to be mounted within the air-conditioned space or above the false ceiling from where the air distribution ducts are to be taken to the conditioned space for distribution of the conditioned supply air. When the indoor unit is mounted in the false ceiling, inspection panel shall be kept in the false ceiling to attend to the indoor unit, and periodic cleaning requirement of air filter. Outdoor unit shall be mounted at the nearest open area where unobstructed flow of outside air is available for the air-cooled condenser.

4.1.2.4 *Installation*

Wall mounted unit and similar exposed indoor unit are to be provided with installation plate for ease in installation. Care shall be taken to ensure clearance space as specified by the manufacturer is provided. The intake of return air shall not have any restrictions.

Ceiling suspended indoor unit shall be provided with vibration absorbers and isolators to minimize vibration transmission to the ceiling.

Outdoor unit shall be mounted on metal frame with anticorrosive coating or made of corrosion resistant material in an open area so that the condenser outlet air is thrown out with no obstruction and possible return of the air to condenser inlet side. Precaution shall also be taken that hot air from any one outdoor unit does not mix with the outdoor air intake of any other air-cooled condenser. This is generally referred as short cycling of the air and shall be avoided. The spacing around the condenser unit shall be ensured as per the manufacturer's installation guideline and recommendation. In case of multiple outdoor units in the same premise, the installations of all the condensing units shall be such that the outlet air from condensers shall not mix with the air inlet of any of the condensing units.

Service valves shall be provided on the outdoor unit for pressure testing of the system for leakages, for evacuation of moisture and air from the system, and to carry out predetermined gas quantity charge into the system. In case of maintenance of any part, it shall be provided with service valves to isolate and store the entire refrigerant charge within the outdoor unit by pumping down, thus saving the entire charge of refrigerant.

4.1.2.5 *Limitations*

Split air conditioners are not recommended for:

a) Where distance between indoor and outdoor – Horizontal, vertical and total exceeds the limits as specified by manufacturers. Generally, the maximum of 30 m or higher as per recommendation of manufacturer from the outdoor unit for units up to 10 500 W (3 TR approximately), the horizontal distance between the indoor unit and outdoor unit should not exceed 10 m.
b) Area requiring close and higher accuracy control of both the indoor temperature and relative humidity which is also referred as precision air conditioning.
c) Special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired.
d) Spaces with large occupancy or high fresh air requirements.

4.1.2.6 For detailed information regarding constructional and performance requirements and methods for establishing rating of split type room air conditioners, reference shall be made to the accepted Indian standards.

4.1.3 *Ducted Split Air Conditioner*

Ducted split air conditioner (packages DX) units are ducted and packaged systems including rooftop and indoor packaged units in commercial air conditioning segment. Also known as unitary and light commercial systems, these typically should be used for small-to-medium commercial buildings to avoid the complexities associated with chilled water air conditioning systems. Packaged air conditioner shall be a self-contained unit suitable for floor mounting, or ceiling suspended ducted indoor units, designed to provide conditioned air through ducting in to the moderate sized conditioned spaces. It shall include a prime source of refrigeration for cooling and dehumidification, distinct facility for drawing of fresh air and mixing with return air, means for cleaning of mixed return and fresh air, and provision for external ducting for uniform air distribution in the conditioned spaces. If required, it shall also include winter heating and humidification package for winter operation. The machine shall be equipped with compressor, evaporator, expansion device and remote air-cooled condenser or water-cooled condenser with interconnected copper refrigerant piping.

Water cooled condenser packaged unit gives higher cooling capacity with lower power consumption as compared to an air-cooled condenser packaged unit which gets considerably de-rated in capacity for high (beyond 35°C) ambient temperature in summer months for most of the cities in India. Air cooled package unit consequently also consumes more power in peak summer months. On the other hand, water-cooled condenser unit requires cooling tower with necessary piping and pump sets for circulating condenser-cooling water but is far more energy efficient at locations where ambient wet bulb temperatures are low in dry-summer months.

Water cooled systems shall be used where water for cooling is available. Treated wastewater, with proper TDS control shall be used in water cooled systems where available.

Packaged units with vertical air discharge should be used; however, if horizontal air discharge unit is procured then heat island effect would have to be avoided by providing clear unblocked space ahead of the condenser discharge.

4.1.3.1 *Suitability*

Packaged units are suitable for wide range of applications including office, club, restaurant, showroom, departmental store, banquet halls and others.

4.1.3.2 Location

Ducted split unit shall be mounted within the air-conditioned space with discharge air plenum or in a separate room from where the air distribution duct is taken to the conditioned space. While deciding location for the packaged unit, provision shall be kept for ease of servicing of the unit.

4.1.3.3 *Installation*

Ducted split unit shall be normally mounted on resilient pads which prevent vibration of the unit from being transmitted to the floor.

4.1.3.4 *Limitations*

Packaged air conditioners are not recommended for:

a) Large multi-storey buildings, where multiplicity of compressors may entail subsequent maintenance problems
b) Where the length of air distribution ducting may exceed 30 m. However, duct length limitation depends upon permissible external static pressure specified by the manufacturer.
c) Where the vertical distance of air-cooled condenser from the packaged unit exceeds about 20 m. The sum of horizontal and vertical distance should generally be kept within 25 m.
d) Special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired. For these applications, special packaged units are available with high micron efficiency filters.

e) Operation theatres where 100 percent fresh air is needed and fire hazard exists depending on the type of anaesthesia being used.

4.1.4 *Variable Refrigerant Flow System*

Variable refrigerant flow (VRF) systems are direct expansion (DX) multi-split system with compressors having ability to vary the refrigerant mass flow rate and, capable of delivering capacity according to variable load requirement. By delivering the variable refrigerant flow, VRF unit delivers required cooling / heating capacity allowing for substantial energy savings at partial-load conditions. VRF system has an outdoor unit connected with multiple number of indoor units via refrigerant piping, an attribute that distinguishes VRF system from other DX system. Other advantages of VRF system are its scalability, variable capacity, distributed temperature control, and the simultaneous cooling / heating mode application in different connected zones.

VRF system achieves temperature control on a zone-by-zone basis primarily by using refrigerant side control. As compared to the basic DX system, VRF Indoor unit has an additional electronic expansion device to control refrigerant flow passing through evaporator coil, to control indoor temperature, precisely based on the instantaneous load requirement. Similar to other air-cooled systems, air cooled VRF systems get derated at temperatures higher than rating temperature 35°C. Therefore, sizing calculation shall be carried out based upon the information provided by the manufacturer about cooling / heating and energy performance at elevated temperatures.

VRF system is available with a dedicated air handling unit for supply of treated fresh air (TFA). In order to cater to fresh air needs, VRF system outdoor unit should be connected with TFA-AHU. A control box equipped with electronic expansion device and communication PCB is needed for TFA-AHU so that it shall communicate seamlessly with the VRF system outdoor unit.

VRF technology comes in two pipe or three pipe system. In a 2-pipe heat pump system, all of the zones shall either be in cooling mode or in heating mode. Application requiring simultaneous heating and cooling should have 3 pipe systems for enabling heat recovery.

4.1.4.1 *Configuration*

VRF system is available with air cooled or water-cooled condenser. Outdoor unit in VRF system could have multiple compressors, with one or more compressor provided with variable speed control. Generally, for air cooled VRF system, outdoor unit is available both with top discharge and with side discharge.

4.1.4.2 *Suitability*

VRF systems are suitable for a wide range of applications including residence, apartment, villa, small and big office, club, restaurant, showroom, departmental store, healthcare facility, hospitality, cultural facility, educational facility and industrial facility.

In VRF system, depending on application, same or different type of indoor units shall be connected to a single outdoor unit or to multiple outdoor units. VRF Indoor units and air handling units for fresh air or for special treatment of re-circulated air, shall be connected to the same refrigerant line, to facilitate more flexible system design, in mid and large size applications. However, usage of bigger AHU in VRF systems may have evident effect on the part load energy efficiency advantage of the system.

4.1.4.3 *Controls*

VRF systems shall have factory-packaged integral controls in each component; these communicate through their system specific protocol, to ensure that all system components operate collectively. VRF indoor and outdoor units include refrigerant and air side sensing and control devices which allow the system to optimize its output (compressor speed, discharge temperature, fan speed) based on inputs from controllers. Depending on the application and design, a VRF systems shall able to operate with at least one of the three different levels of controls: individual/group controller, centralized controller with remote monitoring and interface with building management system (BMS).

a) *Individual/group controller*

VRF indoor units shall be controlled individually with wired or wireless individual remote controller. Control options include ON/OFF temperature change, mode change, fan speed change and integration with the BMS system of the building. Applications such as a large common area in which multiple indoor units are running simultaneously, at the same condition, shall be controlled by a single remote controller by combining these indoor units as a group. All setting conditions remain same for all indoor units connected in the group. Each of the grouped indoor unit may operate according to the sensed return air temperature.

b) *Centralized controller with remote monitoring and control*

Centralized controller allows user to operate and monitor multiple indoor units centrally. Besides having all functions of individual remote controller, centralized controller has the additional facility of scheduling energy saving by operation restrictions, and web monitoring. In some applications, single outdoor unit is used by different tenants connected to different indoor units. In such cases, centralized controller offers facility of tenant billing through software application, depending on individual usage through proportional power distribution.

c) *Interface with building management system*

VRF system shall be integrated with building management system if available, with the use of different interface gateways that communicate with different protocols. With this interfacing, it is easy to operate and monitor air conditioning with user’s building management system.

4.1.5 *Liquid Chilling System*

Liquid chilling system may be based on chilled water, brine, or other secondary coolant for air conditioning or refrigeration. The most frequent application of water chilling is for air conditioning. However, brine cooling systems for low temperature refrigeration requirement and chilling fluids for thermal storage processes, are also common.

The basic components of a vapour-compression, liquid-chilling system shall include a compressor, liquid cooler (evaporator), condenser – which could be air cooled or water cooled), compressor drive, liquid-refrigerant expansion or flow control device and control centre; it also normally includes a receiver, economizer, expansion turbine and/or sub cooler. In addition, auxiliary components may be used, such as a lubricant cooler, lubricant separator, lubricant-return device, purge unit, lubricant pump, refrigerant transfer unit, refrigerant vents, and/or additional control valves. Liquid chilling units are available with air cooled or water-cooled condensers. Wherever water is available for cooling, water cooled chillers shall be opted for.

4.1.5.1 *Vapour compression water chiller*

The unit shall be installed on to a solid foundation on appropriately designed resilient mountings as per the manufacturer recommendation. Pipe connections shall have flexible couplings; these should be considered in conjunction with the design of the pump mountings and the pipe supports.

Capacity control is required in all the chillers that shall be capable to maintain an approximately constant temperature of the chilled water leaving the evaporator. This may be adequate for one or two chiller packages, but a more elaborate central control and plant optimization system is desirable for a large number of chillers. The design of the refrigeration control system should be integrated, or be compatible, with the control system for the heat transfer medium circulated within the cooler.

Multiple chiller configuration, same or different size and types shall be used to achieve the highest energy efficiency and adequate system capacity availability at all conditions. System COP shall be the basis for design and selection of equipment.

Power consumption during operation should be reduced by taking advantage of a fall in the ambient dry bulb and wet bulb temperatures, which permit a corresponding increase in chilled water temperature and decrease in the condenser water temperature, and consequent considerable reduction in the compressor power consumption. It is important to optimize operating cost by optimum equipment selection and careful design of the automatic control system.

The water chilling packages are classified based on the type of compressor, as given below:

a) *Centrifugal compressor* – These compressors use impellers to impart pressure energy to the refrigerant. These may be modulated down to approximately 40 percent of full load capacity, with careful control of the condensing pressure. Part load operation of centrifugal compressor should be restricted to 40 percent or above in order to avoid surging of compressor that may damage it if continues to occur.

In order to save energy, centrifugal compressors with variable speed drives (VFD's) should be preferred over fixed speed chillers. VFD's are used on chillers not only to enhance the part load performance but also to act as an alternate to auto-tap change starter for minimizing the starting current for the compressor.

Modern variable-speed oil-free centrifugal chillers have the shaft with impeller levitated during rotation, using digitally controlled magnetic bearings. This unique feature reduces the friction and heat caused by conventional bearings, adding to the overall high efficiency. It also eliminates the need for lubricating oil and the ancillary components required to support the lubricating oil system, which further improves efficiency.

b) *Screw compressor* – Screw compressors are available in open and semi-hermetic form and are generally coupled directly to two-pole motors. The capacity of the compressor may be modulated down to about 20 percent of full load capacity.

Similar to centrifugal compressors, screw compressors with VFD's may be used as an effective way to enhance the part load performance and also minimize the starting current for the compressor.

These are generally specified and used for capacities up to 1 400 kW (approximately 400 TR).

In systems using a direct expansion evaporator (DX chiller), oil is trapped in the evaporator and an oil recovery system is necessary. With some systems, oil cooler is required in the oil circulation system, to remove the heat gathered by oil during compression cycle.

c) *Scroll Compressor* – Scroll compressors are generally used in residential and small/light commercial air-conditioning. Scroll chillers may be used in smaller sizes up to 425 kW. They offer relatively higher efficiency over other types of compressors, however, scroll compressors are not suitable for higher capacity range.

d) *Reciprocating compressor* – Due to their relatively lower efficiency, reciprocating compressors are nearly phased out from the comfort air-conditioning application. However, for cold storage and other special purpose applications, these still have importance due to their capacity to offer high pressure ratio.

4.2 Vapour Absorption/Adsorption System

The absorption cycle uses a solution which, typically has two working fluids: an absorber and an absorbent. These fluids typically in liquid state, have significant change in solubility of the absorbent at different temperatures. Function of a vapor compressor is replaced by a liquid pump. The absorbent/refrigerant mixture is pumped to a higher pressure as a solution, where the refrigerant is boiled off by the application of heat and is subsequently condensed in the condenser.

Absorption machines are extensively used in liquid-chilling applications. These are most suitable for applications where waste heat is readily available. Solar energy assisted air-conditioning/cooling systems also use absorption system.

4.2.1 *Indirect Firing*

The lithium bromide/water absorption system shall be powered by medium or high temperature hot water and low or medium pressure steam. Water is the refrigerant and lithium bromide the absorbent. The four compartments enclosing the heat exchanger tube bundles for the condenser, evaporator, generator and absorber shall be in a single or multiple pressure vessel arrangement. The whole assembly has to be maintained under a high vacuum, which is essential for the correct functioning of the unit. Water and absorbent solutions are circulated within the unit by electrically driven pumps.

Capacity control down to 10 percent of full load capacity is achieved by modulating the flow of the heating medium in relation to the cooling demand. There is some loss in performance at part load, which shall be compensated by refinements in the system design and control.

4.2.2 *Direct Firing*

Direct fired lithium bromide/water absorption systems have become common, by incorporating precise control of generator temperature necessary to avoid crystallization.

Ammonia/water systems are generally direct fired, but are rarely used for water chilling duties, except for small sized units, which are installed outside the building.

There are two reasons for this; firstly, capital costs are higher and secondly the danger to personnel in the event of leakage of the refrigerant.

Direct firing has the advantage that the losses in an indirect heating system are avoided, but in an air conditioning installation where a boiler system is installed to provide heating, the advantage is not of much concern.

Adsorption machines differ from absorption machines in the manner the two working media interact. Adsorption is a surface phenomenon, unlike absorption. More details about such systems are provided under the section ‘Low Energy Cooling’.

5 REFRIGERANTS

The refrigerant is a working fluid used in the refrigeration cycle of a refrigeration and air conditioning system. Due to its deteriorating impacts on climate (especially ozone depletion and global warming) it is essential to provide an overview of the requirements for the safe use of refrigerants, except ammonia, in mechanical or vapor-compression refrigeration and air conditioning systems that are partly or completely installed inside buildings. It is intended for the guidance of the engineers, contractors, installers, and service technicians on the safe use of these systems and summarizes the guidelines applicable for the safe design, construction, installation, and operation of systems thereby providing insight of environmental impact of refrigerant emission and its management to minimize the emission of environmentally damaging refrigerants.

The refrigerant is a working fluid that is used in the refrigerating cycle of a refrigeration and air conditioning system. Refrigerant molecules shall be broadly classified into three categories: halocarbons, organic compounds, and inorganic compounds. The halocarbons shall be further subdivided into chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), hydrofluorocarbon (HFC), hydrofluoroolefin (HFO) and hydrochlorofluoroolefin (HCFO). The organic compounds consist mostly of hydrocarbons (HC). Inorganic compounds include carbon dioxide and ammonia. Both zeotropic and azeotropic mixtures of two or more pure refrigerants are also used as refrigerants.

5.1 Numbering of Refrigerants

Refrigerants are numbered with an R-, followed by the identification number. The identifying numbers for hydrocarbons (for example, assigned identification of propane is R-290) and halocarbons (for example, assigned identification of difluoromethane is R-32) are explicitly related to their chemical formula. Isomers are identified by appending lowercase letters at the end of the identifying number (for example 1,1,2,2-Tetrafluoroethane and 1,1,1,2-Tetrafluoroethane are isomers, which have assigned identification of R-134 and R-134a, respectively). Alkenes are identified by adding “1” at the beginning of the number determined by the above method. The structural isomers are identified by appending lower case letters at the end. The suffixes "(Z)" and "(E)" are used to differentiate cis- and trans- isomers. For example, R-1234yf, R1234ze(E) and R1234ze(Z) are all isomers of tetrafluoropropene. An inorganic compound is identified by the digit 7 at the hundreds place of the identifying number followed by its molecular weight (for example, assigned identification of Ammonia is R-717). Refrigerant blends having the same pure components are assigned the same number, but different compositions are identified with an uppercase letter after the number. Series 400 (for example, R-410A is a blend of 50 percent by weight of R-32 and 50 percent by weight of R-125) and 500 refrigerant (for example, R-507A is a blend of 50 percent by weight of R-143a and 50 percent by weight of R-125) blends are zeotropic and azeotropic, respectively.

5.2 Safety Group Classification

The table 8 provides the toxicity and flammability-based classifications for refrigerant safety.

Table 8 Refrigerant classification based on Toxicity and flammability
(*Clause* 5.2)

Sl. No.	Flammability	Lower Toxicity Safety Group	Higher Toxicity Safety Group
(1)	(2)	(3)	(4)
i)	No Flame Propagation	A1	B1
ii)	Lower Flammability	A2L	B2L
iii)	Flammable	A2L	B2L
iv)	Higher Flammability	A3	B3

The accepted standard [8-3(9)] has also established the maximum refrigerant concentration limit (RCL) in the air to avoid escape-impairing effects such as asphyxiation, acute toxicity, and flammability in normally occupied enclosed spaces. The RCL is established based on the most conservative limit between asphyxiation, acute toxicity, and flammability. This safety group classification is referred to in the installation and maintenance standards for HVAC equipment.

Product safety standards for AC equipment, such as accepted standard [8-3(10)] and [8-3(11)] specify safety requirements for electrically operated refrigeration and air conditioning appliances that have an incorporated compressor. Accepted standard [8-3(10)] deals with the safety of electrical heat pumps, air-conditioners, and dehumidifiers, while accepted standard [8-3(11)] deals with the safety of commercial refrigerating appliances.

Refrigerants should preferably be non-flammable or have lower flammability. The flammable refrigerant system shall be built with necessary protection system. Similarly, refrigerants with lower toxicity are preferable. Suitable risk mitigation processes and instruments should be implemented to mitigate risk to the occupants and the property per the accepted standards. Accepted standards [8-3(12)], [8-3(13)], [8-3(14)] and [8-3(15)], set forth requirements for safeguarding people and property where refrigeration facilities are located and prescribes safety requirements.

5.3 Environmental Impact of Refrigerants

Refrigerants shall be released from the system during installation, minimizing refrigerant leaks, proper refrigerant recovery, and recycling during installation, operation, and disposal.. Commercially used refrigerants shall be either ozone-depleting substances or greenhouse gases or shall be both. Releasing such refrigerants into the atmosphere shall be damaging to the environment. CFCs and HCFCs are ozone-depleting substances.

NOTE – India ratified the Montreal Protocol agreement On Substances that Deplete the Ozone Layer in 1992 and CFCs in RAC units manufactured beyond 1 January 2003 have been phased out. The HCFCs are being phased out under the HCFC Phase-Out Management Plan (HPMP), and their use in RAC units manufactured beyond 1 January 2025 will be prohibited. The Kigali Amendment to the Montreal Protocol calls for the phase-down of HFCs due to their high GWP. India will complete its phase-down of HFCs in 4 steps from 2032 onwards with a cumulative reduction of 85 percent in 2047. The HFC phase-down schedule for India is scheduled to begin in 2032 and it will be completed in 2047. The baseline will be the average production and consumption of HFCs for the years 2024, 2025 and 2026. The quota will be frozen at the baseline level in 2028. The phase down will be achieved in four steps, with the cumulative reductions of production and consumption by 10 percent in 2032, 20 percent in 2037, 30 percent in 2042 and 85 percent reduction in 2047.

5.4 Classification of commonly used refrigerants

The refrigerants shall be classified in accordance with accepted standard [8-3(9)] as listed in Table 9.

Table 9 Classification of Commonly Used Refrigerants
(*Clause* 5.4)

Sl no.	Refrigerant	Type	Refrigerant safety group classification	Amount of refrigerant in occupied space	
				RCL (g/m^3)	LFL (g/m^3)
(1)	(2)	(3)	(4)	(5)	(6)
i)	R11	CFC	A1	6.1	-
ii)	R12	CFC	A1	90	-
iii)	R22	HCFC	A1	210	
iv)	R32	HFC	A2L	77	306
v)	R123	HCFC	B1	57	
vi)	R134a	HFC	A1	210	
vii)	R290	HC	A3	9.5	38
viii)	R404A	HFC	A1	500	-
ix)	R407C	HFC	A1	290	-
x)	R410A	HFC	A1	420	-
xi)	R448A	HFO	A1	390	-
xii)	R449A	HFO	A1	370	-
xiii)	R454A	HFO	A2L	52	293.9
xiv)	R454B	HFO	A2L	49	352.6
xv)	R454C	HFO	A2L	71	289.5
xvi)	R455A	HFO	A2L	79	432.1
xvii)	R513A	HFO	A1	320	-
xviii)	R514A	HFO	B1	14	-
xix)	R600a	HC	A3	9.5	38
xx)	R744	CO_2	A1	72	-
xxi)	R1234yf	HFO	A2L	75	289
xxii)	R1234ze(E)	HFO	A2L	76	303
xxiii)	R1336mzz(Z)	HFO	A1	84	-

NOTE – The RCL / LFL data is taken from accepted standard [8-3(9)].

5.5 Occupancy based classification.

Refrigerating systems shall have different locations based on how the space connected to them is occupied, which shall depend on how people in that space react to possible refrigerant exposure.

5.5.1 *Institutional Occupancy* – Portion of a building which occupants shall not readily leave without assistance. For example, prisons, hospitals etc.

5.5.2 *Public Places / Public Assembly Occupancy* – Where large number of people gather, and the occupants shall not quickly leave the space due to large gathering. For example, restaurants, movie theatres, auditoriums etc.

5.5.3 *Residential Occupancy* – Where people / occupants live either permanently or temporarily. For example, home / apartment / hotel / hostel etc.

5.5.4 *Commercial Occupancy* – Where people / occupants gather to do commercial transactions like small shops / offices etc.

5.5.5 *Large Mercantile Occupancy* – Where occupants / people gather in large quantities like 70+ people gather to a big grocery store like Big Bazaar.

5.5.6 *Industrial Occupancy* – Occupancy where general public is not allowed. Only controlled people are allowed which shall be used for manufacturing or as a warehouse

5.6 Classification as per Leakage Probability

These guidelines classify systems based on their likelihood of leakage, ensuring appropriate safety measures and maintenance practices are in place for each classification.

5.6.1 *Low Probability Systems (Indirect Systems)* – Any system where the design or placement of parts makes it unlikely that refrigerant will leak from a broken connection, seal, or component into the occupied space.

5.6.2 *High Probability Systems (Direct Systems)* – Those systems where the components are designed or located in a way that makes it likely for refrigerant to leak into an occupied space from a broken connection, seal, or component.

5.7 Classification as per system locations

These guidelines categorize mechanical equipment by location to ensure safety and accessibility, from units within occupied spaces to those in dedicated machinery rooms or ventilated enclosures.

5.7.1 *Class I – Mechanical Equipment Located within the Occupied Space*

If the refrigerating system or any of its refrigerant-containing parts is located indoors in occupied space or non-occupied space that is not sealed from the occupied space or shall leak into the occupied space, then the system is considered to be of Class I unless the system complies with the requirements for other classes. Integral display units are typical examples of this category.

5.7.2 *Class II – Compressors and Pressure Vessels Outside the Occupied Space*

If all compressors and pressure vessels are outside the occupied space and refrigerant leaks from compressors or pressure vessels shall not flow into the occupied space then the requirements for a class II location shall apply to any refrigerant containing part located in the occupied space or that shall leak into the occupied space. Coil-type heat exchangers and pipework, including valves, may be located in an occupied space.

Refrigerant shall leak to the occupied space through heat transfer fluid if, for example:

a) The heat transfer fluid is ventilation air;
b) The heat transfer fluid is an open spray system;
c) Leakage of the refrigerant into the occupied space is caused by leakage of the refrigerant into the heat transfer fluid;
d) There is a heat transfer fluid relief valve or an automatic purge point vents into the space.

5.7.3 *Class III – Machinery Room or Open Air*

The requirements for a Class III location shall apply to any refrigerant containing part located in the open air or in a machinery room that is as per the requirements of accepted standard [8-3(14)]. Water- or air-cooled chillers are typical examples of this type.

5.7.4 *Class IV – Ventilated Enclosures*

If, with the intent of preventing migration of leaked refrigerant to the surrounding area, refrigerant-containing parts are located in a ventilated enclosure that is as per the requirements of accepted standard [8-3(13)], 6.2.17 and 4.6 of [8-3(14)] then the requirements for a Class IV location shall apply.

Heat pump within a ventilated enclosure are typical examples.

5.8 Classification as per Access to Occupied Spaces, Machinery Rooms and Open Air

Access classification shall be determined according to Table 10.

The access category is defined according to Table 10 by consideration of the group of occupants who are least familiar with the safety precautions. For example, in a supermarket, department store or transport terminus an unregulated number of customers who are not familiar with the location or its safety precautions shall gather. In a general office the number of people in the building is more easily regulated and occasional visitors will be accompanied by a regular occupant who shall advise on the safety precautions in the event of an emergency. In a manufacturing facility all of the occupants will be familiar with the safety requirements and access to the workplace will be restricted.

A complex building shall contain several access categories, for example the public areas and the plant rooms in a hospital shall be classified as access Category A and access Category C respectively.

Table 10 Categories of Access
(*Clause* 5.8)

Sl no.	Categories	General characteristics	Examples
(1)	(2)	(3)	(4)
i)	A	General access (least restrictive access to the space) Parts of buildings where a) Sleeping facilities are provided b) People are restricted in their movement, c) An uncontrolled number of people are present, or d) To which any person has access without being personally acquainted with the necessary safety precautions.	Hospitals, courts or prisons, theatres, supermarkets, schools, lecture halls, public transport termini, hotels, dwellings, restaurants, car parks, footpaths, gardens
ii)	B	Supervised access Parts of buildings where only a limited number of people shall be assembled, some being necessarily acquainted with the general safety precautions of the establishment.	Business or professional offices, laboratories, places for general manufacturing, where people work, delivery zones and some non-public areas in supermarkets
iii)	C	Authorized access (most restrictive access to the space) Parts of buildings where only authorized persons have access, who are acquainted with general and special safety precautions of the establishment and where manufacturing, processing, or storage of material or products take place.	Manufacturing facilities, for example, for chemicals, food, cold stores, some non-public areas in supermarkets, fenced outdoor compounds or roofs with restricted access

Open air locations including roofs, car parks and outdoor equipment compounds are considered to be parts of the building. Machinery rooms shall not be considered as an occupied space except as defined in 5.1 of accepted standard [8-3(14)].

Refrigerant quantity limits shall be as per accepted standard [8-3(12)] expect for:

a) *Institutional Occupancy* – Consider a safety factor of 0.5 (limiting the charge to 50 percent of the calculated charge) while calculating the charge limits.
b) *Residential Occupancy* – Listed self-contained systems limited to 3 kg charge limit.
c) *Commercial Occupancy* – Listed self-contained systems limited to 10 kg charge limit

d) Industrial occupancy and large mercantile occupancy spaces to follow requirements of charge limits in accepted standards [8-3(12)], [8-3(13)], [8-3(14)] and [8-3(15)].

5.9 Mixing of refrigerants

Refrigerants with different refrigerant designations as per accepted standard [8-3(18)] shall not be mixed.

5.10 Purity

Refrigerants used in refrigeration systems shall be new, recovered or reclaimed refrigerants as per below

5.10.1 *New Refrigerants* – Refrigerants shall be of purity level specified by the equipment or appliance manufacturer

5.10.2 *Recovered Refrigerants* – Shall not be used in the refrigeration system as it may not meet the quality requirements of a system.

5.10.3 *Recycled Refrigerants* – Refrigerants that are recovered from refrigeration and air-conditioning systems shall not be used in other than the system from which they were recovered and in other systems of the same owner. Recovered refrigerants shall be filtered and dried before reuse.

5.10.4 *Reclaimed Refrigerants* – Used refrigerants shall not be reused in a different owner's equipment or appliances unless tested and found to meet the purity requirements. Contaminated refrigerants shall not be reused unless reclaimed and found to meet the purity requirements. For additional information on purity requirements of refrigerants refer to accepted standard [8-3(47)].

5.10.5 High probability direct systems for human comfort applications shall only use A1 and A2L refrigerants. If the equipment is listed, it shall follow the requirements of accepted standard [8-3(10)] and [8-3(11)]. If the system is designed and installed at site, the requirements of accepted standards [8-3(12)], [8-3(13)], [8-3(14)] and [8-3(15)] will follow.

5.11 Machinery room / plant room systems shall follow accepted standards [8-3(12)], [8-3(13)], [8-3(14)] and [8-3(15)] requirements.

5.12 Lifecycle Management of Refrigerants

Lifecycle Refrigerant Management is an important aspect of Refrigerants. In addressing the impact and developing the mitigation plans of HCFC and HFC, Kigali amendment addresses production and consumption and the schedule to phase down. However, there is a huge amount of refrigerant in the operating systems that will continue to exist till the equipment reaches its end of life. It is important to address the management of these banks.

Life cycle management shall include all product phases from product design to decommissioning and end of life. Corrosion is a critical aspect that is not fully addressed and shall potentially lead to leaks. In the design stage selection of material, designing of interconnecting tubes to ensure the fracture does not occur in tubes during operations, packing to take care of handling and transportation and coating of brazed joints should be the considerations.

All systems using flammable refrigerants shall be evacuated with a vacuum pump and purged with nitrogen as per manufacturer specifications.

Brazing during manufacturing shall be under controlled conditions. Uncontrolled conditions will lead to leaks.

During installation and commissioning care should be taken of using calibrated tools and tackles specifically the torque wrenches, understanding of the environment in which the equipment is installed and corrosion. The equipment should be installed and serviced by trained and certified technicians only.

Decommissioning is the phase wherein there is maximum possibility of refrigerant getting released in the atmosphere. Awareness of customers and technicians is critical.

5.13 Total Equivalent Warming Impact (TEWI)/Life Cycle Climate Performance (LCCP)

There are 2 metrics used to calculate the greenhouse impact of a product/ equipment over its lifetime. This is given in terms of its equivalent CO_2 emissions; in kg or Tonnes depending upon its absolute value.

The second metrics an extension of the first one in that it includes even the warming impact due to the manufacturing of the product as well as the indirect emission due to the atmospheric decomposition of the refrigerant including the energy consumed during the manufacture of the raw materials. For example, consider a Window unit. The coils are made of copper tubes and aluminium fins. Thus, if the copper tube manufacturing process and/or aluminium fin stock manufacturing process is highly energy inefficient then it will reflect badly in the LCCP of the Window unit. LCCP is more comprehensive as it has a “cradle to grave” approach and it has its merit in evaluating the overall impact.

The following equation gives the expression for calculating TEWI for a particular product (it shall not be generalized; it is application/product specific):

$$TEWI = GWP \times L \times n + GWP \times m \times (1-\alpha) + n \times E \times \beta$$

where,

GWP = Refrigerant Global Warming Potential [kg of CO_2/kg of refrigerant]
L = Annual leakage rate [Kg/year]
n = System operating life time [years]
m = Refrigerant charge [kg]

α = Recycling factor [percent]
E = Annual energy consumption [kWh/year]
β = CO_2 emissions on energy generation [kg CO_2/kWh]

The above equation is considering both the direct (due to refrigerant leakage/non recycling) and the indirect effect (due to energy consumption). TEWI is completely product/system/location dependent and shall not be generalized. However, it does give an idea as to how the indirect impact is much more than the direct impact. With the new low-GWP refrigerants being introduced, the value(s) of TEWI would be different than what they were with the old high-GWP refrigerants. Also, an important parameter is the β factor. This is based on the location/country where the system is operating. It is directly dependent on the fuel source/type of power generation plants being used to supply the electrical power. Naturally if the major source of power generation is fossil fuel . Coal-based thermal power generation then this factor will be high, and which turn will result in higher TEWI.

The following equation gives the expression for calculating LCCP for a particular product:

$$\text{LCCP} = \text{Direct Emissions} + \text{Indirect Emissions}$$

$$\text{Direct Emissions} = \text{C} \times (\text{L} \times \text{ALR} + \text{EOL}) \times (\text{GWP} + \text{Adp.GWP})$$

$$I\text{ndirect Emissions} = \text{L} \times \text{AEC} \times \text{EM} + \sum(\text{M} \times \text{mm}) + \sum(\text{mr} \times \text{RM}) \times +\text{C}(1 + \text{L} \times \text{ALR}) \times \text{RFM} + \text{C} \times (1 - \text{EOL}) \times \text{RFD}$$

Where,

C	=	Refrigerant Charge (kg)
L	=	Average Lifetime of Equipment (year)
ALR	=	Annual Leakage Rate (percent of refrigerant charge)
EOL	=	End of Life Refrigerant leakage (percent of refrigerant charge)
GWP	=	Global Warming Potential (kg CO_{2e}/kg)
Adp. GWP	=	GWP of Atmospheric Degradation Product of the refrigerant (kg CO_{2e}/kg)
AEC	=	Annual Energy Consumption (kWh)
EM	=	CO_2 Produced /kWh (kg CO_{2e}/kg)
M	=	Mass of Unit (kg)
MM	=	CO_2 Produced /Material (kg CO_{2e}/kg)
mr	=	Mass of Recycled Material (kg)
RM	=	CO_{2e} Produced/Recycled Material (kg CO_{2e}/kg)
RFM	=	Refrigerant Manufacturing Emissions (kg CO_{2e}/kg)
RFD	=	Refrigerant Disposal Emissions (kg CO_{2e}/kg)

The above equation is as per the Guideline for LCCP recommended by International Institute for Refrigeration.

When it comes to selecting refrigerants and equipment, both choices are crucial due to their direct impact on a user's scope 1 and scope 2 emissions. Scope 1 emissions encompass direct greenhouse gas (GHG) emissions, which, in the case of refrigerants, primarily result from gas leakage at the premises. To mitigate these emissions, it is vital to adopt low global warming potential (GWP) refrigerants that minimize the environmental impact. However, as we push for the rapid adoption of these low-GWP refrigerants, it is equally important to ensure that the efficiency and capacity of the equipment are not compromised. This balance is essential because any reduction in equipment performance shall increase scope 2 emissions, which are indirect GHG emissions from the energy consumed by the equipment.

Leveraging digitally enabled and AI-driven solutions shall significantly enhance our approach to managing refrigerants. These advanced technologies provide predictive insights that help prevent gas leakages, reducing the need for technician visits and minimizing downtime for repairs. By integrating generative AI, we shall proactively address potential issues, further reducing scope 1 emissions by preventing leaks before they occur. Moreover, reducing technician visits not only lessens service providers' tailpipe emissions lowering the end user's scope 3 emissions, which are indirect emissions from third-party activities.

When selecting equipment and refrigerants, it’s crucial to consider the Total Equivalent Warming Impact (TEWI), which factors in both scope 1 and scope 2 emissions. This comprehensive approach ensures that the chosen solutions are sustainable over their entire lifecycle. Additionally, implementing digitization, advanced leak detection systems, and remote monitoring of refrigerants shall effectively map and manage the operational emissions associated with the equipment’s deployment at a user's premise. These technologies ensure that emissions are minimized, aligning with broader sustainability goals and regulatory requirements.

In summary, achieving a balanced and strategic selection of refrigerants and equipment, underpinned by AI and digital solutions, is essential for reducing scope 1, scope 2, and scope 3 emissions. This integrated approach supports the fast-tracking of low-GWP refrigerants while maintaining operational efficiency and capacity, ultimately contributing to a more sustainable and compliant future in building operations.

6 LOW ENERGY COOLING

In addition to the popular air-conditioning options and traditional passive cooling options, various types of modern low energy heating / cooling solutions have also emerged which may be used to provide thermal comfort to occupants using alternative strategies. These include direct, indirect and hybrid evaporative cooling, radiant cooling/heating, structural cooling, solar assisted cooling/heating, and few others.

6.1 Evaporative Air Coolers

Evaporative coolers use the process of evaporation of water to lower air temperature. This method of comfort cooling not only conserves energy but also offers numerous benefits for environment. The principle for evaporative air cooling is straightforward: when water evaporates, it absorbs latent heat of evaporation from the surrounding air, thereby cooling the air. This is also termed as adiabatic cooling. This process is most effective in arid and semi-arid climates where the humidity is low, making evaporation more efficient.

An evaporative cooler typically consists of a fan, absorbent pads, a water reservoir and some kind of water distribution system including pump to distribute water on the pads, and often some set of louvers/deflectors to guide air to desired direction.

The process is:

a) The fan draws warm, dry air from the outside into the cooler,
b) The air passes through the water-saturated pads, where the water evaporates, and thereby absorbing heat from the air, and
c) The cooler but more humid air is then blown into the living space, lowering the temperature.

6.1.1 *Advantages of Evaporative Cooling*

These points highlight the key benefits and positive aspects of the specified system or approach, emphasizing efficiency, performance, and practicality.

a) *Energy efficiency* — Evaporative coolers consume significantly less energy compared to conventional air conditioners. They use only the power needed to run the fan and water pump, resulting in lower electricity bills and reduced carbon footprint.

b) *Environmental benefits* — Traditional air conditioners use refrigerants like CFCs and HFCs, which are harmful to the environment. Evaporative coolers, on the other hand, do not use these chemicals, making them an eco-friendly alternative.

c) *Cost-effective* — The initial purchase cost and maintenance expenses of evaporative coolers are significantly lower than those of air conditioning systems for a given cooling area. Evaporative air coolers have fewer mechanical parts, which means there are fewer components that shall break down.

d) *Improved air quality* — Evaporative coolers add moisture to the air, which shall be beneficial in dry climates where low humidity shall cause respiratory problems and dry skin. They also filter out dust and pollen as the air passes through the pads, improving indoor air quality.

   At times, several processes need humidity (for example, paper mill, garment industry, etc.) and hence evaporative air cooling serves dual purpose of cooling and providing humidity.

e) *Easy installation and maintenance* — These coolers are relatively simple to install, requiring only a water source and an electrical outlet. Maintenance is straightforward, typically involving the periodic cleaning or replacement of pads and ensuring the water reservoir is filled.

6.1.2 *Applications of Evaporative Cooling*

These points describe the various uses and suitable scenarios for implementing evaporative cooling, focusing on its effectiveness in specific environments and conditions. Following are some of different uses:

a) *Residential use* — They are ideal for cooling homes in dry climates. Portable models shall be moved from room to room, providing flexible cooling solutions. Even table top models are available for personal cooling purposes. Window or wall mounted units are available too.

b) *Commercial and industrial use* — Large evaporative coolers shall be used in showrooms, restaurants, institutes, warehouses, factories, and workshops where traditional air conditioning may be impractical or too expensive especially in semi-open spaces.

c) *Outdoor cooling* — Evaporative coolers are popular for outdoor events, patios, and agricultural applications. They shall create comfortable environments in open spaces where conventional cooling systems are ineffective.

d) *Greenhouses* — These coolers are beneficial in horticulture for maintaining optimal temperature and humidity levels, promoting healthy plant growth. Other related uses are poultry farms, pig farms, etc.

6.1.3 *Sizing of Evaporative Cooling*

Air coolers are used either for spot cooling or space cooling.

a) *For spot cooling* — An important parameter to consider is the air throw the distance to which the air cooler will throw air with adequate velocity and air quantity.

b) *For space cooling* — Important parameter is air changeover. Generally, 20 to 40 air changeovers per hour (ACH) are required depending upon application and heat load.

c) *The residential air coolers* — It shall be as per accepted standard [8-3(7)]. The large commercial air evaporative air-cooling system shall be as per the special publication.

NOTES

1 Further, ISHRAE simulation tool called EvapCal shall be used for sizing guidelines based upon city, heat load, required thermal comfort to correctly size the system.

2 Special publication may be ISHRAE Standard 2005:2024.

6.1.4 *Limitations of Evaporative Cooling*

These points outline the challenges and constraints associated with evaporative cooling, highlighting factors that may affect its efficiency and suitability in certain conditions.

a) *Climate dependence* — The efficiency of evaporative coolers decreases significantly in humid climates. When the air is already saturated with moisture, it shall not absorb much more, making evaporation less effective and reducing the cooling capacity of the device.

b) *Limited to cooling only* — Evaporative coolers are designed to only cool the space and shall not condition it like air conditioner. Hence shall not be used for heating or dehumidification.

c) *Increased humidity* — While added humidity shall be beneficial in dry climates, it shall be problematic in areas that are already humid. High humidity levels shall create a sticky, uncomfortable indoor environment and potentially promote mold growth if not designed properly.

d) *Water usage* — Evaporative coolers require a continuous supply of potable quality of water to operate, which shall be a concern in regions facing water scarcity or unavailability. However, their overall water consumption is relatively low compared to other water-intensive appliances.

6.1.5 *New Trends/Technologies in Evaporative Cooling*

Smart Controls, efficient cooling media and two stage, multi stage hybrid evaporative cooling system enhances the efficiency and comfort level. These technologies should be considered based on the climate conditions and application. Two Stage are:

a) *Evaporative cooling systems* — Advanced version of direct evaporative cooling system, many times referred as dual stage evaporative cooling combines use of direct and indirect evaporative cooling system to provide supply air temperature which are much lower than wet bulb temperature and with lower specific humidity making the space temperature very comfortable in dry conditions.

b) *Hybrid systems* — Some systems combine single or multiple stage evaporative cooling with traditional air conditioning, optimizing cooling performance while minimizing energy use. These hybrid systems switch between modes based on ambient conditions, providing efficient cooling in various climates. Indirect (air cooling by passing over a cool coil or heat exchanger) cooling is also often combined with a direct evaporative cooling process such devices are often termed as indirect direct evaporative coolers (IDEC). Cool coil may in turn use chilled water, evaporatively cooled water, pre-cooled air, or any such other cooling media.

6.2 Radiant Cooling and Heating

Radiant cooling system is a temperature-controlled system in which the temperature of the building surface facing indoor (ceiling, floor, wall etc.) is reduced by the means of cool/chilled water which flows through a network of pipes embedded in the surfaces. Any system shall only be called a radiant system if more than 50 percent of heat transfer takes place by radiative heat exchange by the temperature-controlled surface. Reduced surface temperature causes radiative heat exchange between human body and cold/hot surfaces and provide sensible cooling/heating inside the building. A separate air system shall be used for the ventilation requirements and handling the latent load.

The radiant cooling system design and installation shall ensure no condensation in the conditioned space.

6.2.1 *Advantages of Radiant Cooling System*

These points highlight the key benefits of radiant cooling, focusing on energy efficiency, comfort, and improved indoor air quality.

a) *Energy efficiency* — In radiant cooling system, cooling is provided through water which has a higher heat capacity than air which loses more energy in transportation. In radiant cooling system less fan energy is required than conventional all-air system due to very significant reduction in amount of air handled.

b) *Indoor air quality* — As a radiant cooling system is a hybrid system that also includes a separate air system to provide 100 percent outdoor air, the indoor air quality is enhanced.

c) *Thermal comfort* — Uniform temperature shall be maintained with radiant cooling system ensuring better thermal comfort.

d) *Integration with low grade energy/passive cooling sources* — In radiant cooling system a higher temperature 15ºC to 20ºC water temperature shall be used. The low-grade energy sources like cooling tower, geo-thermal and others shall be used.

e) *Noise and reduced duct work* – This cooling system reduces noise, as they do not rely on fan and compressor for cooling, and this system use water pipes instead of the ducts, thereby having reduced duct work.

6.2.2 *Limitations of Radiant Cooling*

Radiant cooling is useful in the building where sensible load is higher and have humidity control. There are several areas like restaurant, lobby, and kitchen etc. where humidity control is very difficult, at such places, its application shall attract a problem of condensation. Similarly, if the latent load in a zone is significant then the use of radiant cooling system is limited. The radiant cooling system also has a limitation of cooling capacity in order to counter the condensation problem. Hence, the surfaces have to be maintained at a higher temperature as compared to the dew point temperature of indoor air.

6.2.3 *Types of Radiant Cooling Systems*

Following three types of Radiant systems are used:

a) *Radiant cooling panels system (RCP)* — The most extensively used system of radiant systems is the PANEL Systems. The insulation over the aluminium panel plays an important role in avoiding the heat transfer to the building structure. Poor connection shall lead to less heat transfer resulting in an in-efficient system.

b) *Thermally activated building system (TABS)* — In thermally active building system (TABS) the conditioning plant operation is varied based on thermal loads. TABS has a high thermal inertia, which enables it to hold a large amount of heat within it during the daytime and release this heat during night time to the hydronic system.

c) *Embedded surface cooling systems* (ESC) — In embedded surface cooling system, an insulation cover on the pipes mounted on the side adjacent to the building structure minimizing thermal energy exchange of heat carrier with the building structure. Some floor systems are made by extruded plastic plates which forms capillary channels. In this case the heat exchange surfaces is very wide and at the same time the thickness of the system is very less which allows very low temperature differences.

6.2.4 *Requirement of Fresh Air Delivery*

Radiant cooling systems require a dedicated an outdoor air system responsible for supply of fresh/ventilation air into the radiant cooled space operating in parallel to the radiant cooling.

In case of high latent load and in case of oversized DOAS, energy savings from a radiant cooling system is reduced.

6.2.5 *Control Requirements* — Following controls are required to efficiently operate a radiant cooling system:

a) Radiant surface temperature minimum two degree centigrade higher than indoor dew point temperature to avoid condensation on radiant surfaces. In case of occurrence,
b) Water supply temperature or flow rate or both need to be controlled.
c) Modulate ventilation air supply as per the CO_2 monitoring.

6.3 Structural Cooling

Due to the high solar insolation during the daytime on built structures, heat gets embedded in the structure or the thermal mass of the buildings and is transmitted indoors. This heat raises the temperature of the indoor surfaces resulting in higher mean radiant temperatures experienced by occupants making them uncomfortable.

This heat has to be flushed out before it shall enter the living space.

This approach significantly reduces the cooling loads on the air conditioning system, in case the indoors are air conditioned.

Structural cooling generally employs the use of cooled water between 15°C to nearly 30°C, which is circulated in embedded piping network laid within the structure.

For air-conditioned areas, the minimum water temperature is 15°C. Depending on the requirements this water temperature shall be higher up to 24°C. This generally requires mechanical refrigeration similar to the chilled water supply in radiant cooling system.

Water between 20°C and 30°C can be generated employing natural cooling processes, which make use of the ambient conditions of air.

Naturally cooled water in ponds, rivers, or from geothermal sources should be considered. Properly designed and selected cooling towers make use of the lower wet bulb temperatures to achieve this cooling of water to slightly above prevailing wet bulb temperatures.

NOTES

1 In a conducive weather condition, cooled water shall be obtained by utilising the night sky cooling and storing the cooled water in an insulated and properly sized tank during the night. The same water shall be used to cool the structure during the harsh times of the day.

2 The water is circulated by employing a small pump, in the closed loop system. Principally, these systems are quite similar to thermally activated buildings covered under radiant cooling section.

6.3.1 *Advantages of Structural Cooling*

Structural cooling impedes solar heat from roof and floors by absorbing it before it causes thermal discomfort to occupants. Following are the advantages of structural cooling:

a) Floor temperatures are maintained below body skin temperature, allowing the body to radiate the heat to the cooler surfaces.
b) Reduces the cooling load on the building and lower size of ancillary cooling systems are required, leading to smaller pipes and ducting.
c) Because of the large thermal mass of the structure, it shall act as a storage of cooling effect.
d) As the Structure is cooled, it is maintained in a small band of temperature variations, thus eliminating the heat stress on the structure. The thermal expansion and contraction of the structure are very low, as compared to a building which is not structurally cooled.

6.3.2 *Applications*

Structural cooling is very versatile and shall be used to cool places like public utility areas, malls, hospitals, residential areas, office buildings, commercial spaces, educational institutes and many more applications to reduce loads and provide comfort.

6.4 Geothermal for Heating and Cooling

Geothermal heating and cooling systems, also known as ground source heat pumps (GSHPs), uses the stable temperatures of the earth's subsurface to provide efficient climate control for buildings. By using the ground as a heat source in the winter and a heat sink in the summer, these systems shall achieve high efficiencies compared to conventional HVAC systems and needs to balance the earth as source.

NOTE – Geothermal systems shall be used in residential, commercial, and industrial buildings. They are particularly beneficial for new constructions but shall also be retrofitted into existing structures. Large-scale applications include district heating systems where multiple buildings are connected to a central geothermal system.

6.4.1 *Advantage of GSHP Systems*

GSHP systems offer significant energy efficiency, environmental benefits, and long-lasting performance. Following are the advantages of GSHP systems:

a) *Energy efficiency* — GSHPs achieves high efficiencies on the coldest winter nights, meaning they produce 3 units to 6 units of heat for every unit of electricity consumed.

b) *Cost savings* — GSHP systems provide substantial cost savings by delivering multiple units of heat for each unit of electricity, reducing energy bills over time.

c) *Environmental impact* — Reduce greenhouse gas emissions and reliance on fossil fuels.

d) *Longevity* — Ground loops life of 50 years and above, and indoor components life of 20 years and above.

6.4.2 *Challenges with GSHP*

GSHP systems face certain challenges related to installation, maintenance, and initial investment

a) *High initial cost* — Installation are expensive due to drilling and trenching requirements depending on terrain.

b) *Site-specific design* — Soil conditions, land availability, and local climate affect feasibility and design.

c) *Maintenance* — While minimal, the system requires periodic maintenance, especially the indoor components. Geothermal heating and cooling systems represent a sustainable and efficient technology for managing building climate control. Despite the high initial investment, their long-term benefits in terms of energy savings, environmental impact, and system longevity make them an attractive option for a wide range of applications. As technology advances and installation costs decrease, geothermal systems are likely to become an increasingly common choice for sustainable building design.

6.5 Solar Cooling

There are different ways to utilise solar energy for producing cooling effect:

a) Solar thermal cooling systems
b) Solar photovoltaic cooling systems

Solar photovoltaic cooling systems is a vapour compression-based systems powered by electricity generated by solar photo voltaic system. Solar thermal based cooling systems use heat-based cooling systems that do not need electricity driven mechanical compressor.

6.5.1 *Solar Thermal Cooling Systems*

There are two different types of solar thermal cooling systems absorption type and desiccant type. All of these are driven by the heat from solar energy as explained below.

6.5.1.1 *Absorption cooling*

Vapour absorption machines (VAMs) are used for cooling using waste steam or hot water as a byproduct of process in various industries. VAMs use a salt-based solution (typically lithium bromide solution) to alternative evaporate water out and then condense it back into the solution. Types of VAMs depending on the temperature of the heat source:

a) *Single effect* — Uses hot water source between 80°C to 90°C to drive the cooling cycle.
b) *Double effect* — Uses 120°C to 140°C steam to drive the cooling cycle.
c) *Triple effect* — Uses 180°C to 210°C steam to drive the cooling cycle.

For most buildings, single effect VAM and double using solar hot water is the viable configuration. Double effect VAMs offer higher COP of 1.2 to 1.4, it is recommended to use single effect VAMs it is recommended to design the VAM around this temperature even though the COP of such system is only 0.7 to 0.8. Higher operating hours in a year make such a system more viable at lower COP.

Double and triple effect VAMs shall be used in buildings where waste heat or low-cost heat >120°C is available in immediate vicinity. This would typically be in industrial settings.

6.5.1.2 *Adsorption cooling*

Adsorption cooling systems use solid desiccant material like silica gel to enable a heat driven cooling cycle. Water is used as a refrigerant in such systems. The cycle works by alternating “adsorption” and “desorption” of water from a solid desiccant. Heat between 60°C to 80°C is required for “desorption” and heat from solar collectors shall be used.

The COP of adsorption chiller is between 0.35 to 0.55 depending on the chilled water temperature required, hot water source temperature and condenser water temperature. While lower COP increases the solar field size, adsorption chiller’s ability to operate even at 60°C source temperature allows.

6.5.1.3 *Desiccant cooling*

This typically refers to liquid desiccant cooling where solar heat is used to regenerate the desiccant. Typical regeneration temperature is 60°C that be consistently achieved using solar collectors.

6.5.2 *Advantages of Solar Thermal Cooling Systems*

Solar thermal cooling systems offer sustainable and energy-efficient solutions by harnessing solar energy for cooling purposes, reducing reliance on conventional energy sources. Following are the advantages of solar thermal cooling systems:

a) *Energy efficiency* — Overall cooling system electricity consumption shall be 0.4 kW/Ton to 0.6 kW/Ton compared to 1 kW/Ton to 1.4 kW/Ton for conventional air conditioning systems.
b) *Lower carbon footprint* — Lower electricity consumption leads to lower carbon footprint of the system. This shall be useful for achieving decarbonization goals of the building or organization.

6.6 Personal Environmental Control Systems

Personal environmental control systems (PECS). PECS includes low-energy, low-powered personalised HVAC systems as well as controls and sensors. The PECS largely shall be categorised into the following five categories and further detailed in table 11:

a) Heating only PECS
b) Cooling only PECS
c) Ventilation only PECS
d) Heating and ventilation PECS
e) Cooling and ventilation PECS
f) Heating, cooling and ventilation PECS

NOTE — Heating PECS and cooling PECS rely only on conduction and radiative heat transfer without convection (air movement). While all PECS with ventilation, rely on air as a heat transfer medium, hence air movement in ventilation PECS is inherent.

Table 11 Personal Environmental Control Systems
(*Clause* 6.6)

a) Heating only PECS Devices

Warmed Seat	**Device Description**	**Warmed Seat heated using electrical elements or embedded water tubes**	The warmed seat is recommended to be used in combination with a foot heater.
	T_{room}	> 5 °C	
	$T_{PECS-surface}$	< 44 °C	
	V_{PECS}	N/A	
	Target Body Parts	Back, buttocks, thighs	
	PECS Position	As the occupant's seat	
	Restriction of Movement	Occupant shall remain in contact with the seat fabric	
	Manual Control	Temperature	
	Background Ventilation	Required	
Radiant Foot Heater		**Radiant Foot Heater heated using electrical elements**	The radiant foot heater should be operated in the range of T_{room}+10 °C to T_{room}+20 °C for optimum comfort.
	T_{room}	> 10 °C	
	$T_{PECS-surface}$	< 30 °C	
	V_{PECS}	N/A	
	Target Body Parts	Feet	
	PECS Position	~20 cm from the feet	
	Restriction of Movement	Feet shall remain adjacent to the heated surface	
	Manual Control	Temperature	
	Background Ventilation	Required	
Radiant Heating Panel		**Radiant Heating Panels placed as desktop partitions heated using electrical elements or embedded water tubes**	The exposed surface area of the radiant heating panel to the occupant should be optimized by placing more panels to the left and right sides of the occupant.
	T_{room}	> 19 °C	
	$T_{PECS-surface}$	< 23 °C	
	V_{PECS}	N/A	
	Target Body Parts	Face, chest, arms, legs	
	PECS Position	~50 cm from the occupant, as the desk partition	
	Restriction of Movement	Occupant should remain in the field of view of the Radiant Panel	
	Manual Control	Temperature	
	Background Ventilation	Required	
Palm Warmer		**Desktop-based Palm Warmers heated using electrical elements**	The device shall be placed such

	T_{room}	> 18 °C	that it acts as a resting spot for the hands while typing.
	$T_{PECS\text{-}surface}$	< 35 °C	
	V_{PECS}	N/A	
	Target Body Parts	Palms	
	PECS Position	On the desktop, between the computer keyboard and the occupant.	
	Restriction of Movement	Palms shall be in direct contact with the device surface	
	Manual Control	None	
	Background Ventilation	Required	

b) Cooling only PECS Devices

Cooled Seat	**Device Description**	**Seat cooling using embedded water pipes cooled using compressive cooling**	It is recommended to use a movable desktop fan in combination with the cooled seat.
	T_{room}	< 45 °C	
	$T_{PECS\text{-}air}$	> 18 °C	
	V_{PECS}	N/A	
	Target Body Parts	Back, buttocks, thighs	
	PECS Position	As the occupant's seat	
	Restriction of Movement	Occupant shall remain in contact with the seat fabric	
	Manual Control	Temperature	
	Background Ventilation	Required	
Cooled Garment		**Jacket-like garment using phase change materials or compressive cool air supply**	Typical cooled garments are battery-operated, with an average charge lasting for ~6 hours; they weigh around 3-5 kg; cooled garments with phase change materials typically perform better than those with embedded fans.
	T_{room}	< 34 °C	
	$T_{PECS\text{-}air}$	> 21 °C	
	V_{PECS}	N/A	
	Target Body Parts	Chest, back, shoulders	
	PECS Position	As the occupant's vest	
	Restriction of Movement	None	
	Manual Control	Temperature	
	Background Ventilation	Required	
		Radiant Cooling Panels placed as desktop partitions cooled	The exposed surface area of

Radiant Cooling Panel		**using embedded water pipes using compressive cooling**	the radiant cooling panel to the occupant should be optimized by placing more panels to the left and right sides of the occupant.
	T_{room}	< 32 °C	
	$T_{PECS-air}$	> 17 °C	
	V_{PECS}	N/A	
	Target Body Parts	Face, chest, arms, legs	
	PECS Position	~50 cm from the occupant, as the desk partition	
	Restriction of Movement	Occupant should remain in the field of view of the radiant panel	
	Manual Control	Temperature	
	Background Ventilation	Required	

c) Ventilation only PECS Devices

Desktop-based Devices	**Device Description**	**Desk-mounted air-terminal device supplying (fresh or recirculated) air at room temperature**	The airflow shall not strike the desktop and the airflow pattern should preferably be kept as close to the natural wind pattern in terms of its turbulence and frequency of variability.
	T_{room}	< 30 °C	
	$T_{PECS-air}$	Same as T_{room}	
	V_{PECS}	< 1.5 m/s	
	Target Body Parts	Face, neck, chest, arms	
	PECS Position	~50 cm from the occupant, on the desktop	
	Restriction of Movement	Occupant shall move while manually changing the airflow direction of the fan/device	
	Manual Control	Air velocity, direction	
	Background Ventilation	Optional	
Movable Panel		**Desktop based movable air-terminal device supplying (fresh or recirculated) air at room temperature**	The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 28 °C	
	$T_{PECS-air}$	Same as T_{room}	
	V_{PECS}	< 0.7 m/s	
	Target Body Parts	Face, neck, chest, arms	
	PECS Position	~50 cm from the occupant, on the desktop	
	Restriction of Movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual Control	Air velocity, direction	

	Background Ventilation	Optional	
Headrest-embedded Device		**Seat headrest-based air-terminal device supplying recirculated air at room temperature**	Air terminal devices with a large opening area require low air velocity and vice versa.
	T_{room}	< 26 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 0.6 m/s	
	Target Body Parts	Face	
	PECS Position	As the seat headrest, next to the cheeks	
	Restriction of Movement	Occupant shall keep the head on the headrest.	
	Manual Control	Air velocity	
	Background Ventilation	Required	
Pedestal Fan		**Pedestal fan supplying recirculated air at room temperature**	The fan direction should be kept such that it does not cause discomfort by displacement of light-weight objects on the desktop.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 2.5 m/s	
	Target Body Parts	Whole body	
	PECS Position	~ 1.5 m from the occupant	
	Restriction of Movement	Occupant is free to move within the flow region while adjusting the direction of the fan	
	Manual Control	Air velocity, direction	
	Background Ventilation	Optional	
Ceiling Fan		**Ceiling-mounted fan supplying recirculated air at room temperature**	To optimize the effect of the fan, it should be placed on the ceiling right above the desktop, with the rotating blades at an angle of 30° to 45° from the ceiling.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Head, shoulders	
	PECS Position	~1.5 m above the occupant, on the ceiling	
	Restriction of Movement	Occupant shall remain in the flow direction	
	Manual Control	Air velocity	
	Background Ventilation	Optional	
Ventilated Seat		**Ventilated seat embedded with fans supplying recirculated air at room temperature**	The occupant's body should not block the

	T_{room}	< 32 °C	complete airflow and it should reach the breathing zone.
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 2 m/s	
	Target Body Parts	Buttocks, back, thighs	
	PECS Position	As the occupant's seat	
	Restriction of Movement	Occupant shall remain in contact with the seat fabric	
	Manual Control	Air velocity	
	Background Ventilation	Required	
Ventilated Garment		**Jacket-like garment embedded with low-wattage fans supplying recirculated air at room temperature**	A typical battery-operated ventilated garment operates up to 7 hours on 60 percent output power.
	T_{room}	< 34 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	Equivalent to a flow rate of < 22 L/s	
	Target Body Parts	Chest, Back	
	PECS Position	As the occupant's vest	
	Restriction of Movement	No restriction in movement	
	Manual Control	Air velocity	
	Background Ventilation	Required	

d) Heating and Ventilation PECS Devices

Desk-mounted Device	**Desk-mounted air-terminal device supplying air warmed through compressive heating**		The device should be used in combination with a Foot-heating Panel; the airflow should not directly strike the eyes of the occupant as it might lead to dry-eye discomfort.
	T_{room}	> 19 °C	
	$T_{PECS\text{-}air}$	< 25 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Face, arms, chest, front thighs	
	PECS Position	~50 cm from the occupant, on the desktop	
	Restriction of Movement	Occupant shall remain in the flow direction	
	Manual Control	Temperature, air velocity, direction	
	Background Ventilation	Optional	
Ventilated and Warmed Seat	**Warmed seat with embedded fans – the seat is warmed using electrical elements or embedded water pipes**		The device should be used in combination with a foot-heating panel
	T_{room}	> 20 °C	
	$T_{PECS\text{-}air}$	< 45 °C	
	V_{PECS}	< 0.7 m/s	

	Target Body Parts	Neck, back, buttocks, back thighs	
	PECS Position	As the occupant's seat	
	Restriction of Movement	Occupant shall remain in contact with the seat	
	Manual Control	Temperature, air velocity	
	Background Ventilation	Required	
Nozzle	**Nozzle-based air terminal device supplying air warmed through compressive heating**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	> 19 °C	
	$T_{PECS\text{-}air}$	< 50 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Head, neck	
	PECS Position	~1 m from the occupant, directed towards the head	
	Restriction of Movement	Occupant shall remain in the flow direction	
	Manual Control	Temperature, air velocity	
	Background Ventilation	Optional	
Movable Panel	**Desk-mounted movable air terminal device supplying air warmed through compressive heating**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	> 20 °C	
	$T_{PECS\text{-}air}$	< 26 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Head, neck, chest, arms	
	PECS Position	~50 cm from the occupant, directed towards the head	
	Restriction of Movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual Control	Temperature, air velocity, direction	
	Background Ventilation	Optional	

e) Cooling and Ventilation PECS Devices

Desk-mounted Device	**Desk-mounted air-terminal device supplying air cooled through compressive cooling**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	> 15 °C	
	V_{PECS}	< 1.5 m/s	
	Target Body Parts	Face, neck, chest	
	PECS Position	~50 cm from the occupant, on the desktop	

	Restriction of Movement	Occupant shall remain in the flow direction	
	Manual Control	Temperature, air velocity	
	Background Ventilation	Optional	
Desk-edge based Device	**Desk-edge mounted horizontal air terminal slits supplying air cooled through compressive cooling**		The device should preferably provide a vertical airflow directly under the occupant's chin and should have adjustable vanes for manual adjustment of airflow direction.
	T_{room}	< 26 °C	
	$T_{PECS-air}$	> 20 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Face, neck	
	PECS Position	~ 10 cm from the occupant, on the desk edge	
	Restriction of Movement	Occupant shall remain directly above the device outlet	
	Manual Control	Temperature, air velocity, direction	
	Background Ventilation	Optional	
Movable Panel	**Desk-mounted movable air terminal device supplying air cooled through compressive cooling**		The air stream should enter the occupant’s breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 30 °C	
	$T_{PECS-air}$	> 20 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Face, neck, chest, shoulders, arms	
	PECS Position	~50 cm from the occupant, on the desktop	
	Restriction of Movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual Control	Temperature, air velocity, direction	
	Background Ventilation	Optional	
Armrest-embedded Device	**Seat armrest-mounted air terminal device supplying air cooled through compressive cooling**		The airflow should strike the occupant at a 45° angle from below.
	T_{room}	< 25 °C	
	$T_{PECS-air}$	> 20 °C	
	V_{PECS}	< 0.7 m/s	
	Target Body Parts	Face, neck, chest, arms	
	PECS Position	As the armrest of the occupant's seat	
	Restriction of Movement	Occupant shall remain seated and the armrests shall not be blocked	

	Manual Control	Temperature, Air Velocity	
	Background Ventilation	Required	
Floor-mounted Device	**Floor-mounted air terminal device supplying air cooled through compressive cooling, also known as underfloor air distribution**		The device should be used in combination with a desk-mounted or movable panel device for better control
	T_{room}	< 27 °C	
	$T_{PECS\text{-}air}$	> 16 °C	
	V_{PECS}	< 1 m/s	
	Target Body Parts	Feet, legs, thighs, buttocks	
	PECS Position	~50 cm from the occupant's seat, on the floor	
	Restriction of Movement	Occupant shall move radially around the device	
	Manual Control	Temperature, air velocity	
	Background Ventilation	Optional	
Ceiling-mounted Device	**Ceiling-mounted air terminal device supplying air cooled through compressive cooling**		The airflow should have a low turbulence intensity and long range.
	T_{room}	< 29 °C	
	$T_{PECS\text{-}air}$	> 21 °C	
	V_{PECS}	< 0.8 m/s	
	Target Body Parts	Head, neck, shoulders	
	PECS Position	~1.5 m above the occupant's head, on the ceiling	
	Restriction of Movement	Occupant shall move around the vertical flow	
	Manual Control	Temperature, air velocity	
	Background Ventilation	Optional	
Radiant Cooling Panel with Fan	**Radiant panels placed as desktop partitions with embedded water pipes cooled using compressive cooling - used in combination with low-power desktop fans**		The exposed surface area of the radiant panel to the occupant should be maximized; the airflow from the fan should not strike the desktop.
	T_{room}	< 28 °C	
	$T_{PECS\text{-}air}$	> 17 °C	
	V_{PECS}	< 1.5 m/s	
	Target Body Parts	Face, neck, chest, arms	
	PECS Position	Radiant panels as the desk partition ~50 cm from the occupant; Fan on the desktop, ~40 cm from the occupant	
	Restriction of Movement	Occupant shall remain exposed to the radiant surface and shall move fan as per comfort	
	Manual Control	Temperature, air velocity, direction	

	Background Ventilation	Optional	

7 DISTRICT COOLING SYSTEMS

District cooling systems (DCS) provides and distributes cooling energy from a central plant to a surrounding cluster of residences, commercial spaces, industries, or institutions occupied by tenants or clients.

In a district cooling system, a large central plant produces chilled water for supply to multiple buildings through an insulated closed-loop underground piping network. Traditional AC systems consume a majority of a building's peak electricity demand, usually at peak cost. With district cooling, peak demand on the grid, as well as operating energy consumption, decreases. It avoids the capital costs of installing multiple HVAC systems that is chillers and cooling towers and associated mechanical and electrical equipment at each building to a central location, freeing up valuable rooftop and building space. By aggregating the cooling needs of multiple buildings, district cooling generates economies of scale.

In India, DCS is ideal for mixed-use developments, large infrastructure projects such as aero cities, industrial clusters, residential clusters, educational campuses, IT parks, smart city infrastructure or retrofit of a DCS system for an existing cluster of individually cooled buildings or a redevelopment of existing buildings.

DCS provide several economic benefits to end-users, including reduced capital and operating costs, less frequent maintenance, space savings, and lower electricity usage than in more traditional AC systems. (*see* Table 12)

Table 12 Benefits of DCS systems
(*Clause* 7)

Environmental	Societal	Economic
(1)	(2)	(3)
		For DCS service providers/investors:
• Energy saving • Peak energy demand reduction • Carbon and GHG emission saving • Enabling transition to low or zero GWP refrigerants • Water conservation • Improved micro-climatic conditions by reduced urban Heat Island Effect • Improved Air quality	• Enhanced aesthetics • Local business development • Skill development and improved employability • Security of supply for cooling • Access to affordable cooling for achieving thermal comfort • Improved quality of life • Reduced noise from cooling equipment	• New business venture with competitive advantage • Long-term stable and profitable revenues • Employment generation Avoided investments in summer electricity peak production, transmission, and distribution Higher energy and resource utilization **For end-users of DCS:** • Avoided capital expenditure (CAPEX) and space requirement for cooling equipment like chillers and cooling towers and related costs • Reduced O&M cost

7.1 Key Components of District Cooling System

District cooling systems (DCS) shall utilize recycled treated water from sewage effluent as cooling tower makeup water. Municipalities should provide this recycled water for in-house treatment, addressing water shortages and promoting water circularity initiatives in cities. Following are the requirements of DCS:

a) DCS benefit from technologies like thermal energy storage (TES) and free cooling. TES reduces peak electricity costs by shifting cooling production to off-peak hours, while free cooling leverages ambient conditions to lower overall electricity demand.

b) In some cases, district cooling systems may directly use seawater or fresh surface water for heat rejection, subject to local laws.

c) Large central plants should use waste heat or geothermal energy for absorption refrigeration in district cooling systems. This approach is more feasible at the district scale than for individual buildings.

7.1.1 *District Cooling Plant*

The district cooling plant (DCP) generates chilled water for cooling services. It includes chillers, cooling towers, pumps, and auxiliary systems. Thermal energy storage (TES) shall enhance chiller capacity. DCPs play a crucial role in efficient and sustainable cooling solutions for urban areas. All new plants with capacity equal to or greater than 10 000 TR shall include a TES system.

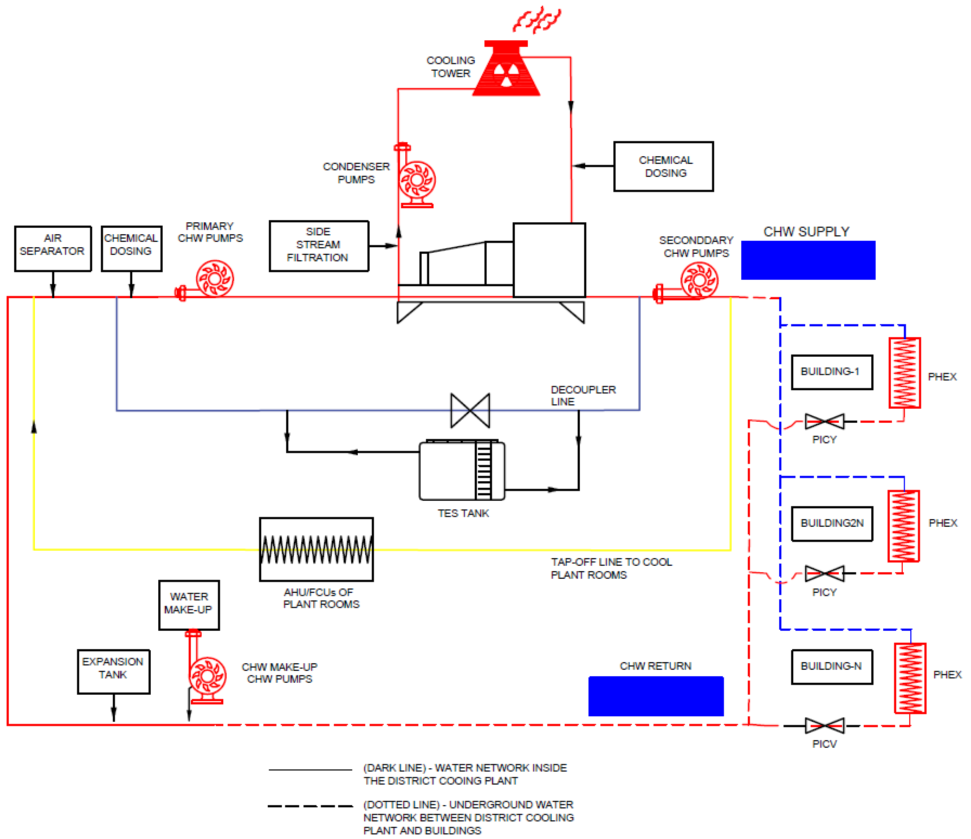


FIG. 2 LAYOUT OF A DISTRICT COOLING SYSTEM

7.1.2 *Distribution Network*

Based upon ease of operation, geographical constraints, safety, and applications, there are two kinds of distribution networks underground pre-insulated and above-ground site insulated chilled water distribution systems. Carbon steel or mild steel pipes should be used for chilled water and condenser water distribution piping, with proper protective coating wrap for preventing thermal losses. In the Indian context, an indicative DC system design (including the distribution system) is presented in Fig. 2. However, the actual design specifications may vary depending on a multitude of factors. Distribution pipelines should be designed with a life expectancy of minimum 40 years. Following shall be the default design conditions for the distribution network, unless specified by the designer/user:

a) Ambient temperature (for design): based on where the DC system is located
b) Chilled water supply temperature at DCP: 5°C ± 1°C

c) Temperature rise in the chilled water supply distribution network: 0.5ºC to1ºC per unit length (0.5ºC up to 5 000 m)
d) Approach across Energy Transfer Station: </= 1.1ºC
e) Chilled water supply temperature at consumer end: 6ºC ± 1ºC
f) Chilled water return temperature at consumer end: 15ºC ± 1ºC
g) Temperature drop in the chilled water return distribution network: 0.5ºC to 1ºC
h) Chilled water return temperature at DCP: 14ºC ± 1ºC
j) Design pressure of the chilled water distribution network: 5 bar to 15 bar (g) (depends on the overall DCS design and building elevation)

7.1.3 *Energy Transfer Station*

An energy transfer station (ETS) serves as a bridge between a district cooling (DC) service and consumers' air conditioning systems. Energy transfer shall be direct or indirect transfer. In district cooling plants where there is uniform time of operation of all spaces and the cooling service provider and end user have no need for decoupling then direct transfer that is supply of chilled water to all air handling units shall be applied. In all other cases indirect heat transfer via an ETS shall be applied.

The ETS transfers thermal energy generated at the central plant to buildings. Within the ETS, heat exchangers allow buildings to utilize this energy for space conditioning. Key components include pumps, isolation valves, and control elements. Proper sizing ensures meeting cooling demand without redundancy. Consideration for equipment access, maintenance, and transport pathways is essential. Controls, such as pressure independent control valves, help in maintaining efficiency.

7.1.4 *Instrumentation, Monitoring and Control System (SCADA)*

A DC instrumentation and control system shall be designed, installed, and commissioned to monitor and control various system components for enhancing operational efficiency of the DC system. The main components of an instrumentation and control system are a programme logic controller (PLC), human machine interface (HMI), and distribution control system. The control system shall be designed to maintain the entire DC plant operations and functionality, and integration with ETSs to maintain transparency in operations. The control system shall monitor comprehensive chiller plant parameters, cooling tower parameters, TES parameters, chemical treatment equipment parameters, building management system (BMS) of the DC plant building, firefighting status of the plant building, etc.

7.1.5 *Measurement and Billing System*

The measurement and monitoring system shall facilitate real time monitoring of kW/TR of the plant. Infrastructure for continuous measurement and logging of cooling production and consumption (TR-h) and complete breakdown of all associated power demand (kW, voltage, ampere, power factor), and energy consumption (kWh) is crucial for district cooling (DC) systems. Separate BTU meters for each cooling consumer, installed at the Energy Transfer Station (ETS), generate monthly cooling bills. Individualizing BTU metering by consumer or apartment enhances responsibility for thermal energy consumption. Properly sized BTU meters accurately measure the entire cooling load range. All BTU meters shall be calibrated annually.

7.2 Design Approach for DCS

7.2.1 *Site Selection Criteria*

Site selection involves careful evaluation of various aspects with different degrees of importance. A methodology should be prepared to ensure that the critical aspects are not overlooked. The aim is to define a set of criteria that helps in shortlisting the most optimum site, which has the following characteristics:

a) Resource-efficient
b) Minimum environmental impact
c) Cost-effective
d) Adequate in terms of logistics
e) Ensures maximum efficiency
f) Offers possibility of easy future expansion
g) Proximity to utilities and drainage

The first stage of site selection is determining the study area and indicators. The second stage involves the diagnosis process, wherein indicators are ranked and weighted according to benchmarks, guidelines, and preferences. Furthermore, this stage involves analysis of data collected for various indicators. The last stage is decision-making, where potential sites are ranked, followed by the development of a feasibility plan. The process shall take place via the traditional method of site suitability analysis or using computer-based applications and the major factors influencing DCS implementation are given in table 13.

Table 13 Major Factors Influencing DC System Implementation
(*Clause* 7.2.1)

Building Design and Use (1)	**Building Energy Demand** (2)	**Local Context** (3)	**Resource Requirement** (4)	**Policy and Governance** (5)
• Availability of space for distribution centre or possibility of extension • Floor Area Ratio or Floor Space Index • Carpet area • Total floor area	• Peak demand • Demand density • Delivery density • Time distribution of energy demand over days, weeks, months and years.	• Topography • Slope and contours • Existing and proposed utility lines • Water • Drainage • Telecom, PNG line, electricity line, etc. • Access to natural	• Financial assistance • Capital Investment • Rate of return • Payback period • Labour and other resources • Availability of skilled labourers	• Existing policies, programmes, and missions • Proactiveness of local government • Administrative capacity • Ease of getting permissions and clearances

Building Design and Use (1)	Building Energy Demand (2)	Local Context (3)	Resource Requirement (4)	Policy and Governance (5)
• Diverse use of buildings • Ownership • Availability of water and power to meet current and future demand • Electricity and water cost	• Potential future cooling demand	cold-water body • Access to renewable energy and/or waste energy source • Road network	• Availability of machinery • Time • Project timeline	

7.2.2 *Sizing Philosophy for DCS*

The sizing of both mechanical and electrical systems is essential to ensure optimal performance, energy efficiency, and reliability of the district cooling system.

7.2.2.1 *Mechanical system sizing (chiller sizing, network and delta T)*

In sizing a chiller for a district cooling system, following critical factors shall be considered.

a) First, the required cooling capacity based on the peak cooling load. This load shall vary significantly depending on the specific application (for example, residential, commercial, or industrial) and local climate conditions.
b) The desired temperature difference between the inlet and outlet water is to be decided. This difference affects the chiller's efficiency and overall performance.
c) The ambient conditions, such as the local climate and ambient temperature. Hotter climates may necessitate larger chillers to handle higher cooling demands effectively.
d) Assess installation constraints, such as available space, and any limitations related to the chiller's physical placement within the district cooling network proper chiller sizing is crucial for achieving efficient and reliable district cooling operations.

The successful implementation of district cooling systems depends greatly on the ability of the system to obtain high-temperature differentials that is delta temperatures (T) between the supply and return water. It is crucial to ensure that the district cooling system shall operate with reasonable size distribution piping and pumps to minimize the pumping energy requirements.

The pipe sizing is governed by four key factors:

a) The system's delta T.
b) Maximum allowable flow velocity.
c) Distribution network pressure at the design load conditions.
d) Minimum differential pressure requirements to service the most remote customers.

NOTES

1 Generally, it is most cost-effective to design for a high delta T in the district cooling system because this allows for smaller pipe sizes in the distribution system. The system operating efficiency also increases with an increased delta T due to the reduced pumping requirements caused by the reduced flow rates and the reduced heat gains/losses in the distribution system. The system's delta T is typically limited to 8ºC to 11ºC.

2 The maximum allowable flow velocities are governed by pressure drop constraints and critical system disturbances caused by transient phenomena (that is water hammer effects). Generally, velocities higher than 2.5 m/s to 3.0 m/s should be avoided unless the system is specifically designed and protected to allow for higher flow velocities.

7.2.2.2 *Electrical system sizing (transformers, diesel generators and substation)*

For efficient and safe functioning of DCS, the electrical supply system plays a critical role. The sizing of electrical supply system components such as transformers, diesel generator and substation shall be designed considering the parameters listed below:

a) *Transformers* – Transformers play a critical role in stepping up or down voltage levels within the distribution network. Sizing shall be done considering:
   1) System voltage level requirements
   2) Capacity for transformer selection.
   3) Diversity considerations
   4) Efficiency/losses
   5) Redundancy/outage considerations

b) *Diesel generators* – DG is a power backup during emergency when main power supply not available. Sizing shall be done considering:
   1) Backup voltage level requirements
   2) Quantum of backup power required when the main power is not available
   3) Allowable loading during continuous operation
   4) Redundancy/outage considerations
   5) Allowable noise considerations

c) *Substation design* – Substation design involves planning, engineering, and constructing electrical substations for efficient power transmission and distribution. It needs to be done based on district cooling plant (DCP) capacity requirement. Accurate sizing ensures efficient and reliable electrical operations in district energy systems. Here are some key points about substation design:
   1) Voltage and power capacity requirements
   2) Component selection
   3) CapEx and OpEx
   4) Footprint requirements

7.3 General Requirements

These requirements ensure that DCS installations meet operational efficiency, safety, and performance standards.

7.3.1 *Specific Power Consumption for DCS*

The specific power consumption shall be measure as ratio of kW electric power to kW thermal output the system efficiency of a DC chiller plant shall not be less than 0.85 input kilowatts per TR (ikW/TR). However, depending on system size and detailed economic analysis, there are opportunities to improve the efficiency levels of DCS.

7.3.2 *Testing and Commissioning Procedures for Hydrotesting and Pipe Conditioning*

Necessary hydro testing shall be carried out for the distribution network. The distribution pipes should be subjected to pressure testing as per the design specifications and guidelines approved by the owner and their design consultant representatives. Where required for certain equipment like chillers, factory testing will be required to ensure design conditions are being complied with. Once the individual equipment is all put together as a system, proper testing of the complete system should be carried out.

The procedures for hydrotesting and flushing of pipes during the testing and commissioning phase for district cooling systems:

7.3.2.1 *Hydrostatic testing*

The strength and integrity of piping system shall be tested by hydrostatic testing at water pressure equivalent to 1.5 times the design operating pressure for stipulated time.

a) *Hydrostatic pressure testing procedure* – The hydrostatic pressure test shall be conducted as mentioned below:

   1) *Step* 1 – Filling the System
      i) Fill the entire piping network with water.
      ii) Ensure that all air pockets are removed.

   2) *Step* 2 – Pressurization
      i) Gradually increase the water pressure to at least 1.5 times the design pressure.
      ii) Maintain this pressure for a specified duration (usually a few hours).

   3) *Step* 3 – Inspection
      i) Inspect the entire system for leaks.
      ii) Pay attention to joints, welds, and connections.

   4) *Step* 4 – Record Keeping
      i) Document the test results, including pressure readings and any observed leaks.

5) *Step* 5 – Depressurization
   i) Gradually reduce the pressure and drain the system.

b) *Safety considerations*

1) Ensure safety protocols are followed during pressurization and depressurization.
2) Personnel should be aware of potential hazards.

c) *Pipe conditioning*

Pipe conditioning removes debris, dirt, and contaminants from the pipes and to form a protective anti corrosive layer on the inner surface of the pipes. The procedure for pipe conditioning is as follows:

1) *Step 1* – Preparation
   i) Ensure the system is clean and free from construction debris.

2) *Step 2* – Flushing Process
   i) Flush the pipes with water to remove loose particles.
   ii) Use stipulated high-velocity flow to dislodge any remaining debris.
   iii) Passing criteria to next step is to get clean water after flushing.

3) *Step 3* – Chemical cleaning
   i) Flush the pipes with water mixed with cleaning chemicals.
   ii) Use stipulated high-velocity flow to dislodge any remaining debris.
   iii) Passing criteria to next step is to get clean water and to meet certain water parameters at the end of chemical cleaning.

4) *Step 4* – Passivation
   i) Circulate the water mixed with passivation chemicals for stipulated period
   ii) Passing criteria is to get clean water and to meet certain water parameters at the end of passivation
   iii) Minimum quantity of passivation chemicals shall be ensured at the end of passivation and throughout the operation period.

5) *Step 5* – Verification
   i) Verify that the system is clean and ready for operation.

6) *Step 6* – Record Keeping
   i) Document the pipe conditioning process.

7.3.2.2 *Performance testing of DCS*

Performance tests fall under two categories, operational performance and availability performance. Operational performance is to ensure that during operation plant is meeting the designed electrical and water performance. Availability test is to ensure that availability of the plant equipment is meeting the availability and reliability conditions set forth over a stipulated time without any downtime.

Following indices shall be used to establish performance of a DCS:

Overall Plant efficiency	kWh/TR-h
Water Consumption	litre/hr
Cooling Tower Water Discharge	litre/hr

Table 14 shall be used for benchmarking of performance of DCS.

Table 14 Recommended performance of DCS
(*Clause* 7.3.2.2)

Sl No.	DCS Plant Type	TES	Condenser Cooling	Water Source	Max kW/ TR-h
(1)	(2)	(3)	(4)	(5)	(6)
			Energy Consumption		
i)	New	Chilled Water	Cooling Tower	Recycled / City supplied	0.87
ii)	New	None	Cooling Tower	Recycled / City supplied	0.91
iii)	New	Ice	Cooling Tower	Recycled / City supplied	1.17
iv)	New	None	Cooling Tower	Sea Water	0.96
v)	Existing	Chilled Water	Cooling Tower	Recycled / City supplied	1.00
			Condenser Water Consumption		litres / TR - hr
i)	New / Existing	Ch Water / None	Cooling Tower	City Supply	8.00
ii)	New / Existing	Ch Water / None	Cooling Tower	Recycled	11.00
iii)	New / Existing	Ch Water / None	Cooling Tower	Recycled	12.00
			Cooling Tower Water Discharge		
i)	New / Existing	Ch Water / None	Cooling Tower	City Supply	1.5 - 2.0
ii)	New / Existing	Ch Water / None	Cooling Tower	Recycled	4.5 – 5.0

7.4 Operation and Maintenance of DCS – Best O&M Practises

Practices as given below shall be followed for operating and maintaining a district cooling system:

a) *Regular Inspections and Maintenance*
   1) Conduct routine inspections of equipment, pipelines, and components.
   2) Address minor issues promptly to prevent major failures.
   3) Implement PPM strategies

b) *Water Treatment and Quality*
   1) Maintain water quality in chilled water and hot water systems.
   ii) Regularly clean and treat cooling towers to prevent scaling, corrosion, and biological growth.

c) *Energy Efficiency Measures*
   1) Optimize the operations of chillers, pumps, cooling towers etc.
   2) Monitoring and control strategies.
   3) Implement variable flow systems and energy-efficient equipment.

d) *Leak Detection and Repair*
   1) Monitor for leaks in distribution networks and fix them promptly.
   2) Leaks waste energy and reduce system efficiency.

e) *Thermal Storage Optimization*
   1) Use thermal energy storage (TES) effectively to balance supply and demand.
   2) Charge TES during off-peak hours and discharge during peak demand.

f) *Metering and Billing Accuracy*
   1) Ensure accurate metering for billing purposes.
   2) Individualize metering for end-users where possible.

7.5 Economics of DCS (Business Model for DCS – CaaS (Cooling as a Service)

Cooling as a service (CaaS) is an innovative business model where end-users subscribe to cooling services without owning the infrastructure. The district cooling provider finance, build and maintains the cooling plant, promoting energy efficiency and sustainability. Users benefit from reduced upfront costs and simplified operations, while the provider ensures reliable service delivery. CaaS shifts the focus from ownership to access, fostering efficient and sustainable cooling solutions

7.5.1 *Tariff Structure - Fixed and Variable Charges + Connection Charges*

The tariff structure for district cooling systems is monthly and typically includes the following components. The recovery mechanism shall be tailored based on the various models in the real estate market say lease, sale, hybrid model etc and hence various contract strictures shall be tailored between real estate developer, DCS developer and end users.

a) *Connection Charge* – It's a one-time fee paid by users when connecting to the district cooling system.
b) *Contract Capacity Charges* – These charges are effectively availability fees, covering capital expenditures (CapEx) and fixed operation and maintenance (O&M) costs. They ensure that the district cooling provider maintains the capacity to deliver cooling services.
c) *Consumption Charge* – The consumption charge covers variable O&M costs, including chemicals, electricity, and water (potable or treated sewage effluent) consumed by the end users.

7.5.2 *Service Level Agreement (SLA) and Key Performance Indicators (KPI)*

These ensure clear expectations and measurable standards for the performance and maintenance of district cooling systems:

a) *Service level agreement (SLA)* – A Service level agreement (SLA) outlines the expected level of service between a service provider (district cooling plant) and its customers. Key components of an SLA for a district cooling plant might include:
   1) Cooling capacity commitment
   2) Reliability and availability
   3) Penalty terms basis performance matrix

b) Key Performance Indicators (KPIs)
   1) Coefficient of performance (COP)
   2) Chilled water supply and return temperature (CHWST / CHWRT)
   3) Chilled water return temperature (CHWRT)
   4) Water usage efficiency (Litre/TRh)

8 SUPPLY AIR DUCTS AND RETURN AIR DUCTS

Following provisions to be considered for supply air ducts and return air ducts construction:

a) Duct Systems are a continuous passageway for the transportation of air which, in addition to the ducts, may include duct fittings, dampers, plenums, grilles and diffusers and such other accessories as may be required. Leak tightness, adequate supporting and proper installation are important requirements.

b) Due to aerodynamic considerations, it is recommended that the aspect ratio of rectangular ducts (height to width ratio) be kept within 1:4.

c) Designer shall specify the material of ducts, appropriate standard to be followed, maximum permitted velocity of air in the duct and the required pressure class as indicated in tables 15 and 16.

d) The duct supports shall be designed to handle the load and also to take into account seismic considerations

e) If false ceiling is provided, the supports for the duct and the false ceiling, shall be independent. Collars for grilles and diffusers shall be taken out only after false ceiling / boxing framework is done and frames for fixing grilles and diffusers have been installed.

f) Where a duct penetrates the masonry wall, it shall either be suitably covered on the outside to isolate it from masonry, to prevent vibration transmission. Please refer Part 4 'Fire and Life Safety' of the Code for safety requirements.

For more details on duct construction and installation, please refer the latest edition of accepted standard [8-3(2)].

Table 15 Classification by Internal Pressure and Pressure Range
(*Clause* 8)

Sl No.	Classification By pressure	Normal Service Pressure Pa		Pressure Limits Pa	
		Positive Pressure	Negative Pressure		
(1)	(2)	(3)	(4)	(5)	
i)	Low Pressure Duct	P ≤ +500	-500 ≤ P	+1000	-750
ii)	Medium Pressure Duct	+500 < P ≤ +1000	-500 > P ≥ -1000	+1500	-1500
iii)	High Pressure Duct	+1000 < P ≤ +2500	-1000 > P ≥ -2000	+3000	-2500

Table 16 Recommended max duct velocities
(*Clause* 8)

Sl No.	Application	Controlling Factor Noise Generation Main Ducts	Controlling Factor - Duct Friction			
			Main Ducts		Branch Ducts	
			Supply	Return	Supply	Return
		m/s	m/s	m/s	m/s	m/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Residences	3	5	4	3	3
ii)	Apartments	5	8	7	6	5
iii)	Hotel Rooms	5	8	7	6	5
iv)	Hospital Rooms	5	8	7	6	5
v)	Private Offices	6	10	8	8	6
vi)	Directors Rooms	6	10	8	8	6
vii)	Libraries	6	10	8	8	6
viii)	Theatres	4	7	6	5	4
ix)	Auditoriums	4	7	6	5	4
x)	General Offices	8	10	8	8	6
xi)	Restaurants	8	10	8	8	6
xii)	Stores	8	10	8	8	6
xiii)	Banks	8	10	8	8	6
xiv)	Cafeterias	9	10	8	8	6
xv)	Industrial **	13	15	9	11	8

NOTE – ** For specific industrial applications, please refer customer specific needs and choose a velocity to optimize energy consumption requirements.

8.1 Space Air Distribution

Space Air Distribution shall be classified by:

a) Their primary objective, and
b) The methods by which the objectives are attempted to be accomplished.

The objectives of Space Air Distribution shall be classified as one of the following:

a) Providing occupant thermal comfort,
b) To support processes within the space, or
c) A combination of (a) and (b).

The occupied zone is a space in any location where occupants normally reside and may differ from project to project. It may be application-specific and should be carefully defined by the designer. The occupied zone is generally considered to be the room volume between the floor level and 1.8 m above the floor level. For additional information special publication may be referred.

NOTE – Special publication maybe ANSI/ASHRAE Standard 55 and Standard 62.1 for further information.

Space Air Distribution methods shall be classified as one of the following:

a) Fully mixed systems (for example, overhead air distribution) which have zero or very little thermal stratification of air in the occupied zone or process space.

b) Fully stratified systems (for example, thermal displacement ventilation) have practically no air mixing in the occupied zone or Process Space.

c) Partially mixed systems (for example, most underfloor air distribution designs) provide limited air mixing in the occupied zone or process space.

d) Unidirectional air flow system (for example a laminar flow system) is designed to ensure no mixing and maintain a consistent air flow pattern, ensuring that air always moves from a clean to less clean areas.

e) Personalized system (for example task / ambient air distribution systems) is an air distribution strategy that combines two different air supply methods to optimize IAQ, thermal comfort and energy efficiency.

8.1.1 *Fully Mixed Systems*

In mixed air systems, comfort is maintained by mixing of high velocity supply air with the room air. The air mixing, heat transfer and velocity reduction should occur outside the occupied zone. The three fundamental characteristics of the system are:

a) The supply air outlets are located far away from the occupied zone.

b) The supply air temperature is considerably lower than the room temperature (the normal ΔT between supply air and room air would be of the order of 11°C to 12°C). When supplying heated air from overhead outlets, ensure that the ΔT between supply air temperature and room air temperature is not more than 8°C to 9°C to avoid stratification.
c) The supply air outlet velocity should be much higher than the desired occupied zone air velocity. The supply air outlet velocity should be of the order of 3.5 m/s to 5.0 m/s. The resultant occupied zone velocity should be between 0.2 m/s to 0.25 m/s for cooling, and not more than 0.15 m/s for heating). When SA outlets are used at the perimeter with vertical projections for heating and / or cooling, they should be located near the perimeter surface. Outlet selection shall be done on the basis of the isothermal terminal velocity of 0.75 m/s extends at least half way down the surface or 1.5 m above the floor (whichever is lower) thus ensuring that the warm air mixes with the cool downdraft on the perimeter surface, to reduce draft in the occupied zone.

8.1.2 *Fully Stratified Systems*

Systems that discharge cool air at low sidewall or floor locations with very little entrainment of room air into the primary air stream create vertical thermal stratification throughout the space. The three fundamental characteristics of the system are:

a) The supply air outlets are located directly in the occupied zone.
b) The supply air temperature is much closer to the room temperature (the normal ΔT between supply air and room air would be of the order of 3°C to 6°C).
c) The supply air (SA) outlet velocity should be of the order of 0.25 m/s to 0.35 m/s.

In spaces where the internal heat gain density exceeds 120 Watts/m^2, care should be taken to ensure comfort by providing supplementary localized cooling terminals to address the higher heat gain densities. Care should be taken to limit downward drafts driven by cold walls or windows. The vertically stratified temperature field needs to be stable for proper functioning.

Ensure that the design provides for appropriate measures for maintaining the RH within the specified levels.

Stationary occupants should not be subjected to discharge velocities exceeding about 0.2 m/s. SA Outlets shall not be located closer than 1 m from any occupant. SA outlets should not be located behind furniture and other obstructions that impede airflow.

Stratified systems shall not be used in conjunction with mixed air systems because mixing destroys natural stratification that drives displacement ventilation.

8.1.3 *Partially Mixed Systems*

Supply air (SA) (usually from the floor) is discharged vertically at relatively high velocities and entrains room air akin to SA outlets in fully mixed systems. Underfloor air distribution systems (UFAD) shall be classified as partially mixed systems. The cavity below the access floor tiles is generally pressurized and used as SA Plenum.

As with fully stratified systems, the partially stratified systems in humid climates should ensure that the design provides for appropriate measures for maintaining the RH within the specified levels.

SA outlets should be of the swirl type with a high-induction core which promotes quick reduction in velocities and temperature gradients.

SA outlets should be located far enough from stationary occupants to ensure that they are not exposed to drafts and noise causing discomfort.

SA temperature in the access floor cavity should be kept at or above 16°C to minimize the risk of condensation and consequent fungal growth.

Access floor plenums should be well sealed to prevent air leakages. Exterior walls should be well insulated and have proper vapour retarders. Night / holiday temperature set-backs should be avoided (or at least reduced) to minimize plenum condensation and thermal mass effect problems.

Return static pressure drop should be relatively equal throughout the space being served by the plenum. This reduces the chances of unequal pressurization within the Plenum.

Partially stratified systems shall not be used in conjunction with mixed air systems because mixing destroys natural stratification that drives displacement ventilation.

8.1.4 *Unidirectional Air Flow Systems*

A unidirectional air flow system is a type of ventilation system that provides a controlled, one-way flow of air through a facility or room. This system is designed to minimize contamination, reduce air turbulence, and improve indoor air quality.

Key features of this system are:

a) Air flows in a single direction, from the cleanest area to the most contaminated area.
b) Air flows in a smooth, parallel stream, reducing turbulence and mixing (laminar flow).
c) Air is filtered to remove particles and contaminants before entering the space.
d) The space is maintained at a positive pressure to prevent outside air from entering.
e) Contaminated air is exhausted directly outside, without recirculation.

The key benefits of the unidirectional air flow system is improved air quality, reduced risk of cross-contamination, enhanced particle count control thus leading to easier regulatory compliance in required applications like cleanrooms, laboratories, healthcare facilities (operating room, isolation rooms), food processing facilities and the like.

8.1.5 *Personalized Systems*

Task / Ambient air distribution systems is an air distribution strategy that combines two different air supply methods to optimize IAQ, thermal comfort and energy efficiency.

Following are the two methods:

a) *Task air* – Supplies conditioned air directly to the breathing zone (directly via special outlets inbuilt in the seating systems / workstations). The SA is very precisely tempered to the correct temperature and humidity,

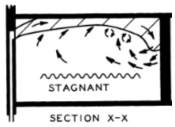
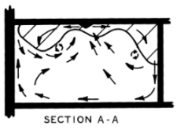
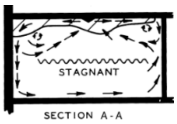
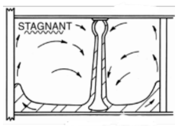
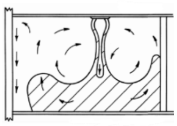
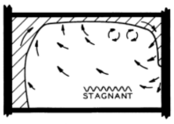
b) *Ambient air* – Supplies to the overall space above and out of the breathing zone so as to maintain a comfortable thermal environment and air quality.

Such personalized systems, by separating the air components into task and ambient, offer several benefits including improved air quality, enhanced thermal comfort and increased energy efficiency.

8.1.6 *Supply Air Outlet (Airflow Mixing) Types and Ventilation Effectiveness*

The tables 17 and 18 below provides an understanding of the various types of systems, their ventilation efficiencies.

Table 17 Various Types of Systems and Their Ventilation Efficiencies
(*Clause* 8.1.6)

Sl. No.	**Methods**	**Suitable Air Outlet**	**Zone Air Distribution/Change Effectiveness (E_z)**		
			Cooling	**Heating**	**Features**
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fully Mixed System, Entrainment from Sidewall	High Sidewall Grilles, Sidewall Diffuser, Nozzle and similar outlet providing ceiling attached flow	 E_z=1 (Ideal)	 E_z =0.8 (Ideal)	Suitable for summer cooling and minor winter heating (temperature difference +10K warm air). Velocity in the occupied zone should be less than 0.35 m/s
ii)	Fully Mixed System, Horizontal Discharge from Ceiling	Ceiling Diffuser, Linear Ceiling Diffuser or similar outlets with Horizontal diffusion pattern	 E_z =1 (Ideal)	 E_z =0.8 (Ideal)	Suitable for summer cooling and minor winter heating (temperature difference +10K warm air). Velocity in the occupied zone should be less than 0.35 m/s
iii)	Fully Mixed System, Vertical Downward Air Projection from Ceiling	Adjustable Grille, Jet Nozzle, Ceiling Spot Diffuser, Linear Ceiling Diffuser or similar outlets with vertical downward air projection	 E_z =1 (Ideal)	 E_z =1 (Ideal)	Suitable for either cooling or heating with increased terminal velocity in order to project warm air up-to the occupied zone.
iv)	Partially Mixed System, Non Spreading Vertical Jet in or near floor	Floor Diffuser, Sidewall Grilles, Sidewall Diffuser or similar outlets with fixed vertical spread pattern.	 E_z =1 (Ideal)	 E_z =1 (Ideal)	Suitable for cooling and heating both at terminal velocity ~ 0.75 m/s (ideal). Outlet shall be placed at 150 mm distance from wall.

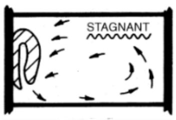
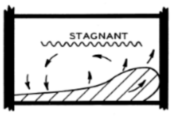
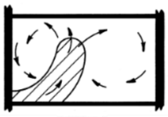
Sl. No.	Methods	Suitable Air Outlet	Zone Air Distribution/Change Effectiveness (E_z)		
			Cooling	Heating	Features
(1)	(2)	(3)	(4)	(5)	(6)
v)	Partially Mixed System, Spreading Vertical Jet in or near floor	Floor Diffuser, Sidewall Grilles, Sidewall Diffuser with adjustable spread pattern or similar outlets	 E_z =1 (Ideal)	 E_z =1 (Ideal)	Suitable for severe heating and minor cooling requirements (temperature difference -8K cool air). Velocity at 1.4m above floor i.e. occupied region should be less than 0.25 m/s
vi)	Fully Stratified System, Low Horizontal Discharge near floor	Baseboard or Low sidewall Grille, Displacement Diffuser or similar outlets	 E_z =1.2 (Ideal)	 E_z =1 (Ideal)	These outlets direct high velocity total air directly into the occupied zone and therefore not recommended for particularly summer cooling. Terminal Velocity <1.5 m/s and mostly suitable for process installations where controlled air velocities are desired.
vii)	Unidirectional Airflow System, Plug type from ceiling exhausted through wall	Laminar Flow Diffuser with perforated/helical face plate			Generally, a preferred choice for use in a cleanroom for manufacturing, healthcare and research. Other performance parameters such as colony forming unit and room class affects its choice and selection

Table 18 Recommended Supply Air Outlet Selection
(*Clause* 8.1.6)

Outlet Types	Fully Mixed			Fully Stratified		Partially Mixed		
	Outlet Location							
	Ceiling	Wall	Floor	Wall	Floor	Ceiling	Wall	Floor
Grilles								
Adjustable Blade	☑	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Fixed Blade	**NR**	☑	**NR**	☑	**NR**	**NR**	**NR**	**NR**
Linear Bar Grille	**NR**	☑	☑	☑	☑	**NR**	**NR**	☑
Jet Nozzle	**NR**	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Diffusers								
Round	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Square	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Perforated Face	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Louvered Face	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Plaque Face	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Laminar Flow	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Slot Diffuser	☑	☑	**NR**	**NR**	**NR**	**NR**	**NR**	**NR**
Swirl Diffuser	☑	**NR**	**NR**	**NR**	☑	**NR**	☑	☑
Displacement	**NR**	**NR**	**NR**	☑	☑	**NR**	**NR**	**NR**

NOTE

1 Obstructions, vane adjustments, and other ceiling elements influencing airflow patterns shall affect comfort and efficiency.

2 Personalised system will increase E_z when used in combination with the above listed methods up to 1.5

3 During partial load, VAV systems shall affect E_z by reducing the air velocity at the outlet. Minimum Airflow should be considered so that velocity in the occupied region does not go below 0.1 m/s while designing such systems and other performance criteria such as outdoor air intake and critical space CO_2 concentration should be monitored and controlled (demand control ventilation). Additionally, a dual duct system, fan powered and reheat terminal may be used in combination with VAV systems where precise and wide climate control range is required without affecting the E_z.

8.1.7 *Return Air Inlets*

Return air intake affects room air motion only immediately around the inlet. the selection of return air inlets should be based on performance data and not merely based on aesthetic and architectural considerations. The table 19 below provides the recommended face velocities across Inlets based on their location:

Table 19 Recommended Face Velocities Across Inlets Based on their Location
(*Clause* 8.1.7)

Sl. No.	Inlet Location	Velocity Across Inlet m/s
(1)	(2)	(3)
i)	Above Occupied Zone	>4
ii)	In Occupied Zone (Not Near Seats)	3 – 4
iii)	In Occupied Zone (Near Seats)	2 – 3
iv)	Door / Wall Louvers	1 – 1.5
v)	Through Door Under-cuts	2 – 1.5

8.2 Airflow Measurements in Space Air Distribution Systems

Air flow measurement requirements and methods of air distribution systems aim to ensure adequate indoor air quality, energy efficiency, and occupant comfort in the occupied space. These requirements vary depending on the specific building code or standard in use, but there are common elements that are often addressed. understanding and adhering to these requirements and methods ensures that air distribution systems in buildings provide adequate ventilation, maintain indoor air quality, and operate efficiently. It is recommended that the airflow measurement should be conducted to meet the following requirements.

8.2.1 *System Balancing*

Air distribution systems shall be balanced to ensure each space receives the designed air flow. This typically involves testing, adjusting, and balancing (TAB) procedures to verify system performance. Airflow measurements using one of the following methods should be conducted in each space to achieve the designed values within a band of $\pm$ 5 percent. Proper documentation of all measurements, adjustments and maintenance activities shall be maintained. The following describes various airflow measurement methods to comply with the above requirements of system balancing:

a) *Anemometers* – Anemometers are used to measure the velocity of air flowing through ducts or at registers/diffusers.

b) *Barometers / flow hoods* – Barometers or Flow hoods are used to measure the airflow directly at the supply air outlets.

c) *Duct traverse method* – Duct traverse method involves measuring air velocity at multiple points across the duct cross-section using a pitot tube or hot-wire anemometer and calculating the average velocity to determine airflow rate.

d) *Pressure measurement* – Differential pressure measurements across known resistances (for example, orifice plates, flow hoods) shall be used to determine airflow rates.

e) *Tracer gas method* – Trace gas method introduces a tracer gas into the airflow and measures its concentration downstream to determine the airflow rate based on dilution principles.

For airflow measurements within ducts, it is recommended to use an air flow measuring station. Such air flow measuring station should ideally be located with a clear straight duct length of at least 4 times the equivalent duct diameter (of the duct in which they are installed), at the inlet of the air flow measuring station.

8.3 Flow Control – Volume Control Dampers

A damper is a valve or plate that stops or regulates the flow of air inside a duct, and other air-handling equipment.

Manual dampers are operated by a handle on the outside of a duct. Automatic dampers are used to regulate airflow constantly and are operated by electric or pneumatic motors, in turn controlled by a thermostat or the building automation system.

Dampers are customized in terms of size to suit the openings, where they are to be installed. A right choice of volume control dampers/s shall result in energy conservation.

8.4 Variable Air Volume (VAV)

Variable air volume terminal units are devices that regulate the amount of air supplied to a specific zone or space in a building. They are an essential component of fully mixed systems, which help to optimize energy efficiency and indoor air quality.

By optimizing air flow and conditioning, VAV terminal units play a crucial role in creating a comfortable, efficient, and sustainable indoor environment. When using VAV terminal units, observe the following guidelines to ensure safe and efficient operation:

a) Wherever possible, a straight duct inlet connection with a minimum length of three duct diameters and the same internal diameter as the inlet should be provided.
b) Never insert a duct inside the Inlet or control calibration will be adversely affected.
c) Ensure accurate sensor calibration to maintain precise control and avoid oscillations.

d) Balance airflow to prevent uneven distribution, reduced efficiency, and increased energy consumption.
e) Inlet air velocity should not exceed 12 m/s at max flow and should not be below 2 m/s. Ensure unit sizing is adequate to meet flow range and also meets noise criterion for the space.
f) When using terminals equipped with re-heat elements, to avoid compromising zone ventilation effectiveness, the discharge temperature should not be more than 8°C warmer than the zone it serves. If electrical re-heat is being used, ensure all safety controls (like air stats / flow switch and other safety cut outs) as required by local codes are provided.
g) Ensure proper access is provided for the unit (like adequately sized access doors).

8.5 Thermal Beams

Chilled beams are a type of convection HVAC system used to heat or cool rooms they are air distribution devices with integral coils designed to heat or cool large buildings. Chilled beams shall be classified into two main categories, passive and active.

Passive chilled beams work using the phenomenon of natural convection, and they do not require any primary air supply.

Active chilled beams consist of a primary air supply connection that provides conditioned / dehumidified air and enhances air induction through the coil.

8.5.1 *Application Considerations*

Chilled beams are intended to operate without condensation. Consequently, active chilled beam supply water temperatures should be maintained at or above the room dew point temperature to prevent condensation on the coil. Passive chilled beam should be kept slightly above the room dew point temperature. In both cases, the chilled water piping shall be adequately insulated to prevent condensation on the pipe itself. Where adequate control of space humidity levels shall not be ensured, higher supply water temperatures and / or suitable condensation control should be considered.

Heating with passive beams is not effective. For heating, the hot water temperature serving the beam’s coil shall be selected to limit the discharge air temperature to less than 8°C above the room design set point.

8.6 Air Curtains

An air curtain unit acts as a controlled barrier for environmental and thermal separation and wind resistance when a building's doors or windows are opened. Air curtains create an invisible barrier at openings and doors which separates different temperature zones without limiting access for people and vehicles. Air curtains are used where it is not feasible to have an engineered air lock.

8.6.1 *Application Considerations*

Air curtain unit selection depends on the opening's width and height. To maximize effectiveness, the air curtain unit shall at least cover or slightly overlap the entire opening and have a minimum velocity projection of 2 m/s at the target surface. The air curtain unit discharge shall have a free and clear path to the entire opening for optimum performance.

9 AIR FILTRATION AND ALTERNATE AIR CLEANING METHODS

With people spending a significant portion of their time indoors, ensuring good indoor air quality (IAQ) is paramount for occupant health, productivity, and overall well-being. This section focuses on indoor spaces that are regularly occupied and are either naturally or mechanically ventilated. Following are the aspects to be considered for air filtration and alternate air cleaning methods.

9.1 Threshold Levels for Pollutants

Threshold values are made available for different pollutants depending on the severity of the health hazard that a pollutant shall create for the occupants. **3.6.3** provides details of threshold values for the different pollutants encountered in indoor air.

9.2 IAQ Monitoring

IAQ is a critical component in ensuring the health, comfort and productivity of occupants in commercial buildings. Monitoring IAQ involves the assessment of various air quality parameters. Some critical pollutants and air quality parameters are monitored continuously, while some are monitored/tested periodically. Continuous monitoring and periodic testing data are essential for interpreting the indoor environment and initiating necessary mitigation measures.

9.2.1 *Continuous Real Time Monitoring*

Pollutants for continuous monitoring include CO_2, TVOC, PM2.5, and ozone. These pollutants should be monitored continuously in all regularly occupiable areas of the building. Regularly occupiable areas may be defined as spaces intended for human occupancy within commercial buildings, excluding areas like the pantry, toilets and store rooms. When determining compliance, missing measurements and data loss will be interpreted as a threshold/range exceedance for that period.

9.2.1.1 *Sampling frequency*

For continuous monitoring of temperature, relative humidity, CO_2, TVOC, PM2.5 and O3, the sampling frequency should be at least once every 5 minutes. Monitoring of these parameters should be done on a 24 hs basis to establish a trend. This provides insights into indoor air quality, leading to possible actions for improvement.

9.2.1.2 *Deployment of sensors/monitoring devices*

Deployment refers to the position and the number of sensors/monitoring devices installed in the indoor space. Ideally, the sensors/monitoring devices should be installed in the breathing zone. The breathing zone is defined as that region of the indoor space between the horizontal planes at 1.1 m and 1.7 m height above the finished floor level. Sensors/monitoring devices may be installed under the ceiling if the ceiling height is restricted to 2.13 m. In such cases, it is necessary to ensure that the air distribution in the room is uniform so that the air parameters at the ceiling will be similar to those in the breathing zone. Sensors/monitoring devices should be installed at least 0.9 m from exits, window openings and air conditioning vents. Every enclosed place, such as cabins or meeting rooms occupied for an average of 50 percent of the daily working hours, shall have dedicated monitoring devices. General office and common areas shall have at least one device for every 450 m^2 floor area.

9.2.1.3 *Calibration of sensors*

All sensors and pumps used in the monitoring devices shall be calibrated to ensure that the accuracy levels are maintained as specified by the manufacturer and to identify any measurement errors. Calibration should cover the parametric range the sensors are expected to experience in real service. Sensors measuring PM2.5 and TVOC values should be recalibrated or replaced annually. CO_2 sensors utilising the automatic baseline correction method shall be recalibrated or replaced once every three years. Sensors measuring thermal comfort parameters shall be recalibrated or replaced once every three years. Field calibrations using a reference sensor are acceptable, provided the master sensor is similar in range, accuracy, least count and resolution to the sensor being calibrated. Moreover, the calibration procedure should be such that the master sensor will perform within the manufacturer’s specified range and accuracy. The master sensor should have been calibrated at a laboratory. The calibration process shall capture a sufficient range and contaminant concentration using known span gases or exposure to ambient pollution to perform adjustments accurately. The calibration activity should be properly documented, and traceability certificates shall be provided wherever applicable.

9.2.1.4 *Display of IAQ data*

All IAQ parameters, under the purview of continuous monitoring, should be prominently displayed in a format that provides easy viewing and understanding to all occupants of the building. Having at least one common display on each floor/section showing the real-time snapshot of all the devices on that particular floor/section is recommended. Alternatively, there could be one common display at the main entrance that provides a real-time representation of the IAQ data for the entire building.

9.2.1.5 *Recommended sensor specifications for continuous monitoring*

The selection of the sensors is a crucial requirement for obtaining reliable and accurate measurements. Improper sensor selection will lead to erroneous data on IAQ. The Table 20 provides details about the type of sensor to be used and their recommended range, accuracy, and resolution to capture meaningful IAQ data.

Table 20 Required Range and Accuracy of Sensors Used for Continuous Monitoring
(*Clause* 9.2.1.5)

Sl no.	Parameters	Unit	Range	Accuracy	Resolution
(1)	(2)	(3)	(4)	(5)	(6)
i)	PM10	μg/m³	0 - 1000 μg/m³	± 10 percent of reading	1 μg/m³
ii)	PM2.5	μg/m³	0 - 1000 μg/m³	± 10 percent of reading	1 μg/m³
iii)	CO_2	ppm	400 - 5000 ppm	± 50 ppm or ± 5 percent of reading (whichever is greater)	1 ppm
iv)	TVOCs	ppb	0 - 5000 ppb	± 20ppb or ± 15 percent of reading (whichever is greater)	1 ppb
v)	Temperature	°C	0 to 100 °C	± 1 °C	0.1 °C
vi)	Relative Humidity	percent	5 - 95 percent	± 5 percent of reading	1 percent
vii)	Ozone	ppb	20-500 ppb	±10 ppb at 0-100 ppb	5 ppb

9.2.2 *Periodic Monitoring/Testing*

Periodic monitoring refers to measuring pollutants at a reasonably low frequency, typically several months apart. Pollutants for periodic monitoring include CO, SOx, NOx and HCHO. Sampling locations for periodic monitoring shall be representative of occupied spaces and should be located in the breathing zone as defined in **9.2.1.2**. Testing should be carried out under regular building conditions. Any test conducted without occupants or when the occupancy is considerably lower than on regular days shall be avoided.

9.2.2.1 *Sampling Frequency during periodic monitoring/testing*

Based on the pollutant's characteristics, the constraints in their monitoring technology, and their occurrence indoors, some pollutants are assessed periodically. The periodicity of such tests may be defined as "at least once every six months". Building operators may resort to a more frequent periodicity if the test results warrant the same.

9.2.2.2 *Procedure for periodic monitoring/testing*

a) HCHO – The test shall be in accordance with best practices*. The sampling duration should be a minimum of one continuous hour or the equivalent duration of the sampling procedure special publication may be referred.

b) CO – The sampling shall be carried out for at least one continuous hour (10 minutes of acclimation followed by 50 minutes of measurement time), with measurements recorded at least once every minute. Recommended procedures are the special publications may be referred. (CO by gas bag sampling).
c) NOx – NOx is measured gravimetrically using the modified Jacob and Hochheiser method and the chemiluminescence test. The monitoring of NOx shall be carried out in accordance with best practices**.
d) SOx – SOx shall be monitored gravimetrically using the improved West and Gaeke method and Ultraviolet Fluorescence.

NOTES
1 * best practices maybe ISO 16000-3 for HCHO.
2 ** best practices maybe ISO 16000-15 for NOx.
3 Special publication maybe ISO16000-3 for sampling procedure in case of HCHO.
4 Special publication for recommended procedures for CO maybe NIOSH Manual of Analytical Methods (NMAM), Fifth Edition,1997, OSHA Methods ID 209: 1993 (CO by direct-reading monitor) and OSHA Methods ID 210: 1991.

9.2.2.3 *Recommended sensor specifications for periodic monitoring/testing*

During periodic monitoring/testing, it is essential to use the appropriate measuring instrument to obtain reliable and accurate measurements. The following table 21 provides details about the type of instrument to be used and their recommended range, accuracy, and resolution to obtain factual test results.

Table 21 Sensor Specifications for Periodic Monitoring/Testing
(*Clause* 9.2.2.3)

Sl no.	**Parameters**	**Unit**	**Range**	**Accuracy**	**Resolution**
(1)	(2)	(3)	(4)	(5)	(6)
i)	CO	ppm	0.1 - 25	± 3 percent or ± 1 ppm (whichever is greater)	0.1 ppm
ii)	NOx	ppb	0 - 500	± 20 ppb or ± 15 percent of reading (whichever is greater)	1 ppb
iii)	SOx	ppb	0 – 500	± 5 percent of reading	1 ppb
iv)	Formaldehyde	ppb	20 – 1 000	± 20 ppb	1 ppb

9.3 Air Filters for Removing Pollutants in Indoor Spaces

Air filters shall be used in HVAC systems to remove airborne pollutants from indoor air and prevent outdoor pollutants from entering the building through outdoor air intakes. The filters shall be as per accepted standards [8-3(16)], [8-3(17)], [8-3(18)] and [8-3(19)] for classification and performance requirements may be referred.

9.3.1 *Classification of Air Filters*

Air filters are classified mainly based on their ability to filter out pollutants. Due to the differences in the methods for determining this ability, air filters shall be classified in multiple ways. Air filters are classified based on their gravimetric efficiency, particulate matter efficiency or fractional particle size efficiency.

9.3.1.1 *Classification of air filters*

The accepted standard [8-3(16)] shall be adopted to classify air filters based on particulate matter efficiency. This method of specifying the performance of air filters applies to fine filters. It is a preferred method of classification while specifying air filters for general human health and wellness applications (comfort applications), as particulate matter concentrations inside buildings directly correlate with the adverse health effects on the occupants. The test method mentioned in the standard determines the initial efficiency of the air filter in both the "as-manufactured" condition and the discharged condition to calculate the minimum and average particulate matter efficiency. The filter class is reported as ISO ePMx (y percent), where x is the particle size referred to (1 µm, 2.5 µm or 10 µm) and y is the particulate matter efficiency. Classification of air filters based on particulate matter efficiency as per accepted standard [8-3(16)] is given Table 22 below:

NOTE – The symbol ePMx describes the efficiency of an air cleaning device to particles with an optical diameter between 0.3 µm and x µm.

Table 22 Classification of Air Filters based on Particulate Matter Efficiency
(*Clause* 9.3.1.1)

Sl. No.	**Group designation**	**Requirement** $ePM_{1, min}$	**Requirement** $ePM_{2.5, min}$	**Requirement** $ePM_{10, min}$	**Class reporting value**
(1)	(2)	(3)	(4)	(5)	(6)
i)	ISO Coarse	NA	NA	< 50 percent	Initial grav arrestance
ii)	ISO *e*PM10	NA	NA	≥ 50 percent	ePM_{10}
iii)	ISO *e*PM2.5	NA	≥ 50 percent	NA	$ePM_{2.5}$
iv)	ISO *e*PM1	≥ 50 percent	NA	NA	ePM_1

9.3.2 *Resistance to Airflow in Air Filters*

The resistance to airflow is measured as the differential pressure across the air filter in a test setup. The resistance vs airflow rate characteristics are established at 25 percent, 50 percent, 75 percent, 100 percent and 125 percent of the rated flow of the air filter. Procedures mentioned in accepted standard [8-3(18)] shall be followed to determine the same. The resistance as a function of airflow rate provides useful information on the selection and performance of an air filter.

9.3.3 *Air Filters Using Electrostatically Charged Fibrous Media*

Some air filters use fibrous media that carries an electrostatic charge. The charge helps in improving the filtration efficiency of smaller particles. This will help achieve higher filtering capabilities at a lower initial resistance for a given airflow rate, thereby reducing operating costs. However, should the charge be compromised for any reason, the filtering capability of these air filters will be drastically reduced. Hence, when electrostatically charged fibrous media air filters are used, it is recommended that suitable monitoring systems be used for measuring the indoor particle concentrations so that any reduction in the filtering capability of the air filter shall be noticed and suitable actions shall be taken.

9.3.4 *High-Efficiency Filters*

High-efficiency filters shall be used in critical industrial, scientific and research applications that demand stringent control of airborne solid and liquid phase pollutants. They are classified based on their filtration efficiency at most penetrating particle size (MPPS). The MPPS is defined as the particle size of the challenge aerosol that will offer the lowest efficiency when challenged onto an air filter. The accepted standard [8-3(20)] shall be used to classify high-efficiency filters. This standard classifies high-efficiency filters based on their overall efficiency and local efficiency (leak scan test). (*see* Table 23)

Table 23 Classification of High-Efficiency Air Filters
(*Clause* 9.3.4)

Sl No. (1)	**Filter class** (2)	**Overall Efficiency at MPPS** percent (3)	**Local efficiency at MPPS** percent (4)
i)	ISO 15 E	≥ 95	NA
ii)	ISO 20 E	≥ 99	NA
iii)	ISO 25 E	≥ 99.5	NA
iv)	ISO 30 E	≥ 99.90	NA
v)	ISO 35 H	≥ 99.95	≥ 99.75
vi)	ISO 40 H	≥ 99.99	≥ 99.95
vii)	ISO 45 H	≥ 99.995	≥ 99.975
viii)	ISO 50 U	≥ 99.999	≥ 99.995
ix)	ISO 55 U	≥ 99.9995	≥ 99.9975
x)	ISO 60 U	≥ 99.9999	≥ 99.9995
xi)	ISO 65 U	≥ 99.99995	≥ 99.99975
xii)	ISO 70 U	≥ 99.99999	≥ 99.9999
xiii)	ISO 75 U	≥ 99.999995	≥ 99.9999

9.3.5 *Air Filters for Removing Airborne Molecular Contamination*

A gaseous state pollutant in the air is called an airborne molecular contamination. Many gas phase pollutants are detected in the indoor air of buildings, and they shall be broadly classified as acid gases, base gases, aldehydes, oxidising gases, VOCs and other miscellaneous gases. Adsorption and chemisorption filters are used in HVAC systems and outdoor air intakes to remove these pollutants (for example H_2S, NH_3, HCHO, O_3, VOCs, NOx, SOx, Cl_2, CO etc.) from indoor air. These filters use adsorbents, known as molecular sieves, to remove the pollutants from the air stream through physical adsorption. Activated carbon, activated alumina and zeolites are the commonly used adsorbents. Additionally, the adsorbents are impregnated with suitable chemicals that react with the adsorbed pollutant to prevent their desorption. This process is called chemisorption. Molecular sieves are available as granules, pellets, and powders coated on fibrous media; hence, they shall be constructed as packed bed filters and extended surface pleated filters. For additional information special publications may be referred to assess the performance of these air filters.

NOTE – Special publications maybe ISO 10121-2:2013 and ISO 10121-3: 2022.

The fundamental criteria for air filter selection is based on its:

a) Filtration efficiency at the particle size range of interest.
b) Gravimetric, particulate matter, or fractional particle size efficiencies.
c) Resistance the air filter offers at its rated airflow.
d) Test dust capacity.

9.3.6 *Installation of Air Filters in HVAC Systems*

Most air filter installations in HVAC systems comprise of multiple air filters in a single system. The installation of air filters is vital since improper installation could lead to filter bypass, compromising the overall filtration system's efficiency even though the individual air filters may be good. Proper mounting arrangements and usage of gaskets to avoid filter bypass are essential to ensure the proper installation of an air filter.

9.3.7 *Field Testing of Air Filters*

Since the test results from standard laboratory tests shall vary from performance results in real service, conducting a filtration performance test in situ under real service conditions will help understand the actual performance. For *in-situ* testing purpose special publications may be referred, which provides the method for *in-situ* field testing of air filters and systems, shall be adopted.

NOTE – Special publication maybe ISO 29462: 2022.

9.4 *Alternate Air Cleaning Technologies*

To ensure the indoor concentration of these pollutants within the safe levels as mentioned in sub section **3.6.3**. The following text provides functional principle and instructions for use of various types of air cleaning technologies.

9.4.1 *Electrostatic Precipitators*

Electrostatic precipitators (ESP) use the principle of electrostatic attraction to trap particles. They are commonly used in industrial applications with high particle concentrations where mechanical (fibrous media extended surface) air filters may not be practical. ESPs have been used in comfort HVAC / AHU applications to reduce indoor PM2.5 concentration. ESPs also efficiently remove oil mist, such as in kitchen smoke and certain other industrial applications.

Ionization of the air stream may lead to ozone generation. ESP shall be designed to keep the ozone generation level to a safe limit for humans. IAQ sensors shall be fitted to monitor the air stream parameters when ESPs are used. Any trace of Ozone emitted by ESP filters shall be suitably treated using chemical filters or ozone-reducing 254 nm wavelength UVGI downstream. They shall be designed with safety interlocks to avoid electrical shocks and to stop the power module in case of less airflow.

The pressure loss of the electrostatic precipitator is very low and stays nearly constant. However, the filtration efficiency decreases as the collection plates accumulate with particles. Hence, the ionization and collection sections need to be cleaned regularly. ESPs are preferably located upstream of AHU cooling coils.

9.4.2 *Ultraviolet Germicidal Irradiation*

Ultraviolet germicidal irradiation (UVGI) systems in buildings shall be installed inside air handling units (AHUs) or air ducts. Additionally, they shall be installed as upper-zone UVGI systems (UZ-UVGI). The upper zone units have uniquely designed baffles that irradiate the upper zone of the room towards the ceiling. A gentle air movement in the room makes the upper zone unit more effective. For UZ-UVGI systems, the UV equipment/lamp shall be out of the line of sight for the occupants from all parts of the room. To meet the safe exposure limit of 60 J/m^2 for an 8-hour exposure period, the UV radiation intensity at the occupied zone shall be less than 0.002 W/m^2.

The use of UVGI for the heat transfer coils of air conditioning equipment is found to be very effective in eliminating biofilm build-up on coils and condensate drain pans, thereby improving heat transfer efficiency and hygiene inside air conditioning equipment.

Direct and visual contact of humans with UVGI systems shall be avoided. Service personnel shall wear the required safety goggles and aprons while attending to any service issue in AHU fitted with UVGI systems. The HVAC equipment fitted with UVGI shall have visible stickers on the equipment mentioning ‘UVGI installed inside’.

NOTE – The degradation of materials used in HVAC equipment like AHUs due to UV exposure is another important aspect to consider when installing UVGI systems. Material compatibility with UVGI shall be assessed during design or subsequent retrofits.

9.4.3 *Photocatalytic Oxidation*

Photocatalytic oxidation (PCO) is a light-mediated redox (oxidation and reduction) reaction of gases and biological matter. This is achieved by impinging ultraviolet rays on a catalyst material and giving out hydroxyl radicals and super oxides, commonly referred to as reactive oxidative species (ROS).

9.4.4 *Photo-Hydro Ionization*

Photo-hydro ionization (PHI) is a light-mediated active air cleaning method similar to PCO. Removes bioaerosols (bacteria, viruses, fungi, etc), VOCs, formaldehyde and certain odour-causing chemicals from the air.

9.4.5 *Air Ionizers*

The use of air ionizers helps easier removal of particles by agglomeration.

9.4.6 *Plasma Air Ionization*

Ions are formed as air passes over the ionization tubes. Pollutants, including bioaerosols coming in contact with the ions, are oxidized and destroyed. Additionally, the generated ions encourage the agglomeration of particles, allowing them to be more easily removed through gravitational settlement and by the air filtration systems.

10 OTHER COMPONENTS OF CENTRAL HVAC SYSTEM

These components are essential for the efficient functioning and regulation of heating, ventilation, and air conditioning in a centralized system.

10.1 Cooling Tower

Cooling towers are used to dissipate heat from water cooled refrigeration, air conditioning and industrial process systems to the atmosphere. Cooling is achieved by evaporating a small proportion of the recirculating water to the atmosphere. Cooling towers shall be installed at a place where free flow of atmospheric air is available.

Range of a cooling tower is defined as temperature difference between the entering and leaving water. Approach of the cooling tower is the difference between leaving water temperature and the ambient air wet-bulb temperature.

10.1.1 *Selection of Cooling Tower*

Following factors shall be considered for selection of cooling tower:

a) Recirculating water flow rate,
b) Design wet-bulb temperature,
c) Approach, the designer shall endeavour for reducing the approach for maximizing energy conservation in the chiller,
d) Range,
e) Water quality and
f) Outside air quality for cooling tower.
g) Height limitation and aesthetic requirement.
h) Location of cooling tower considering possibility of easy drain back from the system.

j) Placement with regard to adjacent walls, windows and other buildings, and effects on these from any water carried over by the air stream, also known as drift.
k) Sound levels, particularly during silent hours.
m) Material of construction of the tower; particularly considering the nature/quality of ambient air and recirculating water.
n) Direction and flow of prevailing wind; to minimise recirculation and interference.
p) Quality of water used for make-up; maintenance and service space availability.

10.1.2 *Selection Criteria*

These factors ensure the optimal performance, efficiency, and suitability of cooling towers for specific HVAC system requirements.

10.1.2.1 *Location of the cooling tower*

Location of cooling tower shall be determined by one or more of the following:

a) Architectural compatibility,
b) Rigging limitations,
c) Structural support requirements,
d) Cost of bringing auxiliary services to the cooling tower, and
e) Noise transmission, plume, and drift considerations.

These are best handled by proper site selection during the planning stage. Cooling tower shall be installed raised above the mounting surface by 0.45 m to 1.25 m to permit installation of pot strainer in condenser water line from cooling tower sump; also, to provide easy drainage and maintenance of mounting surface as follows:

1) Cooling tower accessories shall be project-specific and shall include such items as walking platform; stairs and ladder safety cage; bird screen; tower loading and supporting structure; and variable speed drive fan motor. However, variable speed drives should be used only in very specific instances as allowing the cooling tower fan to run at full speed during periods of low load is generally more beneficial due to the lower water temperature achieved by the cooling tower that results in higher condenser efficiency and, hence, lower power consumption in the air-conditioning plant.

2) Cooling tower installation shall include installation of conductivity controller, flow meter on the makeup water line, overflow alarm and low-level alarm.

3) The recommended floor area requirement for various types of cooling tower is as given below:

Mechanical draft cooling tower	:	0.014 to 0.28 m^2/kW (0.05 to 0.10 m^2/TR)

NOTE – The recommended floor area above does not include the area required around the tower for unobstructed air flow.

4) Structural provision for the cooling tower shall be taken into account while designing the building. Vibration isolation shall be an important consideration in structural design.

5) Special care should be taken in design where noise transmitted to the adjoining building shall be of serious concern. Special vibration control and sound attenuation devices may be required in that case. Appropriate sound insulation and noise control measures shall be taken in such cases in accordance with Part 8 'Building Services', Section 4 'Acoustics, Sound Insulation and Noise Control' of the Code.

10.1.2.2 *Water quality*

Water is commonly used as a heat transfer medium to remove heat from the refrigerant vapour in the condenser. A cooling tower is used to dissipate the heat from the air-conditioning system to atmosphere. A cooling tower shall cool condenser water to within 2°C to 3°C of the ambient wet-bulb temperature, with modern cooling towers even achieving approach as low as 1°C. Therefore, a water-cooled system operates at a condenser temperature that could be more than 20°C in a corresponding air-cooled system, resulting in considerably improved efficiency and significantly reduced energy consumption.

Where make-up water is expensive, or not available at all or in limited quantities only, the use of an adiabatic cooler should be considered. An adiabatic cooler allows the use of water-cooled air-conditioning plant with water consumption 70 percent to 90 percent lower than that of a conventional cooling tower.

Certain amount of water is lost from circulating water in the cooling tower, as given below:

a) *Evaporation loss* – It is approximately 1 percent of the rate of water circulation per 6°C of range.
b) *Drift loss* –The drift loss shall be below 0.1 percent of the rate of water circulation.
c) *Blow-down/bleed-off* –The amount of blow-down shall be below 0.8 percent of the total water circulation. If simple blow-down is inadequate to control scale formation, chemicals may be added to inhibit corrosion and limit microbiological growth.

Provision shall be made to make-up for the loss of circulating water. Provision for make-up water tank to the cooling tower shall be made. Make-up water tank to the cooling tower shall be separate from the tank serving drinking water. Makeup water should be sourced from treated water from sewage treatment, wastewater treatment plant, or from rain water harvesting.

Make-up water having contaminants or hardness, which shall adversely affect the refrigeration plant life, shall be treated. Treated water where hardness as ppm of $CaCO_3$ is reduced to 50 ppm or below is recommended for air conditioning applications. Water with pH value less than 5 shall also need to be treated. For treatment of water for cooling towers good practice [8-3(44)] shall be referred.

Cooling tower should be so located as to eliminate nuisance from drift to adjoining structures. Cooling tower approach and minimum efficiency shall be as per table 24.

Table 24 Cooling Tower Approach and Minimum Efficiency
(*Clause* 10.1.2.2)

Sl. No.	**Building**	**Chiller** kWr	**HWT** ºC	**CWT** ºC	**WBT** ºC	**Efficiency** kW/LPS
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	all others	Any	36.4	30.8	28.3	0.35
ii)	24x7 facilities	Any	35.6	30.0	28.3	0.35

10.1.2.3 *Installation of cooling tower*

The cooling tower shall be mounted on a set of four or six numbers of reinforced cement concrete pillars (structural foundation) as per manufacturer's recommendations. Height of these pillars shall be not less than 1 m, actual height is decided at site as per space required to install a pot strainer below the water level in cooling tower sump, drain pipe and valve for complete drainage of sump, and to permit maintenance of slab upon which structural foundation is installed.

Cooling tower should be located at a well-ventilated place, preferably on the terrace of the building, in consultation with the structural consultant. Dynamic structural loading on the terrace shall be considered. Cooling tower shall be installed in such a way that its dynamic load is transferred directly to the building structural columns, for which necessary mild steel I-section may have to be provided. Anticorrosive coating such as epoxy coating shall be applied required for these mild steel I-sections. Suitable thickness of vibration isolation pads shall be placed between the tower and the I-sections to avoid transfer of vibration to building structure. Sufficient space shall be left all around the cooling tower support structure for efficient operation of the cooling tower.

When cooling tower is installed at ground level, contiguous to the utility services block, great care has to be exercised to prevent users and visitors from coming in close proximity to the cooling tower. This is necessary to avoid their exposure to legionellae bacteria which shall hibernate in the cooling tower sump, if operator does not follow strict instructions for regular bleed-off and chemical treatment of condenser water.

Also, the bleed-off tap should be given in the return line to cooling tower, instead of only providing in the sump to ensure the desired water quality.

10.1.2.4 *Safety aspects (while designing tower installation)*

a) Access to and from maintenance access doors, top of tower access platform with handrail system should be provided.
b) Ladders (either portable or permanent) to gain access to the discharge level or maintenance access doors should be provided.
c) Surrounding area should be clear

d) Provision for lockout of mechanical equipment should be provided.
e) Safety cages around ladders should be provided.
f) cooling tower shall be with appropriate electrical earthing
g) Motor terminals shall be provided with appropriate enclosure for appropriate ingress protection.
h) Bird cages shall be provided from all sides to prevent birds entering into the cooling tower

10.1.2.5 *Testing of cooling tower*

Upon completion of installation, the cooling tower shall be tested for performance. The entering and leaving water temperatures, the entering air wet-bulb temperature, and the flow rate of water through the condenser water circuit shall be measured. The fan power consumption shall be checked from measurements at the fan motor. The tower capability shall then be calculated using the measured values and the manufacturer's performance curves given with the technical submittal of the cooling tower and shall not be less than 95 percent.

10.1.2.6 *Critical parameters for cooling tower*

For Cooling Tower system following are the critical parameters.

a) Water flow rate
b) Water temperature:
    1) *Inlet temperature* – Measures the temperature of the water entering the tower.
    2) *Outlet temperature* – Measures the temperature of the water leaving the tower.
c) Cooling range measures the difference between inlet and outlet water temperatures.
d) Wet-bulb approach measures the difference between the outlet water temperature and the ambient wet-bulb temperature.
e) Fan power consumption monitors the energy used by the fan.
f) Water level
g) pH level
h) Conductivity/Total dissolved solids(TDS)
j) Drift rate

10.1.2.7 *Water quality management in HVAC system*

The objective of Cooling water Treatment is to:

a) Increase production
b) Reduce downtime
c) Lower operating and chemical costs
d) Reduce your operation's impact on the planet

Treatment of cooling water will be different depending upon the kind of system in use. Here are the basic types:

a) Once-through
b) Open recirculating
c) Closed recirculating
d) Specialized

NOTE – A specialized cooling system might utilize compression or absorption-type refrigeration or air conditioning systems or it might include the use of industrial air washers in which air is filtered, sprayed and then forced through a series of mist eliminators.

Water quality is crucial in HVAC systems to prevent scaling, corrosion, and microbiological growth, which shall lead to reduced efficiency, equipment damage, and health risks.

Water treatment should be considered to prevent scaling, corrosion, and biological fouling of the condenser and circulating system.

Large system shall be provided with fixed continuous-feeding chemical treatment system in which chemicals, including acids for pH control, are diluted, blended and pumped into the condenser water system.

Corrosion-resistant materials should be required for the treatment of system components that come in contact with these chemicals. In piping system design, provision for feeding the chemicals, blow down, drain, and on-line testing should be included.

Treatment system design should incorporate mainstream filtration without separate pumping system.

Additionally side stream filtration incorporation in the system design should be considered especially when the primary make-up water is from an un-clarified water source (bore well-tanker water, STP effluent etc) that is high in suspended solids and/or iron.

10.1.2.8 *Recommended methods to control scale formation*

a) *Elimination at source* – Limit the concentration of scale-forming minerals by controlling cycles of concentration, or by removing the minerals before they enter the system.
b) *Monitoring cycle of concentration* – The ratio of makeup water rate to the sum of blow down and drift rate. The cycle of concentration shall be monitored by calculating the ratio of chloride ion, which is highly soluble in the system water, to that in the makeup water.
c) Mechanical changes in the system, like increasing water flow and providing exchanger with larger surface area, to reduce the chances of scale formation.
d) Feed acid to keep the common scale forming minerals, like, calcium carbonate, in dissolved state. Organic acid based specialty chemical formulations (pH reducers) are best suited for pH reduction in cooling water systems in terms of reducing the risk of acid induced corrosion.
e) Treat with chemicals designed to prevent scale. (for example, scale inhibitors, dispersants and crystal modifiers).

For treatment of water for cooling towers, good practice [8-3(44)] shall be referred.

10.2 Closed-Loop Water System Treatment

Cooling and heating systems harness the power of water and refrigerant to transfer heat. Open circuits use cooling towers, while closed loops enclose water in pipes, cooling it through tubes and refrigerant, ensuring efficient temperature control in three precise steps.

Closed-loop systems have a reduced chance of contamination, but they are not maintenance free. Neglecting maintenance of a closed system promotes the growth of sludge and deposits. The most common problem with these systems is black magnetic iron oxide mud deposits. Over time, magnetic iron oxide particles bind together and collect on narrowed parts of the system. The most common place for this sludge is narrowed pipes, heat-transfer surfaces, cooling or heating coils and AHU and fan coils

The pH level of the water drops leads to bacterial growth or a system leak. Bacteria shall lead to pinhole leaks in the pipes, which shall affect both the water levels and chemistry. In addition to leaks, bacteria or mineral deposits shall reduce the ability of the system to transfer heat by coating the surfaces of the parts. Regular care of your components through water testing and chemical maintenance prevents the corrosion of the interior components of the system. In the closed system, effect of corrosion shall not be diagnosed.

While open systems need monitoring of water levels and watching for particulate matter from the environment in the water, closed circuit systems need control of the water's chemistry.

10.2.1 *Chemical Treatment of Closed Loop Systems*

To prevent corrosion in carbon steel components, the water shall maintain a high, or alkaline, pH. To keep the correct chemical balance, water treatment professionals have several options at their disposal:

a) *Polymers* – Prevent corrosion and scale by dispersing harmful components in water, without environmental impact.
b) *Corrosion inhibitors* – Form a protective film on system surfaces, reducing corrosion, buffering pH, and reacting with oxygen.
c) *Biocides* – Eliminate bacteria, preventing organic growth, biofilms, and Legionella bacteria, which shall contribute to corrosion.

10.3 Chilled and Condenser Water Pumps

Radial flow centrifugal pumps are recommended for use in HVAC systems for circulation or transfer of water or water/glycol solutions. Direct coupled pump assembly and inline pump should be used for smaller flow applications. Higher flow rate requiring motor size above 7.5 kW, pumps shall be coupled with high efficiency (IE3 and above) motors. Mono-block pumps shall be used up to 7.5 kW.

The split case horizontal pump shall be used in larger applications. Pumps shall be provided with the tapping on bearing housing for mounting of Vibration and temperature sensors, which shall be used for condition monitoring. For these pumps minimum IE3 (high efficiency class) motors are recommended.

Cavitation shall be avoided by selecting suitable location of pump with respect to the cooling tower, so as to always meet the net positive suction head (NPSH) requirement of condenser water pump.

10.3.1 *Selection Criteria and Types of Pumping System*

Pump shall be selected for optimized efficiency over the load profile, to operate at or near the best efficiency point (BEP) not more than 5 percent from the maximum efficiency curve to achieve energy efficiency. Pump shall be selected for optimized efficiency over the load profile, to operate at or near the best efficiency point (BEP) not more than 5 percent from the maximum efficiency curve to achieve energy efficiency. Wherever there is variable speed application, the pumps shall be with motor mounted VFDs or integrated drives with inbuilt intelligent IOT controls. IoT based controls shall have pump predictive analysis function with alert mechanism through SMS/email for various operational parameters.

Pump motor shall be energy efficient, having minimum IE3 (high efficiency class) motors, totally enclosed, fan-cooled, Class-F insulation and suitable for operation on AFD. Motor shall be specially designed for quiet operation. The motor rating shall be such as to ensure non overloading of the motor throughout its capacity range. Motor shall be suitable for 3-phase 415 + 10 percent volts, variable frequency power supply.

For water pumps, available net positive suction head (NPSH) shall exceed required NPSH to avoid pump cavitation.

The possible types of chilled water recirculation pumps are as given below:

a) Constant speed pumping system;
b) Variable speed pumping system (VSPS)
    1) Parallel VSPS configuration,
    2) Zoned VSPS configuration, and
    3) Primary secondary tertiary pumping system (P-S-T); and
c) Primary only variable speed pumping system (PVF).

In order to improve energy efficiency of larger systems, where pumping energy amounts to 5 percent to 9 percent of total energy consumption in a building, glass flake coatings for large size pumps may be considered, based on life cycle cost assessment as it reduces friction improves and sustain efficiency.

Chilled water circulation system having pump motor larger than 3.7 kW rating are generally designed for variable fluid flow to offer large savings in operating cost.

10.3.2 *Installation of Pump*

The vertical in-line pumps do not require concrete pump foundation as they are of pipe mounted design. They become integral part of the piping system when installed as per manufacturer's instructions. Installation of efficient suction guide and triple duty valves shall also eliminate many piping accessories, resulting smaller installed footprint, as well as lowest embodied and life cycle carbon.

The horizontal base mounted pump base frame shall be mounted on concrete block which in turn shall be mounted on machinery isolation cork or any other equivalent isolation material. More than one pump set shall not be installed on a single base or on a single cement concrete block. Foundation bolts are required, shall be embedded correctly. Before the bolts are grouted and the coupling bolted, the base frame level shall be checked before proceeding with work.

The pump motor shall then be mounted on base frame, alignment checked and shall then be connected to the pump with flexible coupling and with guard, both for the condenser and chilled water pumps.

The insulation for chilled water pump shall be carried out in a manner so that it allows maintenance of the pump without causing damage to the insulation. After installation of the complete system and before testing, the pump shall be lubricated in strict accordance with the manufacturer’s instructions.

10.3.3 *Testing of Pump*

Upon completion of installation, capacity of the pump shall be checked by measuring water flow, using the balancing valve in fully open position, motor current and pressure differential between the inlet and outlet. The readings shall be compared with actual performance identified in the technical submittal of the pump.

10.3.4 *Critical Parameters for Pumping System*

a) Pumps for condenser/chilled water:

1) Water flow rate as established from pump curves based on suction/discharge pressure; and
2) *Head pressure* – Measures the pressure generated by the pump.
3) *Current and power consumption* – Monitors the current drawn and energy used by the pump.
4) *Vibration* – Tracks the mechanical vibration of the pump.
5) *Temperature* – Monitors the pump's and motor’s operating temperature.
6) *Discharge pressure* – Measures the pressure at the pump outlet.
7) *Suction pressure* – Measures the pressure at the pump inlet.
8) *Efficiency* – Calculates the pump's efficiency based on flow rate and power consumption.

10.4 Air Handling Unit (AHU)

All-air system is commonly used for comfort, healthcare, pharma, process applications. This section doesn't apply to AHUs used for data-center application.

10.4.1 *Selection Criteria*

The designer shall select the air handling unit on the basis of supply air temperature and volume; outdoor air requirement; desired space pressure; heating and cooling coil capacity; humidification and dehumidification capacity; return, relief, and exhaust air volume requirement; filtration levels, and the corresponding pressure capability of the fan(s). Controls may be added as required for project specific requirements.

Air handling unit shall be as per accepted standard [8-3(25)] of AHU. It should be verified or certified for the compliance of the standard through an third part certifying agencies for compliance as per the accepted standard [8-3(25)]. Selection criteria should include the sound levels of the AHU like casing radiated, supply and return to help acoustic engineers.

10.4.2 *Fan*

Fan selection should be based on efficiency and sound power level throughout the anticipated range of operation, as well as on the ability of the fan to provide the required flow at the anticipated static pressure.

fans used in AHUs, with motor power exceeding 0.37 kW shall be of minimum mechanical efficiency and minimum fan motors efficiency requirements as specified in below table or as per ESCBC whichever is stringent:

System Type	*Fan Type*	*Mechanical Efficiency*	*Motor efficiency {As per [8-3(26)]}*
Air- Handling unit	Supply, return and Exhaust	65 percent	IE3 and above

In addition, all fans used in AHUs having shaft power 2.5 kw or higher shall meet or exceed the FEI requirements of > 1.1.

a) Fan speed modulation control should be considered to save energy using duct static pressure signal.
b) The power consumed by the AHU to be declared in the selection output and that should be part of the critical parameter for validation and measurement.

10.4.3 *Cooling coil*

Cooling coil shall be designed as per the sensible and latent load. Number of rows of coils shall be determined as per the dehumidification requirements. Provisions shall be made to modulate the chilled water flow rate in the cooling coil for achieving high energy efficiency.

10.4.4 *Reheat coil*

Reheat coil is heating coil placed downstream of a cooling coil. Reheat system is strongly discouraged, unless recovered thermal energy is used. Reheat coil is used to provide precise humidity control, which is generally not required for comfort conditions in most applications. Either reheat or desiccant is usually required to dehumidify outdoor air.

Reheating is necessary for specific applications like, laboratory, health care, or similar applications where temperature and relative humidity shall be controlled accurately. Hot-water coil, which provides a very controllable source of reheat energy, and thereby accurate relative humidity control is the preferred option for reheat coil. Condenser water recirculation through reheat coils may be considered for energy saving.

10.4.5 *Humidifier*

Humidifier shall be installed as part of the air handling unit only where close humidity control of selected spaces is required. For comfort installations requiring humidity control, moisture shall be added to the air by mechanical atomizer or point-of-use electric or ultrasonic humidifier placed in the conditioned area.

10.4.6 *Air to Air Energy Recovery Devices*

All hospitality and healthcare occupancies with energy recovery systems shall have air-to-air heat recovery equipment with minimum 60 percent recovery effectiveness at design conditions.

To prevent the wheel media from transferring exhaust air to the supply air duct, the heat wheel shall be fitted with an adjustable purging sector, with adjustable angle provision. The center of the wheel media shall consist of a hub with a shaft and bearings with efficient seal provided in the clearance between the rotor and the casing to minimize leakage between the supply air and exhaust air. Recommended higher face velocity limit is 3.5 m/s.

The outdoor air correction factor (OACF) and exhaust air transfer ratio (EATR) have direct impact on the energy consumption of the fans. The OACF should be in the range of 0.9 to 1. The EATR > 5 percent should not be acceptable.

10.4.7 *Fan coil unit (FCU)*

FCU shall be in accordance with accepted standard [8-3(25)].

10.4.8 *Air Filters*

Air filters used in AHUs shall be in accordance with accepted standards [8-3(16)], [8-3(17)], [8-3(18)] and [8-3(19)]. It is recommended to use ISO ePM1 50 percent in combination with ISO coarse and ISO ePM1 80 percent as second stage, for comfort applications (apart from critical applications like healthcare and cleanroom etc).

AHU filters shall be tested for filter bypass leakage in accordance with the accepted standard [8-3(25)].

10.4.9 *Vibration Isolation*

Where floor mounted fans are used, the AHU shall have an internal vibration isolation system by mounting fan, motor and drive assembly on suitable deflection type anti-vibration mountings as well the fan discharge shall be connected to the AHU casing through canvas connection to prevent vibration transfer.

10.4.10 *Dampers*

The exhaust air damper/s shall not allow inflow of outdoor air under any circumstances. Dampers should be modulated via an automated control system.

10.5 Installation of Air Handling Unit (AHU)

Following provisions to be considered of installation of air handling units:

a) Floor mounted air handling unit is generally installed on a set of precast PCC blocks to raise it off the mounting surface to permit easy drainage of the AHU drain pan and cleaning of the mounting surface. A set of 4 or 6 numbers of 0.20 m x 0.20 m x 0.20 m blocks are generally used for AHUs up to capacity of 10000 m^3/h airflow, and 6 or more 0.30 m x 0.30 m x 0.30 m blocks for higher capacity AHU.

b) It is essential to provide floor trap in the AHU room for disposal of condensate which accumulates in the drain pan during operation of AHU. AHU room floor should slope in the direction of floor trap to avoid the accumulation of water in AHU room. The condensate drain piping shall be connected with U-trap of the floor drain to avoid odour carry over with the return air.

c) AHU location shall be marked on the AHU floor as per approved shop drawings/manufacturer’s details. Co-ordination with contractors for civil works and other services shall be checked prior to installation.

d) Easy accesses and sufficient clearance shall be ensured for servicing and maintenance, that is, for cleaning of filters, maintenance of strainer/valve packages, tightening of fan belts, and repair as well as possible replacement of fan motor.

e) Duct flexible connection made of fire-proof material, shall be fixed on air outlet of the AHU, and if possible, also in perpendicular direction in main ducts within AHU room, to avoid vibration transmission along the ducts beyond the AHU room.

f) The valve package and piping connections shall be completed as per approved shop drawings.

g) Installation of ceiling suspended air handling unit shall be done with rod and fasteners as per the procedure stated above, barring the PCC blocks required for floor mounted AHU, and that insulated condensate drain pipe shall be laid in slope within ceiling space terminating into the U-trap of the nearest floor drain.

h) Since the AHUs have the tendency to vibrate, both floor mounted and ceiling suspended AHUs shall be isolated from the structure by suitable rubber or spring-based isolators.

10.5.1 *Installation of Air Washer Unit (AWU)* – Air washer unit (AWU) components are similar to those of AHU, except for water spray section with in-line recirculation pump, which replaces the cooling coil. Installation of AWU shall follow the same steps as described above for AHU. Ceiling suspended AWU should be avoided.

10.6 Thermal Insulation

10.6.1 Air conditioning and water distribution systems, carrying chilled or heated fluids/air shall be thermally insulated to prevent undue heat gain or loss and to prevent internal and external condensation. Vapour seal shall be provided on chilled water pipes to avoid possibility of condensation.

10.6.2 The thermal insulation material shall be selected based on following physical characteristics:

a) *Fire properties* – Insulating materials shall be fire resistant and, in case of fire, shall not produce noxious smoke and toxic fumes. Materials and their finishes should inherently prohibit rotting, mould and fungal growth, attack by vermin, and should be non-hygroscopic.

b) Material should not give rise to objectionable odour at the temperature at which they are to be used.

c) It should not cause a known hazard to health during application, while in use, or on removal, either from particulate matter or from toxic fumes.

d) It should have a low thermal conductivity throughout the entire working temperature range.

e) It should have good mechanical strength and rigidity, otherwise it should be cladded for protection.

10.6.3 *Material*

Selection of material shall be as per design requirement, such as, fibre glass, closed cell flexible elastomeric foams, expanded/extruded polystyrene (EPS/XPS) and phenolic foam. Insulation should be flexible in natural to ease of handling, should be able to take contours of the surface on which it is installed, and thickness of insulation should be calculated for each project. For additional information special publication may be referred. The fire rating of insulation material for Class 0 for fire propagation test and Class 1 for surface spread of flame test may be referred from special publication for additional information.

> NOTE – Special publication maybe DIN EN 12667 and EN ISO 8497 for testing thermal conductivity, and BS 476 Part 6: 1989 for fire rating Class 0 for fire propagation test and BS 476 Part 7, 1987 for fire rating Class 1 for surface spread of flame test.

Insulation should possess the self-extinguishing property and it should not drip or spread the flames. Insulation should have zero ozone depletion potential, zero global warming potential, dust and fibre free. Insulation should have good resistance to ozone, oil and chemical. Insulation material should be compatible to various covering options like metal, polymeric, glass cloth, silver polymeric laminate etc

The guidelines for insulating with fibre glass are given below; for other insulation materials, manufacturers' recommendations for installation should be followed.

10.6.4 *Thermal Insulation of Duct*

Insulation material for ducts shall be anti-microbial to ensure the indoor air quality. For microbiological growth on insulation surface and bacterial resistance special publications may be referred.

> NOTE – Special publications maybe ASTM G-21 for Microbiological growth and ASTM 2180 or EN ISO 846 method A and Method C for bacterial resistance.

The insulation materials shall be phenolic foam {as per accepted standard [8-3(27)}/ closed cell flexible elastomeric foam/ fiber glass based. The insulation materials should be non-hydroscopic. PUF / Polyurethane shall not be used.

Elastomeric foam tubes, due to its vulnerability to fire, should be used only with full protection fire against with full cladding to smaller size pipes, and not on ducts.

The thermal insulation material should be wrapped around the duct with facing on outer side. Joints of insulation should be properly sealed with either same type of material or tape of 50 mm width on all longitudinal/transverse joints. Finally, straps should be fixed at suitable interval to ensure that the insulation is properly fixed with the ducts.

10.6.5 *Acoustic Lining of Duct*

Acoustic lining of duct should be carried out as follows:

a) The inside surface of duct on which the acoustic lining is to be provided should be thoroughly cleaned with wire brush and rendered free from all dust and grease.

b) The materials to be used for duct lining shall be 15/25 mm thick resin bonded fiberglass having density of 48 kg/m^3. Open cell flexible elastomeric foam specially formulated only for sound attenuation not for inside duct surfaces, due to its poor fire and smoke emission risks.

c) The insulation should be fixed inside the duct using suitable adhesive and covered with fibre glass tissue paper. Open cell flexible elastomeric Foam should be installed with eco-friendly low VOC adhesive elastomeric foam should pass the tests (for test procedure special publications may be referred) for 50 kW/m^2 exposure.

NOTE – Special publications may be ISO 5659-2.

d) The plain insulation materials used should have an air erosion test certified so as no particles/fibres are dislodged with high velocity air and mix with conditioned air compromising indoor air quality. Materials used should have antimicrobial properties.

e) The insulation should then be covered with 0.5 mm thick perforated aluminium sheet with at least 20 percent to 40 percent perforation.

f) The insulation and aluminium sheet should be secured with cadmium coated bolts, nuts and cup washers/steel screws.

g) Finally, the ends should be sealed completely, so that no lining material is exposed.

h) The lining of initial length of the duct may have to be done as per the requirement at site.

10.6.6 *Acoustic Lining in Equipment Room*

Acoustic treatment in equipment room to prevent noise transmission to adjacent occupied areas should be provided on the walls and ceiling of equipment room with acoustic lining of thermal insulation material.

10.6.7 *Insulation of CHW/HW Refrigerant Pipes*

Pipe insulation Standard material should be EPS/XPS/PUF/closed cell flexible elastomeric foam/fibre glass as per requirement, specified with suitable density and thickness. Adhesive used for setting the insulation should be non-flammable, vapour proof, cold-setting, eco-friendly compound.

The insulation should then be finished as per the specific requirement of the site, as given below:

a) *Inside the building* — Insulation over the pipe work exposed in the building should be finished with specified thickness of aluminium sheet cladding, over a vapour barrier, with 50 mm overlap and tied down with lacing wire.
b) *Outside the building* — Insulation over the pipe work exposed to weather should be finished with vapour barrier, and 12 mm thick cement-sand plaster in two layers of 6mm thick each, followed by curing of minimum 48 h.
c) *Buried pipe insulation* — For pipes outside the building and laid underground, the insulation should be covered with suitable gauge polythene faced hessian, (the polythene facing outward), with 50 mm overlap. All joints should be sealed

with bitumen. A layer of maximum 0.50 mm x 20 mm GI wire mesh netting should be provided over it butting all joint, and it should be laced down with GI wire. A 20 mm thick cement-sand plaster (1:4) should be provided in 2 layers of 10 mm thickness each and should be waterproofed by applying hot bitumen and fixing tar-felt over the plaster. It should be finally finished with a coat of hot bitumen.

d) *Pump insulation* — Chilled water pump should be insulated to the same thickness as the pipe to which they are connected, and application should be same as above. Care should be taken to apply insulation in a manner as to allow the dismantling of pumps without damaging the insulation.
e) *Insulation of valves and fittings in chilled water line* — All valves, fittings, strainers, etc, should be insulated to the same thickness and in the same manner as for the respective piping, taking care to allow operation of valves without damaging the insulation.
f) The thermal insulation of VRF system should be flexible elastomeric rubber insulations with UV resistance.

10.7 Thermal Energy Storage for Demand Management

Thermal storage may be used for limiting maximum demand, by controlling peak electricity load through reduction of chiller capacity, and by taking advantage of high system efficiency during low ambient conditions. Thermal storage will also help in reducing operating cost by using differential time-of-the day power tariff, where applicable. TES system may be designed in accordance with special publications.

NOTE – Special publications maybe API-650 / AWWA D-100.

TES systems should be carefully designed and installed, considering factors like:

a) *Location* – Central plant TES location shall be determined in consultation with the air conditioning engineer, ensuring optimal performance and efficiency.
b) *Structural Integrity* – Adequate structural provisions to accommodate TES system loads, open-area surface installations shall consider vertical system options, complete with approach ladders for manholes etc.
c) *Buried Installations* – Designs shall account for vehicular loads and movements above the installation area. The tanks may be rectangular or Circular with RCC construction.
d) *Insulation* – To meet the thermal performance specifications, the tank to be provided with adequate insulation and cladding.

Thermal storage tank should be technically evaluated for tank material selection, insulation, and sizing, as well as the selection of suitable thermal energy storage media like water, ice, or phase-change materials. System design and controls should also be optimized, including charging and discharging strategies, temperature control, and integration with building management systems. TES systems should be designed with scalability and flexibility, allowing for modular expansion and integration with various HVAC systems.

10.8 Thermal Energy Storage for Critical Facilities

During power outage, chilled water to be made available for the duration the DG set starts and chillers ramp up. TES tanks are to be installed in line with the chillers, so that chilled water flows through the TES tanks then to the load, this to ensure that the tanks are always in charged condition.

TES tanks to be pressurized cylindrical vertical, all welded CS vessels with upper and lower ellipsoidal dish heads. For designing, manufacturing, certification and testing of tanks special publications maybe referred.

NOTE – Special publication may be ASME Section VIII Div.1.

Pressure vessels TES tanks to be fitted with radial disk diffusers to maintain stratification of water to ensure that the chilled water is delivered at the designed temperature and duration.

Designing of TES system and radial disk diffusers may be referred from special publications.

NOTE – Special publication may be ASHRAE Handbook, HVAC Systems and Equipment, Chapter 51.

Pressure vessels to be adequately insulated to meet the thermal performance specifications. Insulation to be protected with cladding.

System controls should also be optimized for charging and discharging strategies, temperature monitoring, and integration with building management systems.

11 HEATING

The efficiency of a heating equipment shall never be more than 100 percent, while a refrigeration system for heating usage shall have the coefficient of performance (COP) than its cooling mode.

Heating Systems are mainly used for hot water generation and space heating for comfort applications and also for Industrial use. The various applications where heating shall be effectively used are:

a) Sanitary hot water generation for residential, commercial and hospitality industry.
b) Space heating for residential, commercial and industrial sector in winters / as required depending on location and climatic conditions.
c) Hot water generation for industrial requirements.

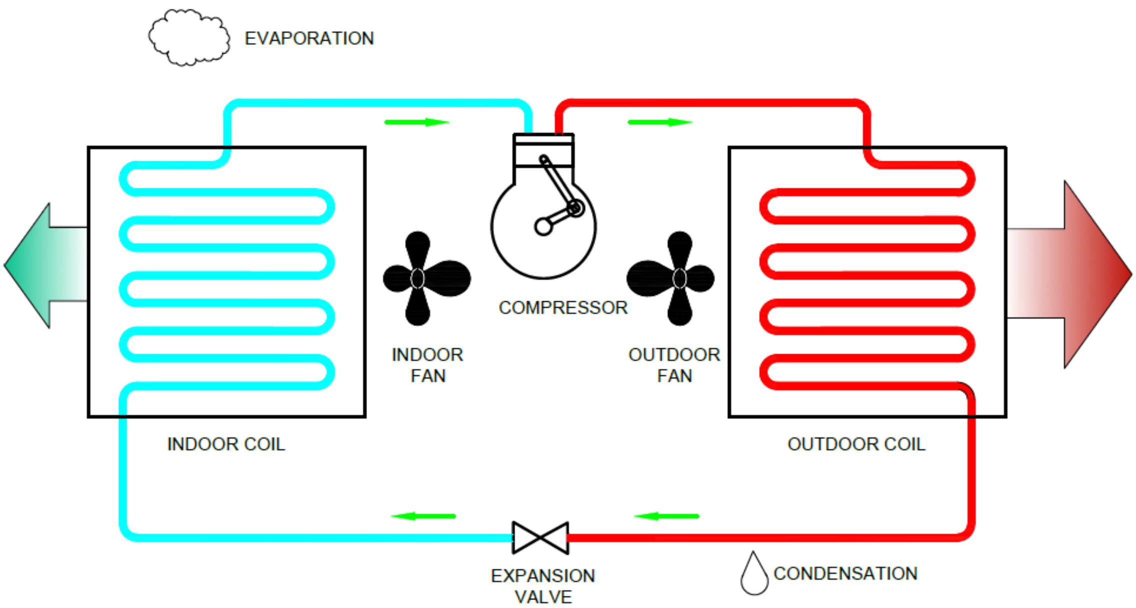
11.1 Various heating equipment / systems

Various heating equipment/systems are described under **11.1.1** to **11.1.7**. These heating equipment / systems shall be used for the building space and water heating applications based on their effectiveness, efficiency, and life cycle cost and installation process.

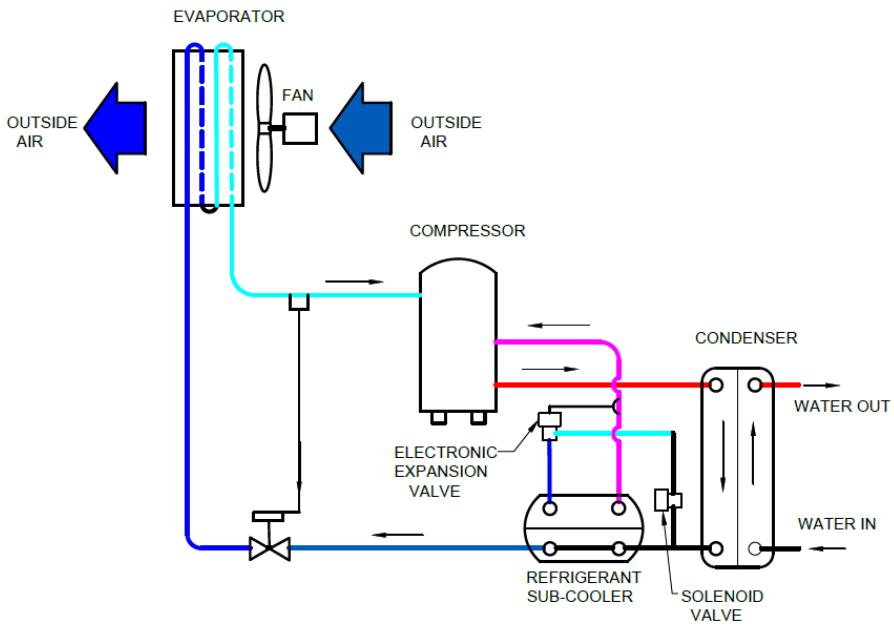
11.1.1 *Heat Pump – Air to Water and Air to Air and Water to Water Type*

There are two types of air source heat pumps. It extracts heat from the air and then transfers heat to either the inside or outside depending on the season is called air to air heat pump. The air-to-air heat pump shall be as per accepted standard [8-3(5)], [8-3(6)] or [8-3(28)] based on its capacity and type (*see* Fig. 3). The air to water heat pump shall be as per best practices given special publications. Water to water heat pump shall be as per standard [8-3(28)] (*see* Fig. 4).

NOTE – Special publication may be ISO 21978.



3A AIR -TO - AIR HEAT PUMP



3B AIR -TO - WATER HEAT PUMP

FIG. 3 AIR TO AIR AND AIR TO WATER HEAT PUMP

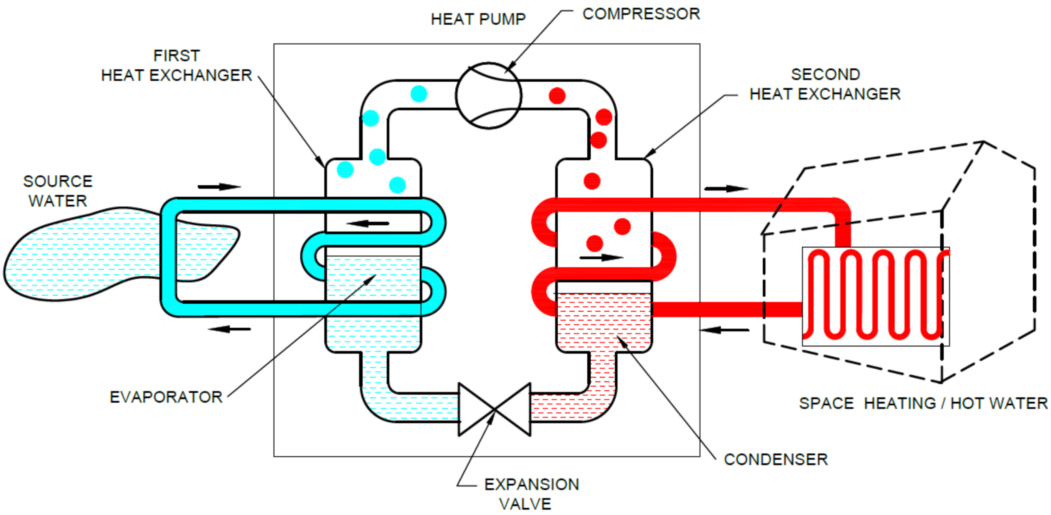


FIG. 4 WATER TO WATER HEAT PUMP

11.1.2 *Heat Pump – Ground Source*

Ground source heat pump uses the earth, or ground water, or both as the source of heat in the winter, and as the sink for heat removed from the conditioned areas in the summer. Heat is removed from the earth by using groundwater or an antifreeze solution; the liquid's temperature is raised by the heat pump; and the heat is transferred to indoor air. For year-round air conditioning, the process is reversed during summer months, heat is taken from indoor air and transferred to the earth, by the ground water. Fig 5 illustrates the schematic of ground source heat pump. This shall be effectively used in locations having low temperature also.

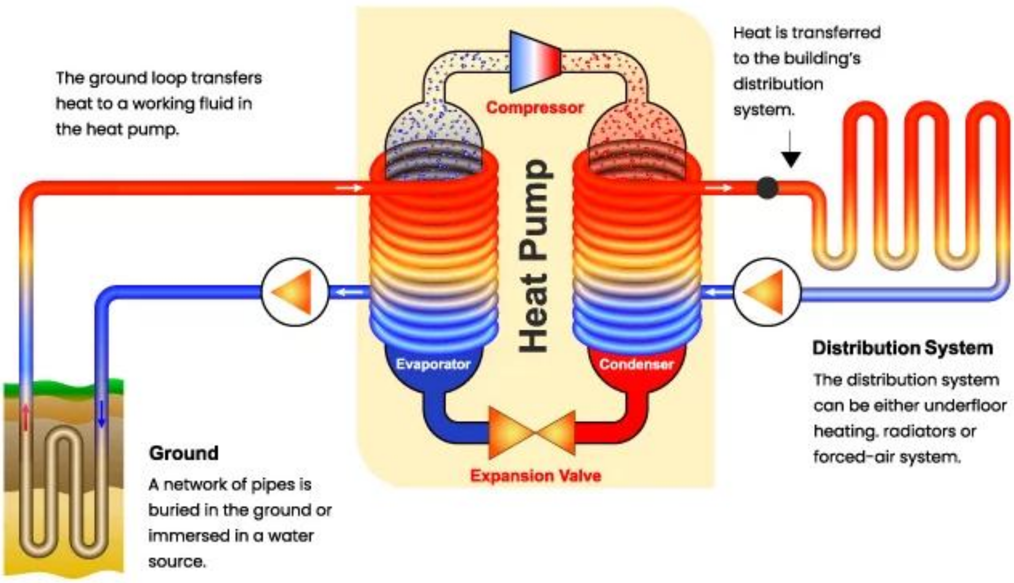


FIG. 5 GROUND SOURCE HEAT PUMP

11.1.3 *Reverse Cycle Systems*

Air conditioner window and split type, VRF system and Dx package units, these systems are available with reverse cycle operation mode which shall supply cold air for cooling in summer and hot air for heating in winter. The performance of Window air conditioners shall be as per accepted standard [8-3(4)], the split air conditioners shall be as per accepted standard [8-3(5)], the ducted split air conditioners shall be as per accepted standard [8-3(6)]. The variable refrigerant flow systems shall be as per accepted standard [8-3(29)] and chillers shall be as per accepted standard [8-3(28)]. The following fig. 6 shows the reversible heat pump both in heating and cooling mode of operation.

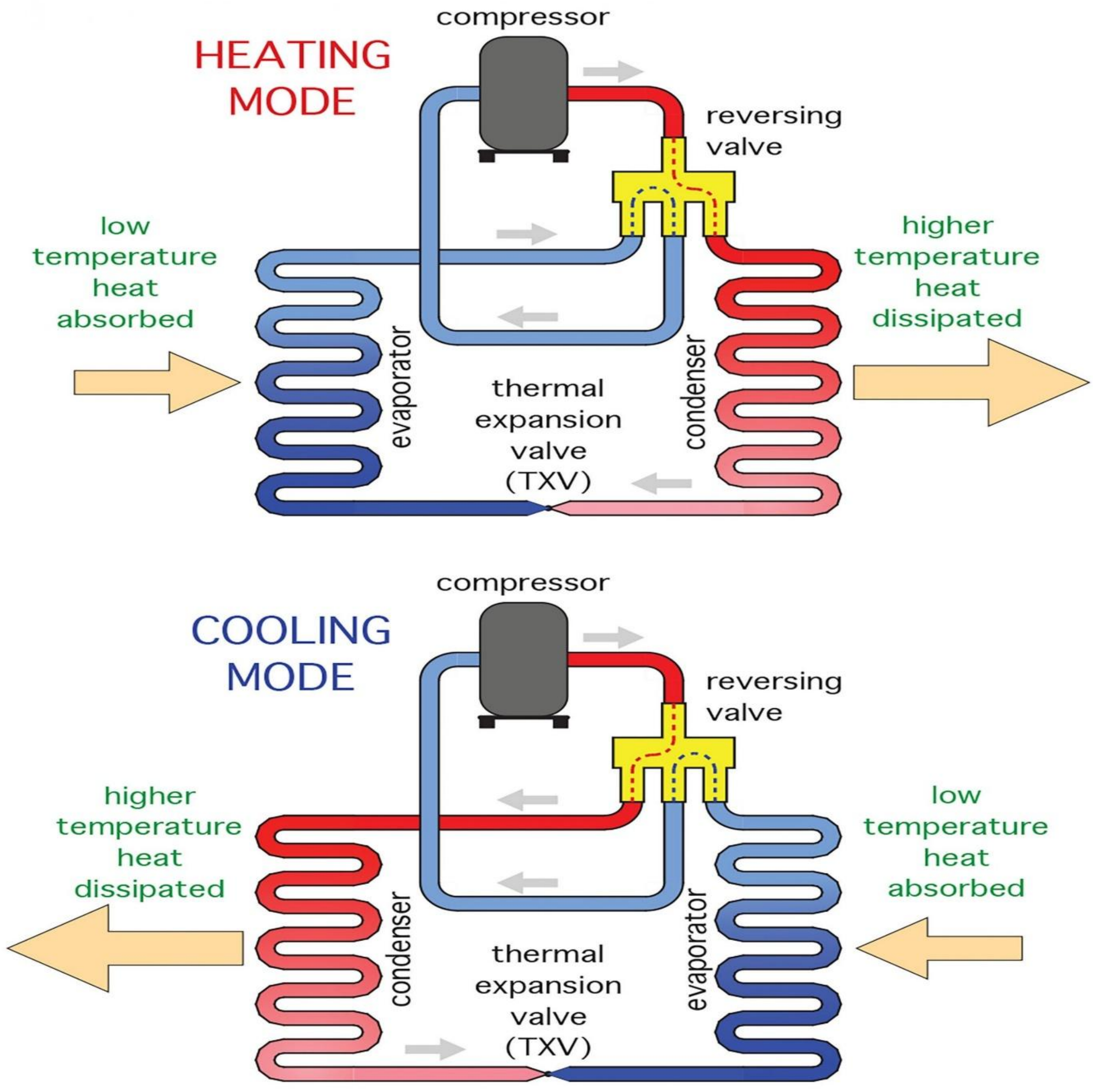


FIG. 6 REVERSIBLE HEAT PUMP

11.1.4 *Solar Water Heating (SWH) System*

SWH system converts energy content of solar radiation into heat energy for water heating using a solar thermal collector. In a close-coupled SWH system, the hot water storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermal siphon flow. In a pump circulated system, the storage tank is ground or floor mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

SWH systems are designed to deliver hot water for most times of the year. However, in winter/monsoon, sometimes there may not be sufficient solar heat gain to deliver sufficient hot water. Therefore, alternative back up system is recommended to be used to meet hot water requirements.

Residential solar thermal installations fall into two groups; passive systems (sometimes called compact) and active systems (sometimes called pumped). Both typically include an auxiliary energy source (electric heating element or gas connection for the hot water storage tank, or fuel oil fired central heating system or heat pump) which is activated when the water in the tank falls below a minimum temperature setting such as 55°C. However, it is recommended to use heat pump in active as well as passive systems to reduce carbon footprint and protect environment hence, hot water is always available. The combination of solar water heating and using the back-up heat from heat pump to heat water shall enable a hot water system to work all year round in cooler climates.

The amount of heat delivered by a solar water heating system depends primarily on the amount of heat delivered by the sun at a particular place, that is, the insolation. In tropical places, the insolation shall be relatively high, for example, 7 kWh/m^2 per day, whereas the insolation shall be much lower in temperate areas where the days are shorter in winter, for example, 3.2 kWh/m^2 per day. Even at the same latitude the average insolation shall vary a great deal from location to location due to differences in local weather patterns and the amount of overcast. The design, installation and performance evaluation of solar heating systems shall be in accordance with the good practice.

11.1.5 *Condenser Heat Recovery System*

Condenser heat recovery system captures energy that would otherwise be wasted in the atmosphere and converts this energy into useful heat. It is possible to capture this heat from the condenser and use it to generate hot water. By capturing this heat, overall system efficiency is considerably improved. Such a system should be used, wherever there is heating requirement concurrent with cooling demand. In a well-designed system this improves the performance of the cooling or refrigeration

11.1.6 *Solar Air Heating (SAH) System*

SAH system converts energy content of solar radiation into heat energy for air heating using a solar thermal collector. SAH systems shall be once through or of recirculating type. In the once through system fresh outdoor air is heated to a higher temperature of around 60 °C to 65°C and supplied indoors through insulated ducting. This air mixes with the conditioned space air to maintain the indoor at a comfortable temperature typically between 18°C to 22°C. In the recirculating type, the conditioned space air is recirculated through the roof or wall integrated solar air heaters. In this case the air delivery temperatures shall be moderate at around 30°C to 45°C. Electric fans or blowers are used to enable circulation of the air. Solar air heaters shall offer solar collector efficiency in the range of 50 percent to 80 percent. Reversible air-to-air heat pumps powered with grid electricity shall be used as backup.

11.1.7 *Electric Heating*

Electric heating system are highly energy consuming and should be applied to specific application where other efficient Heating system shall not be applied due to technical/ location constraints. With all electric heating, care should be taken to preclude the risk of fire under abnormal conditions of operation, by the use of a suitably positioned temperature sensitive trip of the manual reset type, to cut off the electric supply in case of temperature rise beyond the specified limit.

It is recommended to avoid electrical heating to maximum extent possible for the building space or water heating applications.

12 BUILDING TYPOLOGY RELATED CONSIDERATIONS

The general guidance, for various selected building typologies, for the factors that usually influence the selection of the type, design and layout of the air conditioning or ventilating system, to be used are given in this chapter. The primary objective of these is to define the special provisions required for the air conditioning system, to ensure comfort conditions or defined conditions as the case may be for occupants in the respective applications.

These are the following typical building typologies normally envisaged in construction for different applications based on the usage factors:

a) Residential Buildings
b) Office Buildings
c) Campus Buildings
d) Hospitality Buildings
e) Healthcare Buildings
f) Underground Metro Stations
g) Airport Buildings
h) Shopping Complex Buildings
j) Industrial Buildings
k) Tall Buildings

The following criteria shall be common to most of the building typologies:

1) *Building Layout and Orientation* – North-south orientation is often preferred to minimize direct sun exposure. The building orientation to be optimized to reduce heat gain. The design floor plans shall facilitate natural ventilation, air

circulation and daylighting avoiding deep floor plans that limit these measures in case of naturally ventilated buildings.

2) *General Considerations* – Buildings may include both the outer and inner zones. The outer zone may be considered as extending from approximately 4 m to 6 m inwards from the outer wall of the building and is generally subjected to wide load variation owing to daily and annual changes in outside temperature and solar radiation. Ideally, the system(s) selected to serve an outer zone should be able to provide summer cooling and winter heating. During intermediate seasons, the outer zone of one side of the building may require cooling and at the same time, the outer zone on another side of the building may require heating. The main factors affecting load are usually window area and choice of shading devices.

   The other important factors are the internal gain owing to people, light, and other equipment loads. The choice of system may be affected by requirements to counteract down-draughts and chilling effects due to radiation associated with single glazing during winter. Cooling load for the inner zone is generally entirely from the heat gain from people, lights, and equipment, which is generally uniform throughout the year.

   Other important considerations in building applications may include requirements for individual room control, partitioning flexibility serving multiple tenants or residents, and the requirement of operating selected areas outside of normal working hours.

3) *Building Envelope* – The building envelope shall be designed to minimize energy use. Materials with low thermal transmittance (U-value) for walls, roofs, and selection of glass following a detailed study of solar heat gain coefficient (SHGC), U-value and visible light transmittance (VLT) shall be selected. For additional information on high-efficiency insulation materials, special publication may be referred.

   NOTE – Special Publication may be Energy Conservation and Sustainability Building Code (ECSBC) 2024

4) *Ventilation* – Minimum outdoor airflow rate based on occupancy and area requirements shall be provided as detailed in **3** of this chapter. Comprehensive mechanical ventilation system with usage of energy/heat recovery system and CO_2 monitoring and control system to adjust airflow following indoor air quality norms shall be utilised. Also refer to 5.2.5 of Part 8 'Building Services Section 1 Lighting and Natural Ventilation' of the Code.

5) *Indoor Air Quality (IAQ) and Thermal Comfort* – For threshold values related to indoor air quality and requirements for thermal comfort, article on 'Basis of Design' in this section shall be referred.

12.1 Residential Building Typology

This classification helps in understanding the different types of residential buildings based on their design, usage, and structure.

12.1.1 *Room-Specific Design*

a) *Bedrooms* – Quiet AC operation and individual temperature control for better thermal comfort shall be ensured. Outdoor unit of the air-conditioner shall not be installed towards the room/living spaces/balconies. Hot air of the outdoor unit shall be directed toward open spaces/ambient.

b) *Living rooms* – Design of AC in living room shall be appropriate considering peak occupancy. For better thermal comfort and energy savings, AC and ceiling fan both shall be installed in living room.

c) *Kitchens* – Ventilation hoods to remove excess heat and gaseous contaminants shall be installed.

12.1.2 *Insulation and Thermal Mass*

a) Insulation – High-quality insulation in walls, roofs, and floors to reduce cooling loads shall be entertained.

b) Thermal mass – Materials with high thermal mass (for example brick) to stabilize indoor temperatures shall bring in better energy efficiency.

12.1.3 *Window Design and Shading*

a) *Glazing* – Glazing in residential houses refers to the installation of glass in windows, doors, skylights, and other transparent or translucent building components. The choice of glazing impacts energy efficiency, aesthetics, security, and comfort. Glass preferably of lower SHGC based on climatic zone shall be selected. Ratio of VLT / SHGC shall be more.

b) *Shading devices* – Install external permanent /movable shading devices (for example, shade, awnings, louvers) to block direct sunlight. Consider the use of trees and vegetation for natural shading. For large dwelling/projects, optimising shading shall lead to reduced cost and more benefits. Facade shall be designed with specific shading devices/solutions.

c) *Window placement* – Strategically placement of windows to maximize natural light while minimizing heat gain shall be encouraged.

12.1.4 *Ventilation*

a) *Natural ventilation* – Cross-ventilation by aligning windows and openings to allow air to flow through the building shall be envisaged. For a building to be naturally ventilated, it shall have operable windows that occupants shall adjust to maintain their thermal comfort. These windows may include dynamic components like louvers to regulate the amount of air exchange. Open door/window and operation of exhaust fan to ventilate during night, to cool the spaces and remove the heat that traps during daytime shall be worked out.

b) *Mechanical ventilation* – Mechanical ventilation systems shall be designed to complement AC systems, providing fresh air without compromising energy efficiency.

12.1.5 *Sustainability Measures*

a) *Passive cooling* – Passive cooling strategies such as orientation, providing buffer spaces, thermal chimneys, evaporative cooling, and night purging to reduce reliance on AC shall be included in the design.

b) *Landscaping* – Strategic landscaping (for example, planting trees, creating windbreaks) to naturally cool the building and reduce AC load shall be used.

12.1.6 *Cultural and Climatic Adaptations*

a) *Regional design adaptations* – Building design shall adapt to local climatic conditions, such as high humidity areas requiring enhanced dehumidification.

b) *Cultural preferences* – Cultural preferences in building layout and AC usage, such as preferred room temperatures and ventilation styles shall be investigated and included during design.

12.1.7 *Adaptive Reuse and Retrofitting*

a) *Historic buildings* – When retrofitting historic buildings, the preservation of architectural features with the integration of modern AC systems shall be balanced.

b) *Older homes* – Upgrading insulation, windows, and ductwork to improve the efficiency of new AC systems shall be envisaged.

12.2 Office Building Typology

Important considerations in office building applications may include requirements for individual room control, partitioning flexibility serving multiple tenants, and the requirement of operating selected areas outside of normal office hours. Areas such as conference rooms, board rooms, shall teens, etc., will often require independent systems.

12.2.1 *Specific Guidelines for Large / Small Office Buildings*

a) *Centralized HVAC systems* – Centralized HVAC systems shall be specifically considered for their high efficiency and flexibility in handling variable loads. Centralized systems shall provide cooling and heating based on the specific needs of different zones, enhancing overall energy efficiency.

b) *Demand-controlled ventilation (DCV)* – Implementing demand controlled ventilation (DCV) should be considered to optimize ventilation rates based on real-time occupancy and indoor air quality. This shall reduce energy consumption while maintaining a comfortable environment.

c) *Indoor air quality monitoring (IAQ)* – IAQ sensors shall be considered to continuously monitor and maintain optimal indoor air quality levels. These sensors shall measure parameters such as CO_2 levels, humidity, and volatile organic compounds (VOCs), there by maintaining and monitoring to ensure a healthy indoor environment.

d) *Air purification technologies* – Advanced air purification technologies such as UV-C light / bipolar ionization / other passive air purification methods should be used to reduce airborne contaminants of their levels exceed the threshold values given in **3**. These technologies shall be particularly beneficial in reducing the spread of airborne diseases and improving overall air quality.

e) *Predictive maintenance* – Predictive maintenance using IoT and smart sensors should be considered. This approach shall identify potential issues before they lead to system failures, reducing downtime and maintenance costs.

f) *Enhanced humidity control* – Desiccant dehumidification systems should manage high humidity levels, particularly in areas with high latent gains. Proper humidity control is essential for maintaining comfort and improving indoor air quality.

g) *Energy recovery ventilation (ERV)* – ERV systems to improve indoor air quality inclusion shall enhance energy efficiency by recovering energy from exhaust air. ERVs shall significantly reduce the load on heating and cooling systems by pre-conditioning incoming fresh air. For additional information, special publication may be referred for the Energy recovery system.

NOTE – Special publication maybe ISO 16494.

h) *Advanced zoning strategies* – Implementing advanced zoning strategies for large office spaces should be considered by dividing office spaces into detailed zones based on occupancy and usage patterns and use of automated systems to adjust HVAC settings dynamically in different zones shall lead to energy efficiency to systems.

j) *Building management systems (BMS) and IoT integration* – HVAC systems should be integrated with building management systems (BMS) for centralized control and monitoring and utilizing IoT devices to enable real-time data collection and automated adjustments, shall optimize energy efficiency and system performance.

k) *Noise reduction measures* – Advanced soundproofing materials and design techniques to minimize the operating noise levels of HVAC equipment and further ensuring low noise levels enhances occupant comfort, especially in open office environments.

m) *Green building practices* – Green building practices such as incorporating renewable energy sources (for example, solar panels) to power HVAC systems and using sustainable building materials should be considered. This aligns with global trends towards environmental responsibility and sustainability.

12.3 Campus Building Typology

This section outlines HVAC requirements for a large campus (facility consisting of multiple single or multi-use buildings or structures within a premise), including residential and (or) non-residential educational institutions, IT/ITES parks. The design and implementation of heating, ventilation, and air conditioning (HVAC) systems for campus projects shall meet several key requirements to ensure efficient, effective, and sustainable operation.

12.3.1 *General Requirements*

These guidelines help in categorizing and designing buildings within a campus based on their function, layout, and structural needs.

a) *Scalability and flexibility* – The system design shall allow for future expansion as well as varying nature of usage of spaces by designing modular components for easy upgrades to ensure flexibility to adapt.

b) *Energy efficiency* – Central HVAC systems with advanced controls, with predictive maintenance and energy system for optimum energy use shall be designed. Centralized air-conditioning system with a diligent feasibility/viability study of a particular system invariably leads to better energy efficiency solutions. In case of mixed used buildings (residential, office, laboratories, etc) in the campus, the projects should consider choosing district cooling system for better resource efficiency and sustainability. The system design feasibility for district cooling systems or alternate energy cooling systems shall be referred in detail from **6** and **7**. Variable speed drives for motors and fans shall be used

   Life cycle analysis shall further support to demonstrate business case of selecting a particular system. Minimizing the ecological footprint of HVAC systems and use environmentally friendly refrigerants, implementation of systems that conserve water and other resources should be considered

c) *Heating systems* – Heat pumps/high efficiency central heating system as detailed in **11** for space heating as well as water heating Integrate heating systems with building management / optimization systems (BMS) for optimal control.

d) *Zoning and control* – Multiple zones for different buildings or areas use advanced control systems for precise temperature and humidity levels and incorporate programmable thermostats and building management systems (BMS). Advanced zoning strategies for large campuses by dividing campus buildings into detailed zones based on occupancy and usage patterns, automated systems to adjust HVAC settings dynamically in different zones shall be standard practices. Occupancy diversity into zoning for better control and energy savings as well as thermal control strategies based on space type and usage shall be considered. For more details on building automation and zoning control refer to **15**.

e) *Occupancy and lighting schedules* – HVAC and lighting schedules with occupancy to optimize energy use shall be aligned. Automated lighting systems with daylight harvesting and occupancy sensors and scheduling HVAC operations before occupancy starts for optimal usage is preferred.

f) *Urban heat island (UHI)* – Urban heat island (UHI) causes discomfort and increases energy consumption of air-conditioners. Mitigation measures to reduce the impact of UHI and its associated impacts shall be considered. Proper placement of HVAC equipment to avoid UHI and manage distance between equipment (especially air-cooled outdoor equipment) to release the heat and avoid creating local heat spots need a due consideration.

12.3.2 *Operation and Maintenance (O&M)*

These ensure the effective management, upkeep, and long-term performance of campus buildings and their systems

a) *Energy management* – Energy management strategies within the BMS to minimize energy consumption by scheduling HVAC operations to match occupancy patterns and utilizing energy-efficient modes during non-peak hours and similarly system designed to showcase performance levels (square foot/TR) shall lead to better energy management.

b) *Maintenance* – As the energy consumption in the large campuses is huge, the predictive maintenance and cloud monitoring for advanced energy efficiency may be considered as part of the system for effective monitoring and for taking proactive measures. Advanced monitoring systems to track performance in real-time and scheduled maintenance based on predictive analytics will lead to lower down times. Detailed logs using a computerized maintenance management system (CMMS) shall be maintained.

c) *Retro/re-commissioning* – Analysing HVAC system performance after one year of operation to compare design with actual performance. Necessary retro-re/commissioning to improve performance based on load profiles of several components for example fan/pump/motor etc. (following over/under load conditions) shall be undertaken.

12.3.3 *Specific Requirements for Campus Project*

These requirements address the unique operational needs and considerations for designing and managing campus buildings.

a) *Climate adaptation* – Implement HVAC system modifications for different climatic zones (hot and dry, warm and humid, composite, temperate, cold).

Use adaptive thermal comfort models to enhance occupant comfort and energy savings.

b) *Water conservation* – Emphasize water-efficient HVAC systems, especially in water-scarce regions. Encourage the use of condensate recovery systems to reuse water in cooling towers or irrigation. Promote the use of water-efficient fixtures and fittings in all campus buildings.

c) *Sustainability practices* – Campus buildings are encouraged to use sustainability practices (green building guidelines) and sustainability standards shall follow for enhanced sustainability. Promote the use of recycled and sustainable materials in HVAC installations.

d) *Resilience and reliability* – HVAC systems that shall handle frequent power outages and voltage fluctuations shall be envisaged. The inclusion of backup systems to ensure continuous operation during power failures shall be an essentiality. Robust disaster recovery plans to maintain HVAC operations during emergencies shall be included.

e) *Testing and commissioning* – Thorough testing, balancing, and commissioning procedures shall be followed. Standardized protocols for verifying system performance before handover shall be compulsory. For detailed guidelines refer **17**.

12.3.4 *Educational Campus Buildings*

Special attention for the design of the HVAC systems shall be paid to meet the needs of every age group in this type of buildings. The equipment should be easy to operate and maintain and the design should provide no drafts. These facilities have two distinct occupant zones: (a) the floor level, where younger children play, and (b) normal adult height, for the teachers. The administrative and teachers' offices shall be considered as a separate zone.

Special consideration shall be given to operating schedule for setback. Supply air outlets should be positioned to avoid drafts. Proper ventilation and exhaust shall be provided for controlling odours and to prevent the spread of diseases. University and college campus having large diversity in cooling/heating loads, should be provided with large central utility plant or smaller mechanical rooms serving a cluster of buildings. The central utility plant shall supply chilled/hot water depending on the zonal requirement. The designer should consider site constraints, including geographic location. In addition to accommodating the mechanical and electrical equipment, central utility plant may also house engineering, operation and maintenance personnel. A central control room shall be provided for energy monitoring.

12.4 Hospitality Buildings Typology

It is critical to focus on guest comfort, energy efficiency, and system reliability. Each guest room or each zone shall be provided with not less than one thermostat capable of being set from 20°C to 30°C and capable of operating the system's cooling and heating. The thermostat or control system, or both, to have an adjustable dead band, the range of which includes a setting of 12°C between cooling and heating, where automatic changeover is provided. Wall mounted temperature control shall be mounted preferably on an inside wall and shall meet the requirements given in **15**.

12.4.1 *Guest Rooms*

Guest room systems are required to be available for operation on a continuous basis. The room may be unoccupied for most of the day and therefore provision for operating at reduced capacity, or switching off, is essential. Low operating noise level, reliability and ease of maintenance are essential. Treated fresh air (TFA) is introduced through an independent TFA system, it is generally balanced with the bathroom extract ventilation, to ensure air circulation into the bathroom. Fan coil unit is generally found to be the most suitable for this kind of application with speed control for fan and motorized/modulating valve for chilled water control for cooling.

12.4.2 *Restaurant, Cafeteria, Bar and Night Club*

These applications have several factors in common; highly variable loads, with high latent gains (low sensible heat factor) from occupants and meals, and high odour concentrations (body, food and tobacco smoke odours) requiring adequate control of fresh air extract volumes, direction of air movement for avoidance of draughts and make up air requirement for associated kitchens to ensure an uncontaminated supply. This type of application is generally best served by the all-air type of system preferably with some reheat or return air bypass control, to limit relative humidity. Either self-contained packaged unit or split system, or air handling unit served from a central chilled system, may be used. Sufficient control flexibility to handle adequately the complete range of anticipated loads, is essential.

12.4.3 *Specific Criteria to be Adhered for Hospitality Buildings*

a) *Occupant (guest) comfort* – Air-conditioning system to maintain consistent temperature and humidity control in guest rooms, lobbies, restaurants, and common areas. There shall be individual temperature and ventilation controls in guest rooms for personalized comfort. Ensure rapid response to temperature adjustments for good comfort conditions.

b) *Energy efficiency* – Energy-efficient HVAC equipment such as high-efficiency chillers/cooling system, boilers, and heat pumps shall be needed. Occupancy sensors and smart thermostats reduce energy use in unoccupied rooms. Integrating energy recovery ventilation systems to reclaim and reuse waste heat or cooling shall bring in additional energy efficiency. Heat recovery system shall be sized based on floor/occupancy loading.

c) *Zoning and control* – HVAC systems cater to multiple zones with different activity areas of the hotel, such as guest rooms, dining areas, and conference rooms. Advanced control systems for precise temperature and humidity regulation as well as building management system (BMS) for centralized monitoring and control of HVAC operations shall be designed and used as detailed in **15**.

It shall be necessary to avoid mixing of air of various type of zoning (corridor, guest rooms, guest areas where smoking allowed, kitchen ventilation, etc), designate smoking and non-smoking areas by pressure differentials between zones.

d) *Noise control* – Low-noise HVAC equipment shall be used to ensure a quiet environment. Necessary sound attenuation measures shall be installed in ductwork and mechanical rooms to reduce noise. Proper acoustic insulation in guest rooms and other sensitive areas for ensuring low/nil cross talk between areas shall be initiated.

e) *Sustainability* – Integrating passive and active heating/cooling system to minimize greenhouse gas emissions and developing the hotel/hospitality project to incorporate sustainable design practices shall be followed.

f) *Reliability and maintenance* – Durable and reliable HVAC equipment to minimize downtime and maintenance issues shall be needed as the systems are generally required to function round the clock throughout the year. Systems should have easy-access for maintenance and repairs and a preventive maintenance schedule to ensure long-term system reliability and performance shall be implemented.

g) *Aesthetic integration* – HVAC design shall coordinate with the hotel's interior design to minimize visual impact and use discreet and aesthetically pleasing diffusers, grilles, and other HVAC components without compromising on functional effectiveness and air distribution patterns. HVAC components shall be selected to seamlessly integrated into the overall architectural design.

h) *Environmental impact* – The ecological footprint of HVAC systems shall be minimised by using environmentally friendly refrigerants and materials. Water conservation measures, particularly in cooling towers and other water-intensive components shall be a priority. Use of treated water for cooling tower and designing systems to reduce overall energy consumption and waste shall be adhered. Calculate environmental impacts of refrigerants used in air-conditioning/fire suppression system (calculate ODP – ozone depleting potential if applicable and GWP – global warming potential). Project to utilise new age refrigerant/natural refrigerant to minimize or avoid negative impact of refrigerants. For more details, please refer to **5**.

j) *Guest room control systems* – User-friendly interfaces for guests to control room temperature, ventilation, and other comfort settings shall be provided. Integrating with hotel management systems to optimize energy use based on occupancy and guest preferences and by offering customizable settings enhance the guest experience and also accommodates individual needs.

k) *Operation and maintenance of HVAC system* – Comprehensive training for facility managers and maintenance staff on the operation and maintenance of HVAC systems shall be provided. Ongoing support and service agreements with HVAC vendors for timely repairs and updates and constant skill upgradation for staff on energy-saving practices and the proper use of HVAC control systems shall be followed. Make provision to clean ducts periodically to offer hygiene conditions to guest, staff/occupants.

m) *Scalability* – HVAC systems shall be designed to accommodate future expansions or renovations, use modular components for easy upgrades and modifications. Ensure the system shall adapt to varying occupancy rates and seasonal changes.

n) *Specialty areas* – HVAC systems shall be designed for specialty areas such as spas, kitchens, and conference rooms for meeting specific requirements. Adequate ventilation and humidity control in spas, pools, and fitness centres and robust exhaust systems in kitchens to manage odors, heat, and smoke effectively shall be provided.

12.5 Healthcare Building Typology

HVAC Systems in healthcare facilities provide a broad range of services in support of people who are vulnerable to an elevated risk of health, fire and safety hazard.

12.5.1 *Basic Classification of Health Care Facilities*

Health care facilities vary widely in the nature and complexity of services they provide and the relative degree of illness or injury to the patients treated- like clinic, diagnostic centers, medical centers, specialty hospitals, super specialty hospitals etc., Environmental control requirements and the role of HVAC system in life safety and infection control becomes very important with the medical services provided.

Ventilation in healthcare buildings is crucial for maintaining air quality, controlling infections, and ensuring the comfort and safety of patients, staff, and visitors. Healthcare facilities have unique ventilation requirements due to the need to manage airborne pathogens, chemical contaminants, and varying needs of different areas.

12.5.2 *Design Criteria*

While designing HVAC for a healthcare facility, Patient therapy shall be the prime consideration, the plan shall include the following parameters which shall be taken into consideration:

a) Temperature and humidity requirements of various spaces.
b) Ventilation requirements /Air changes requirements
c) Filtration requirements for contamination control.
d) Restriction on air movement between adjoining spaces.
e) Permitted tolerance on environmental conditions.
f) Redundancy/backup
g) Life safety
h) Efficiency bench marking on the equipment
j) Guidelines for parameters
k) Standards/ good practices
m) Ease of installation and Maintenance friendly

12.5.3 *Key Considerations*

These considerations ensure that healthcare buildings are designed to meet the specific functional, safety, and regulatory requirements essential for patient care and medical operations.

a) *Comfort conditioning* – Across health care facilities, health care practices often expose patients and staff to conditions that dictate unique environmental requirements. As in any other building, comfort of occupants is fundamental to overall well-being and productivity also it has a significant role in facilitating healing and recovery.

b) *Therapeutic conditioning* – Certain Medical functions, treatments or healing processes demand controlled environmental temperature and relative humidity conditions that deviate from the requirements for personal comfort. Operating rooms and other key areas require a range of room temperature spanning several degrees regardless of the season to best facilitate a given procedure or patient condition.

c) *Infection control* – Medical facilities are places where relatively high levels of pathogens are generated and concentrated by an infected patient population or by procedures that handle infected human tissues and bodily fluids. Filtration levels and air changes per hour (ACH) play a vital role in controlling the risk.

d) *Pressure differentials* – Implement negative pressure in airborne infection isolation (AII) rooms to contain airborne pathogens and positive pressure in operating rooms (OR) / protective environment (PE) rooms to protect patients from outside contaminants.

e) *Life safety* – HVAC systems are required to support special building compartmentation, opening protection, smoke control and smoke detection systems. Containment is facilitated by smoke and fire dampers and some cases restricting cross overs between smoke zones.

f) *Noise control* – Noise control is of high importance because of negative impact of high noise levels on the patients and the need to safeguard patient privacy.

12.5.4 *Energy Efficiency/Sustainability Considerations*

These guidelines focus on optimizing energy use and incorporating sustainable practices in the design and operation of buildings to reduce environmental impact.

a) *Role of building envelope* – The building envelope in healthcare facilities is a critical component that affects energy efficiency, indoor environmental quality, and overall functionality. Given the unique needs of healthcare environments, the building envelope shall be designed with stringent requirements to ensure patient safety, comfort, and operational efficiency.

b) *Energy-Efficient Window* – Windows with low solar heat gain may be used in order to minimize heat loss and gain shall be used. Windows shall have proper seals to prevent air infiltration.

c) *Air Tightness* – Building envelope shall be well-sealed to prevent air leaks by providing proper sealed building envelope. This is essential for controlling indoor air quality and maintaining the efficacy of HVAC systems.

d) *Testing and Commissioning* – Apart from the procedures listed in **,** additionally shall conduct blower door tests and infrared thermography tests during commissioning to identify and rectify any air leakage points.

e) *Natural Light and Views Daylighting* – The building envelope shall be designed to maximize natural light, reducing the need for artificial lighting and creating a more patient friendly environment. This includes the strategic placement of windows, skylights, and light wells.

f) *Glare Control* – Shading devices, low-E glass, or other technologies shall be incorporated to control glare and excessive solar heat gain, enhancing comfort and reducing cooling loads.

Guidelines for the above parameters for various functional spaces in a health care facility are given in tables 25 and 26.

Table 25 Guidelines for Parameters to be Considered for HVAC System Design for Health Care Facilities
(*Clause* 12.5.4)

Sl No.	**Area / Functional Space**	**Temperature** ˚C	**Relative Humidity** percent	**Minimum Total Air Changes per Hour**	**Minimum Air Changes of Outdoor Air per Hour**	**Air Pressure in Relation to Surrounding Area / All Room air directly exhausted to outdoors**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Operating theatres	20-24	20-60	20	4	Positive / NR
ii)	Cath labs	21-24	Max 60	15	3	Positive / NR
iii)	Delivery rooms	20-24	20-60	20	4	Positive / NR
iv)	Recovery room, ICU, Treatment rooms	21-24	Max60	6	2	Equal / NR
v)	Endoscopy, Bronchoscopy	20-23	Max60	12	2	Negative/NR

Sl No.	Area / Functional Space	Temperature °C	Relative Humidity percent	Minimum Total Air Changes per Hour	Minimum Air Changes of Outdoor Air per Hour	Air Pressure in Relation to Surrounding Area / All Room air directly exhausted to outdoors
(1)	(2)	(3)	(4)	(5)	(6)	(7)
vi)	Patient rooms	21-24	Max60	6	2	Equal / NR
vii)	Toilets	-	-	-	10	Negative/Yes
viii)	Protective environment rooms (Immuno suppressed patients)	21-24	Max60	12	2	Positive / NR
ix)	Isolation room (for patients with infectious disease)	21-24	Max60	12	2	Negative/Yes
x)	Corridors	-	-	2	2	Negative/NR
xi)	X-ray/Radiology	21-24	Max60	15	3	Positive / NR
xii)	Laboratories (Other than biochemistry and serology)	22-26	Max60	6	2	Negative
xiii)	Biochemistry and serology labs and pharmacy	22-26	Max60	6	2	Positive / NR
xiv)	Admission/Waiting rooms	22-24	Max60	6	2	NR / NR
xv)	Diagnostic/Treatment OPD	21-24	30-60	12	2	NR / NR
xvi)	Sterilizer Equipment room	NR	NR	10	-	Negative/Yes
xvii)	Sterilizer storage	22-26	Max 60	4	2	Positive / NR

Table 26 Guidelines for Filter Efficiency Requirement in Health Care Facilities
(*Clause* 12.5.4)

Sl No.	Category	Area/Designation	Filter Class (Efficiency)	
			Filter Bed 1	Filter Bed 2
(1)	(2)	(3)	(4)	(5)
i)	Category 1	a) Orthopedic OT b) Bone marrow transplant OT c) Organ transplant OT d) PE rooms including Burn Units	G4 (MERV 8)	F8 (MERV 14 and (HEPA at outlets)
ii)	Category 2	a) General OT delivery rooms	-G4 (MERV 8)	F8 (MERV 14)
		b) ICU, patient care rooms	G4 (MERV 8)	Not required
iii)	Category 3	a) Treatment rooms b) Diagnostic areas	G4 (MERV 8)	Not required
iv)	Category 4	a) Laboratories b) Sterile storage	G4 (MERV 8)	Not required
v)	Category 5	a) Food preparation b) Laundry c) Admin, etc	G4 (MERV 8)	Not required

12.5.5 *Air Distribution System*

The fresh air changes per hour as well as the total air changes shall be minimum as per the guidelines given in table 25 above.

For critical care areas, variable air volume systems shall be used for energy conservation by controlling supply, exhaust and return air and maintaining the pressure relationships as per standards and inside design conditions without any compromise. Critical areas in general are operating theatres, ICUs, isolation rooms, sterile areas, post-operative patient care; any place which houses medical surgical procedures and some of the laboratories.

For patient rooms and non-critical areas, variable air volume system shall be considered for energy conservation. However, when variable air volume systems are used, care should be taken to ensure that minimum ventilation requirements are not compromised and pressure balance is maintained even at minimum flow.

Active smoke control systems shall be used along with fire and smoke partitions to limit the spread of smoke in the event of fire. Smoke and fire management shall be done in accordance with Part 4 'Fire and Life Safety' of the Code and **19**. For health care facilities which provide ambulatory care to patients, safety from fire and smoke is a paramount design consideration and shall be provided in accordance with Part 4 'Fire and Life Safety' of the Code.

A separate exhaust system shall be provided for removal of anaesthesia gases from the operation theatre. Alternatively, proper isolation dampers may be provided in the air circulation system for removal of anaesthesia gases or fumigation effect if this system of fumigation is followed in health care.

Air handling devices shall be designed to prevent water intrusion and permit access for inspection and maintenance. Draw through air handling systems shall be used as moisture ingression is minimized in these systems. Lower face velocity across the coil in the range of 1.27 m/s to1.52 m/s shall be considered for better heat transfer.

When humidifiers are provided, they shall be located with-in the air handling unit or duct work in such a way that moisture accumulation on downstream components do not take place. Evaporative pan type humidifiers shall not be used.

Fibrous acoustic insulating material shall not be used as duct lining for critical spaces. Supply air ducts shall be externally insulated as required.

Multiple direct drive plenum fans may be used in air handling units serving critical areas. This provides redundancy and minimizes shut down of critical areas in case of single fan failure.

For critical areas, both supply air and return air shall be ducted. Ducts shall be sized for medium velocity and medium pressure drop 12 m/s and 4 mm for 10 m maximum. For applications like operation theatres and intensive care units, the preferred material for ductwork should be of corrosion resistive metal sheets.

Ultraviolet germicidal irradiation is recommended for air handling units serving health care facilities. Lamps may be installed either upstream or downstream of the evaporator coil but away from the filter media.

12.5.6 *Air Flow and Filtration*

Outside air intakes shall be located minimum 8 m away from exhaust stacks, cooling tower and/or any other polluting source. Bottom of an outdoor air intake shall not be located less than 2 m above ground level and 1 m above any roof terrace level.

Exhaust outlets shall be located at a minimum height of 3 m away from ground level and away from doors, occupied areas and operable windows. Locating exhaust outlets above the roof, projecting upwards, is preferred.

While installing filters, care shall be taken to see that there is no scope for leakage between frame and filters and between filter segments. Filters shall be as per tested to accepted standards [8-3(16)], [8-3(17)], [8-3(18)] and [8-3(19)].

All openings in ducting/diffusers collars shall be sealed to prevent infusion of dust and dirt. All slab openings shall be terminated in enclosed rooms and airflow systems shall be designed and balanced to create positive or negative air pressure with-in specified areas.

It is recommended that supply air outlets shall be located at or near the ceiling and return/exhaust is collected near the floor level. This is to ensure that clean conditioned air moves through breathing and working space to the floor area, for return/exhaust.

For operating room and procedure room, where patients are highly susceptible to infection, such as orthopaedic and cardiac operating theatres, laminar air flow system shall be considered. A unidirectional air flow pattern at a max velocity of 0.13 m/s to 0.18 m/s should be aimed for to prevent the thermal plume at surgical site getting disturbed. A vertical laminar flow system which will wash the patient on the operating table and flow downwards, to be collected near floor level, shall be chosen for such rooms. The area of laminar flow grid shall extend by a minimum of 0.450 m beyond the footprint of the operating table on all sides. If required, additional supply diffusers may be provided for achievement of required temperature and humidity.

Minimum two (2) exhaust grilles shall be provided at opposite corners of the room at approximately 0.200 m above the finished floor level.

12.5.7 *Pressure Differential*

Operating rooms where highly infectious patients are treated and isolation is required, an anteroom shall be provided between the operating room and external area. Anteroom shall be maintained at positive pressure with respect to both the operating room and the surrounding areas.

All air from operating rooms shall be recirculated with adequate fresh air changes and Total air changes per hours and filtration as per tables above or exhausted after energy recovery. Similarly, from all airborne infection isolation rooms, all air shall be exhausted directly to outdoors through high efficiency particulate air (HEPA) filters. Such rooms shall be maintained at a minimum negative pressure of 2.5 N/m^2 with respect to surrounding areas.

Protective environment rooms, such as, bone marrow transplants and organ transplants, shall be maintained at a positive pressure of 2.5 N/m^2 with respect to surrounding spaces.

12.5.8 *Conditioning Equipment*

Cooling equipment shall be central or local chilled water systems, direct expansion type condensing units or variable refrigerant flow systems. Indirect cooling systems using chilled water are preferred and, if direct cooling systems are used, required safety measures should be adopted. Heating equipment shall include heat pumps and heat exchangers.

Sizing and arrangement shall give adequate consideration to minimum loading and standby facility for critical areas. It shall be possible for the facility to operate even when one of the systems is under break down or maintenance.

Where specific areas are to be maintained at a low temperature coupled with low humidity, an additional direct expansion coil may be introduced downstream of the regular evaporator coil. In such cases, the control strategy shall ensure that the DX coil is energized only after the main evaporator coil is at full load.

When variable refrigerant flow systems are used, care shall be taken to see that minimum air change and pressure differential considerations are not compromised.

12.5.9 *Installation and Maintenance*

The air distribution system shall be provided with access panels to allow inspection and cleaning. Duct systems shall be cleaned of construction debris before commissioning.

Surfaces of air terminals shall be suitable for cleaning.

Access to equipment rooms shall be planned so as to avoid intrusion of maintenance personnel into critical care areas. Equipment room layout shall allow easy access to equipment for its operation and maintenance.

Operation and maintenance records shall include indoor temperature and pressure requirements as well as permitted tolerances for all spaces. It shall also include standard operating procedures for emergencies, such as power failure, equipment breakdown and fire situation.

Pressure differentials of operating rooms, protective environment rooms, and air borne infection isolation rooms with respect to surrounding areas, shall be verified and recorded semi-annually.

HEPA filters shall be replaced periodically based on pressure drop. Filters of fan coil units and air handling units (AHU) shall be cleaned according to a regular maintenance schedule. AHU/fan coil drain pans shall be of stainless-steel construction and shall be cleaned monthly.

Supply and return air ducts for critical areas shall be tested for air leakage and an air blow down process shall be undertaken before loading of filters. All areas served by the AHU shall be cleaned and mopped before the AHU is started. Filters shall be loaded in sequence. Pre-filters shall be loaded first followed by microvee or fine filters and finally HEPA filters. AHU shall be run with each set of filters for 24 h and the conditioned area shall be cleaned and mopped each time before the next set of filters is loaded.

After air balancing, and adjusting of air quantity, a validation process shall be carried out by recording temperature, humidity and pressure differentials. For critical areas, validation process shall be repeated and recorded at least once every year.

For operating rooms where validation is needed the air handling devices shall be run 24 h. However, the system deliverables shall be limited to maintaining minimum pressure differentials considerations with turndown procedures to control and limit contamination (unoccupied turn down is permitted subject to maintaining pressure differentials).

12.6 Underground Metro Station Buildings

A typical underground metro station generally consists of 2 underground levels. The first level at minus 1 being the concourse with a minimum height of 6m followed by Platform level at minus 2 again of minimum height 6 m. In addition, there is always the rail level below the platform level and an under-croft level of depth 1.5 m below the platform. The ancillary building is over the ground generally with two levels of ground and 1st floor.

The underground metro station is provided with environment control system (ECS). The ECS system shall serve following function:

a) Station public area and ancillary room air conditioning,
b) Mechanical ventilation of plant rooms, and
c) Smoke management system.

12.6.1 *Station Public Area and Ancillary Room Air Conditioning*

12.6.1.1 *Station air conditioning design*

The underground stations of the metro corridor shall be designed to provide forced ventilation for removal of large quantity of heat dissipated from train equipment, station electrical accessories, equipment, passenger body heat, obnoxious odours and harmful gases such as CO_2. The station heat load shall be considered as

a) Unsteady heat load due to train movement - The major source of heat for the station is from the train air conditioning systems and the train traction and braking systems. The air that gets pushed in to the tunnel due to the piston effect gets exhausted through separate gravity dampers provided at the top of tunnel.

b) Steady heat load

   1) *Passenger heat load* — The passenger occupancy at station is taken from peak hour peak direction traffic (PHPDT) data given in detail project report (DPR). Passenger heat gain shall be computed from the above data.

2) *Lighting and miscellaneous equipment load* — It is based on lighting in public area and equipment like lifts, escalators and AFC Gates contributing to the heat load.

3) *Fresh air loads* — Fresh air is supplied to the platform and concourse to meet the physiological requirements of the passengers. Fresh air quantity shall be calculated as per **3.**

12.6.1.1.1 *Design criteria*

The station environment control shall be by a central air conditioning system. Station shall have provision of fresh air intake and exhaust shaft. The station shall be supplied with conditioned air via ductwork from air handling unit (AHU) located in plant room. AHU shall be supplied with chilled water from water cooled chillers and its associated pumping system. The AHU shall be as per accepted standard [8-3(25)] and the liquid chillers shall be as per accepted standard [8-3(28)].

To extract the return air, trackway exhaust system shall be installed in the trainways of each station to capture both excessive tunnel airflows and the heat rejected by the vehicle propulsion/braking/air-conditioning systems as the train dwells in the station. An under-platform exhaust (UPE) duct is often utilized to capture heat from the train's undercarriage heat sources. This UPE duct runs in the under-croft area (Below PF) and air pushed through it to be supplied at track level. An Over track exhaust duct is constructed in the tunnel with exhaust diffusers. The air which is pushed through UPE mixes with cool air from platform leakage and is sucked by the OTE and goes back to the system. Basically, UPE and OTE are used as plenums, and this is generally called "Cooling dump". The Over track exhaust duct also serves the purpose of capturing heat that is rejected from the above the car area of dwelling trains like the heat from the roof top mounted air-conditioning units of the rail cars. Openings in the OTE and UPE shall be located to be near the heat generating sources on the train.

12.6.1.1.2 *Modes of operation*

There are namely two types of mode of operation:

a) *Open mode operation* — In open mode, 100 percent outside air is circulated in the stations. It is an economical mode of operation when the outside air enthalpy is relatively low and favourable for the inside condition (the best-case scenario is when the outside air enthalpy is same as the design AHU coil leaving air enthalpy). AHU shall draw the air directly from outside via fresh air shaft and deliver the air at platform level and concourse level. Trackway exhaust fans (TEF) shall extract the air from OTE and UPE and discharge it outside directly via exhaust shaft. The water-cooled chillers units shall remain shut down in this mode. This mode is known as "Enthalpy Economiser Cycle" and is generally available during winter season.

b) *Closed mode operation* – In close mode, air is extracted from the public areas of the station and returned to the air handling units to be cooled and delivered back to the platform and concourse. Closed mode operation is proposed when the outside air temperature and humidity are high. In this operation, AHU shall recirculate the air of OTE and UPE with the addition of fresh air, brought in by fresh air fans (FAF). The TEF will take the exhaust from OTE and UPE and deliver to return air plenum where fresh air is also mixed with the return air. This mode is generally used during summer and monsoon season.

12.6.1.2 *Ancillary Area Air Conditioning*

Air conditioning of back of the house areas and ancillary areas, that are occupied by staff and non-travelling persons, who are going to stay in these areas for considerable duration, shall be same as air conditioning system for commercial buildings.

12.6.2 *Smoke Management System*

The smoke extract fans (SEF) and trackway exhaust fans (TEF) are used respectively for concourse and platform smoke extraction. The smoke extraction fans and other system components like duct, dampers, attenuators, etc, shall have suitable fire rating. Smoke extraction fans with related equipment shall be installed in the ECS plant rooms provided at concourse level at each end of the station. Where a smoke extract ducting passes through protected areas, it shall be rated to the same fire resistance as the walls of the compartments. Flow switches shall be provided for exhaust. Station smoke removal fans to provide a positive indication of the fan operation at the station control rooms (SCR) as well as operations control centres (OCC).

12.6.3 *Staircase Pressurization*

Pressurization of the firemen's staircase and emergency staircase shall be done in accordance with Part 4 'Fire and Life Safety' of the Code.

12.6.4 *Few notable points on electrical*

A few notable points on electrical panels and cables are below:

a) All the panels are accepted standard [8-3(40)] complied; this is generally colloquially termed as TTA panels.

b) The panels are housed with a gas flooding system, which in turn is integrated with FDA system.

c) The cables which are used for evacuation purpose like SEF, fire etc., are Fire Survival (FS) cables, testing may be done as per criteria in special publications tested, otherwise it is LSZH, as per special publication, complied. FS cables are generally Cu cables.

d) The Panels are supplied with double incomers, if one fails the other shall come into service.

NOTE – Special publication may be IEC 60331-21 for FS cables and BS 7846 for LSZH.

12.7 Airport Buildings

HVAC systems for airports shall address unique requirements due to the complexity, scale, and diverse usage of these facilities. The key considerations for airport typology as given below shall be followed for energy efficient and sustainable building.

12.7.1 *Passenger Comfort*

These recommendations focus on maintaining optimal air quality, temperature, and humidity levels to enhance the comfort and experience of passengers in airport terminals.

a) *Temperature control* – Consistent and comfortable temperatures to provide thermal comfort in passenger areas, considering high traffic and varying external conditions as detailed in **3** of this code basis of design shall be ensured.

b) *Humidity control* – Optimal humidity levels to enhance comfort and protect electronic equipment shall be ensured. (*see* **3**)

c) Indoor air quality shall be as per the requirements as specified in **3**.

12.7.2 *Energy Efficiency*

The equipment like variable air volume (VAV) Systems, energy recovery ventilation (ERV) systems, and BMS as specified in **15**, should be considered.

12.7.3 *Ventilation and Air Exchange*

The ventilation and air exchange rate shall refer to the **3** and **8**.

12.7.4 *Load Management*

These guidelines focus on optimizing energy consumption and ensuring efficient operation of HVAC systems in response to fluctuating passenger traffic and varying environmental conditions:

a) *Peak load handling* – Systems shall be designed to handle peak loads during busy periods without compromising comfort.

b) Demand control ventilation should be implemented to adjust ventilation rates based on occupancy to reduce energy use during off-peak hours.

12.7.5 *Redundancy and Reliability*

These considerations ensure the continuous, uninterrupted operation of HVAC systems by incorporating backup systems and fail-safe mechanisms to handle critical airport operations:

a) *Backup systems* – Backup HVAC systems and power supplies shall be incorporated to ensure continuous operation during power outages or system failures as the systems are expected to operate continuously all 365 days of the year.

b) *Maintenance access* – Easy access to HVAC components for regular maintenance and emergency repairs shall be envisaged.

12.7.6 *Special Considerations for Specific Areas*

For the following specific areas, special considerations should be taken:

a) *Control towers* – HVAC system shall be designed for precise temperature and humidity control along with high air quality. Design should be fail safe system with redundancy.

b) *Baggage handling areas* – Maintain moderate temperatures to protect mechanical systems and baggage handling equipment.

c) *Retail and Dining Areas* – Adequate ventilation and temperature control to ensure comfort for patrons and staff shall be provided.

12.7.7 *Noise Control*

These recommendations focus on minimizing noise pollution from HVAC systems to ensure a quiet and comfortable environment for passengers and staff in airport terminals:

a) The acoustic design of HVAC system should be considered to lower the noise level.

b) *Sound attenuation* – Sound attenuators and low-noise equipment to control noise levels in critical areas should be used.

12.7.8 *Advanced HVAC Technologies*

These technologies aim to enhance energy efficiency, air quality, and overall system performance, ensuring a more sustainable and comfortable environment for passengers and staff.

a) *Smart sensors* – Occupancy and air quality sensors to optimize HVAC operations dynamically should be used.

b) *Advanced controls* – Advanced control systems to automate and optimize HVAC performance based on real-time data should be implemented **15**.

c) *High velocity low speed fans (HVLS fans)* – These fans should be used in conjunction with air conditioning systems to provide better thermal comfort in high ceiling areas there by enhancing passenger comfort and energy efficiency.

12.7.9 *Scalability*

The system should be designed with flexibility in mind to accommodate future expansion needs. This includes providing sufficient capacity, space, and infrastructure to allow for easy integration of additional components, equipment, or systems as the airport's operations grow. It should also consider scalability in terms of power, cooling, and airflow requirements, ensuring that the system can be upgraded or modified without significant disruption.

12.8 Shopping complex buildings

HVAC systems for shopping complex buildings like malls shall be designed to handle the unique demands of large, complex spaces with varying loads and occupancy levels.

For a small shop and store, unitary split type air conditioning system shall offer many advantages, including low initial cost, minimum space requirement and ease of installation. For large department store a very careful analysis of the location and requirement of individual department shall be essential as these may vary widely, for example, for lighting department, food halls, restaurants, etc. Some system flexibility to accommodate future changes should be attempted in design.

Generally, internal loads from lighting and people are predominate considerations shall be given to initial and operating costs, system space requirements, ease of maintenance and type of operating personnel operating the system.

The economical options of all-air type of system, with variable volume distribution from local air handling unit, shall be considered. Facilities to take all outside air, for "free cooling" under favourable conditions, should be provided.

a) *Load Calculations* – The following considerations should be taken into account for load calculation:

   1) *Diverse spaces* - Malls include various spaces such as retail shops, food courts, fine dining restaurants, cinemas, play zones and common areas, each with different HVAC needs.
   2) *Peak occupancy* – Systems shall accommodate peak load times, such as weekends and holidays.
   3) *Heat loads* – Due consideration for heat loads from lighting, equipment, and occupants shall be accounted.

b) *Zoning* – Proper zoning is essential for ensuring optimal comfort and energy efficiency in HVAC systems which shall be ensured by adhering to following:

   1) *Multiple zones* – Separate zones for different areas to ensure comfort and efficiency shall be designed. For example, food courts, theatres, and individual stores should have their own control zones served by common or individual air handlers with distinct functioning options.
   2) *Independent controls* – Each zone should have independent temperature and humidity controls.

c) *Ventilation* – The following considerations should be taken into account for ventilation:

1) *Fresh air requirements* – Adequate ventilation to ensure indoor air quality, with proper intake of fresh air as detailed in **3** shall be followed.
2) *Exhaust systems* – Effective exhaust systems for areas with specific requirements, such as food courts and restrooms, shall be needed for controlling odour, and pollutants.

d) *Air Distribution* – Effective air distribution is crucial for maintaining consistent comfort and air quality across all areas of the space.

1) *Even distribution* – The system should be designed for uniform air distribution.
2) *Diffusers and grilles* – These shall be appropriately selected and placed for efficient air distribution.

e) *Energy Efficiency* – The system should be designed for energy-efficient operation, aiming to minimize energy consumption while maintaining optimal comfort levels. Proper system sizing, effective load management, and routine maintenance practices are essential to ensure the HVAC system operates at peak efficiency, reducing overall energy costs and environmental impact.

f) *Humidity Control* – The following considerations should be considered for humidity control:

1) *Dehumidification* – Proper dehumidification to maintain comfort and prevent mold growth shall be planned in humid climates or areas located in zones with high humid ambient conditions.
2) *Humidification* – In colder climates, additional humidification strategies in air handlers shall be added to maintain comfort.

g) *System Redundancy* – To ensure system redundancy following recommendations to be considered:

1) The design should consider backup systems for critical components to reduce downtime.
2) The system design should be for easy maintenance access.

h) *Building Management Systems (BMS)* – The design of BMS should focus on centralizing control and monitoring of various building systems to enhance operational efficiency and energy management by adhering to following:

1) *Integrated control* – BMS should be planned for centralized control and monitoring and integrating various operating HVAC systems and other systems such as lighting controls, lift management, water pumping systems, DG sets and MCC panels as well as fire alarm system to provide comprehensive and energy efficient operations.

2) Real-time monitoring should be incorporated for feedback on the performance and provide opportunity for necessary alterations to achieve energy efficiency goals.

j) *Noise Control* – Systems should be designed to minimize noise as well as sound transfer from one zone to another, especially in common areas and near sensitive zones like screens in multiplex, conference areas etc.

k) *Monitoring and Diagnostics* – Should implement predictive maintenance strategies using data analytics to reduce downtime and maintenance costs.

m) *Commissioning and Re-Commissioning* – Thorough initial commissioning as well as ongoing recommissioning shall be carried out as detailed in **17**.

n) *Climate Resilience* – The systems shall be designed to withstand and operate efficiently during extreme weather conditions as per the weather data provided in the code.

p) *Water Management* – Water management systems should be designed to optimize water usage, enhance efficiency, and support sustainability within the building's HVAC operations and overall facility management which shall be ensured through:

1) *Condensate management* – This shall be ensured by efficiently managing and reusing condensate water from air conditioning systems.
2) *Cooling towers* – Principally all types of cooling towers need make up water as well as constant replenishment and to achieve better system efficiency lower approach, designing of cooling towers may be referred from special publication.

NOTE – Special publication may be Energy Conservation and Sustainability Building Code 2024 (ECSBC).

q) *Operational Training* – Operational training is essential to ensure that maintenance and operational staff are well-equipped, to manage the HVAC systems efficiently and respond effectively to emergencies and following may be adhered:

1) *Staff training* - Comprehensive training shall be provided for maintenance and operational staff on system use and troubleshooting.
2) *Emergency procedures* – Emergency procedures shall be established with clear procedures for HVAC-related emergencies, such as system failures or fire / smoke instances.

r) *Tenant Coordination* – Effective coordination with tenants is essential to ensure that their HVAC needs are addressed while maintaining overall system efficiency. The following points outline key aspects of this coordination:

1) *Tenant integration* – Coordinate with tenants shall be done to ensure their HVAC needs are met without compromising overall system efficiency.

2) *Tenant fit-out* – Proper guidelines shall be provided for tenant fit-out to maintain compatibility with the central HVAC system installed.

s) *Other requirements* – Other requirements such as safety, system type and components, shall be as per Part 4 'Fire and Life Safety' of this code. HVAC should be designed flexible to accommodate future expansion.

1) The design shall ensure thermal comfort as defined in **3**. (Adaptive controls – Adaptive control algorithms that respond to real-time occupancy and environmental data should be incorporated.)
2) Demand control ventilation (DCV) should be considered as reference to the thermal comfort and Indoor air quality requirements defined in this section.
3) *Backup power* – Critical HVAC systems shall have backup power to maintain operation during power outages.

12.9 Industrial Facility Buildings

12.9.1 *Zoning*

Zoning of different spaces shall be planned according to the functionality. Based on the hazard classification of different entities, compartmentation measures and safe distances shall be maintained. Emergency exits and assembly points shall be planned in line with the local regulations.

Planning shall consider adequate ventilation and natural light ingress into majority of the working spaces.

12.9.2 *Indoor Conditions*

Indoor conditions of different spaces shall be planned in line with the functional requirements of the spaces in general. Temperature, relative humidity and air quality shall be planned as per guidelines.

Ventilation and air conditioning shall be planned based on the functional requirements of the industrial buildings in line with basis of design brought out in Chapter **3**.

In industrial buildings, acceptable working conditions shall be ensured rather than comfort as providing comfortable conditions in huge volumetric spaces will not be efficient in terms of energy usage and cost economics. However, the ancillaries and office spaces shall be planned for comfort conditions in line with the guidelines.

The ventilation systems may contain chemical compounds or toxic substances in concentrations crossing prescribed safe limits. Necessary precautionary arrangements shall be made to remove, contain, exhaust and maintain the hazardous pollutants within acceptable limits in occupied spaces.

Emergency preparedness includes fire safety measures, with designated smoke extraction and pressurization systems integrated for safe evacuation and emergency response capabilities. Additionally, industrial zones shall be equipped with specialized

HVAC systems, ensuring operational continuity within sensitive areas such as equipment rooms, control centers, and personnel amenities.

12.9.3 *Energy Efficiency and Conservation*

Energy-saving initiatives such as variable air volume (VAV) systems in public and operational zones, optimizing airflow and energy consumption based on real-time demand, variable frequency drives (VFDs) control AHUs, pumps, air compressors and chillers, optimizing operational efficiency during fluctuating production cycles, enthalpy economizer cycle in 100 percent Fresh air scenario and adaptive thermal comfort approach should be considered.

12.9.4 *Fire Safety and Electrical Integration*

Shall be as defined in the Part 4 'Fire and Life Safety' of the code.

12.10 *Tall buildings typology*

12.10.1 *General*

Tall buildings are defined as structures with a height greater than 100 meters. Buildings that exceed 300 meters are classified as super tall buildings. Furthermore, buildings taller than 600 meters are categorized as mega tall buildings.

Important considerations for tall / super tall / mega tall buildings are:

a) The effect of ambient air temperature over the height of buildings especially for super tall and mega tall buildings.
b) Facades for tall Buildings, leakage rates and pressure resistance.
c) Natural ventilation for tall buildings
d) Energy consumption / conservation and new trends in HVAC design for tall / super tall / mega tall buildings
e) Stack effect
f) Green / Sustainable tall buildings

12.10.2 *Architectural Consideration*

Following key points outline key aspects of architectural consideration:

12.10.2.1 *Core design*

Design of core areas determine the projects floor to floor heights. This reflects in the building cost and architectural as well as HVAC design. An important consideration for architecture shall be the core design comprising of the 3 commonly used cores – Central Core/ Double Core / Single sided (or offset) core. For hot and humid as well as temperate climates the core is suggested to be located on the east and west facades to insulate the interior zones from ambient conditions. Also, the cooling loads are found to be minimal when the double core configuration with glazing is used on north south and south facade and core on east and west facades. The core incorporates the following minimum entities:

Fire escape stairs / vertical transportation elements / rest rooms / electrical closets / communication closets / local fan rooms / shafts for HVAC risers / shafts for HVAC and plumbing systems / electrical distribution and building management and fire alarm system cabling.

12.10.2.2 *Facade systems*

The orientation influences the either increased or decreased infiltration rates and solar loads through facades. This is specifically important for mega tall and super tall buildings as infiltration from wind loads shall be significant for very tall buildings since there may not be adjacent buildings to mitigate high winds.

A high-performance facade needs to be planned to minimize solar cooling load and allow for efficient performance of air-conditioning systems while maintaining thermal comfort.

Facade is to be designed to minimize solar gain to 10 percent to 20 percent of the incident radiation. A double skin facade with fan coil / chilled ceiling / chilled beam cooling systems with return air directed to the floor of the perimeter and up between exterior and interior windows could be used.

Different types of multi skin facades such as one story faced module / corridor facade / multiple story facade and shaft box facade shall be designed

12.10.3 *Shading Strategies*

Shading strategies are important especially for cooling load dominated climates. It is better to minimize window to wall ratio as shall be seen the difference between 40 percent window to wall ratio and 65 percent window to wall ratio as seen in most modern buildings.

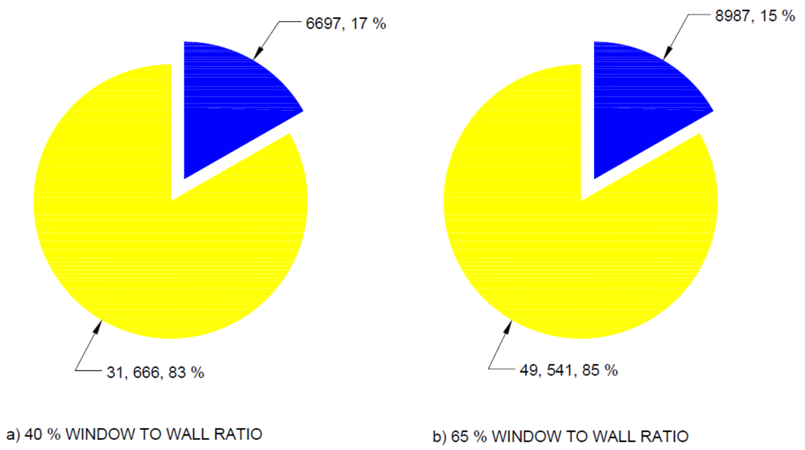


FIG. 7 IN 40 PERCENT THE HEAT TRANSFER THROUGH THE GLAZING IS 83 PERCENT OF THE LOAD TO THE SPACE AND IN 65 PERCENT IT IS 85 PERCENT TO THE SPACE.

12.10.4 *Facade Leakage Rates*

Envelope leakage depends on HVAC system operation. In pressurized buildings when HVAC systems operate the infiltration leakage could be very low. In accordance with the best practices of special publications recommended air leakage test of the completed building shall be with a leakage rate of not exceeding 2.0 l/s.m^2 at 75 Pa pressure differential.

As per special publication the recommended leakage rate value is 9.0 l/sm^2 at 75 Pa pressure differential.

The following are the 2 options as recommendations either as per special publications:

a) 2.0 l/s.m^2 at 75Pa
b) 9.0 l/s.m^2 at 75 Pa

NOTE – Special publications maybe International Energy Conservation Code (IECC) and ASHRAE 90.1.

The leakage rate for tall building however shall vary with height. If the maximum leakage rate is achieved at a particular height, then at any height above this there will be facade leakage as infiltration load. (*see* Fig. 8)

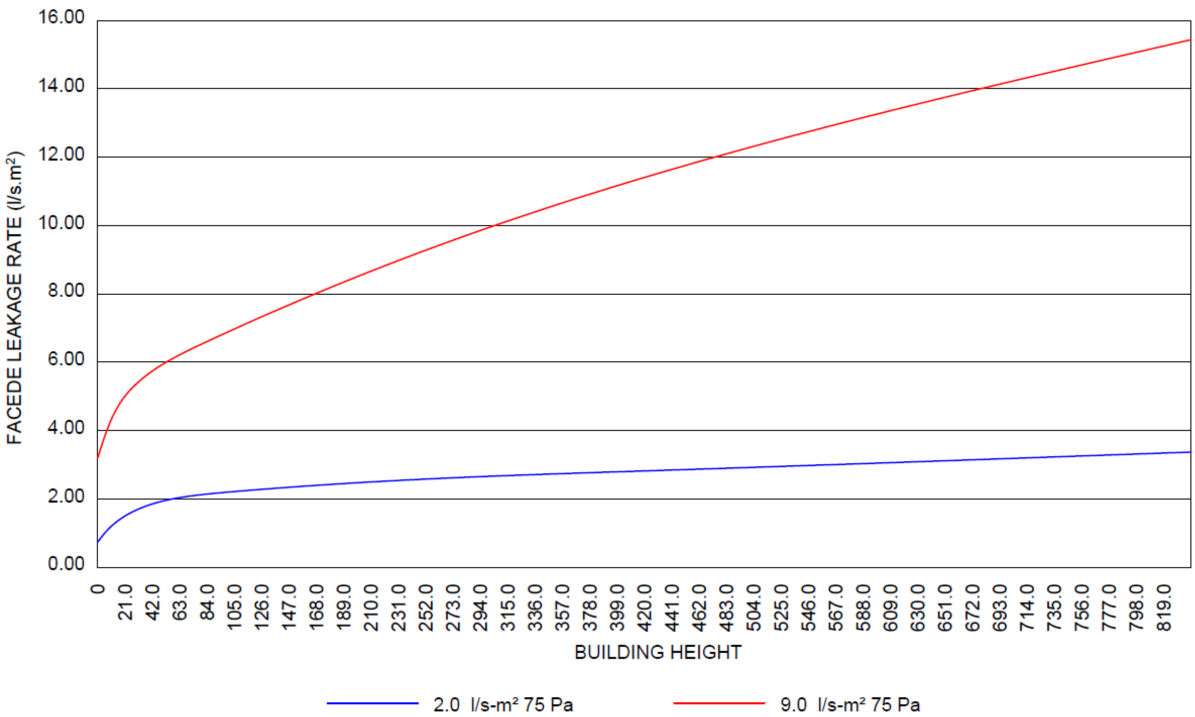


FIG. 8 CALCULATED LEAKAGE RATES FROM WIND SPEED IN CFM(L/S) OF FACADE AREA FOR TALL / MEGA TALL BUILDING

12.10.5 *Climate Data*

Generation of climate data at upper elevations is a shall. It could be achieved through:

a) Remote sensing technologies or ballon releases

b) Model using weather forecasting techniques.

Following are some of the calculation methods:

1) To obtain external temperature at different building heights use:

$$T = T_g - 0.00649h$$

where,

T = temperature at height h (m)
T_g = Temperature at ground level F ('C)
h = height from ground level (m)

2) External Pressure vertically with the building height is

$$P = 101325(1-2.25577 \times〖 10〗^{(-5)} \times H)〖^{5.2559}〗$$

where, P = pressure (kPa)

3) Density of air vertically with the height of the building shall be

$$\rho = P_{abs} / [0.2869(T + 273.1)]$$

where,

T = absolute temperature K
P_{abs} = absolute pressure Pa
ρ = air density (kg/m^3)

4) Wind speed and pressure are generally obtained from meteorological stations located away from urban environments. This wind speed shall be corrected for terrain conditions and for building height relative to wind measurement at that height. Approximate correction factor is:

$$v_z = v_m k z^a$$

where,
v_z = wind speed at the building height (m/s)
v_m = wind speed measures in open country at a height of 10 m (m/s)
Z = building height (m)
k and a = constants dependent on terrain as per table below:

Wind Speed terrain Constants:

Terrain Category	*k*	*a*
Open, flat country	0.68	0.17
Country with scattered wind breaks	0.52	0.20
Urban	0.35	0.25
City	0.21	0.33

12.10.6 *Stack Effect*

By Convention the stack pressure differences are positive when building is pressurized relative to outdoors which causes flow out of building.

When indoors is warmer than outdoors the base building is depressurized, and top is pressurized relative to outdoors. When the indoors is cooler than outdoors then the reverse becomes true. At some elevation in building the pressure indoors is equal to the outdoors and this height is known a neutral pressure level (NPL). NPL is influenced by leakage distribution and not necessarily at mid height of building.

The location of NPL (h) is expressed by:

$$h = H / (1+ \quad (A1/A2)^2 T_i/T_o)$$

where,

$A1$ and $A2$ = lower and higher leakage areas
T_o and T_i = outdoor and indoor absolute temperatures
H = Building height

12.10.7 *Heating and Cooling Loads*

Cooling and heating loads shall be calculated by dividing the building into sections. For example, splitting the building as 100 m sections and calculate heating and cooling loads in view of variable outside temperature, density and pressure over the building height as compared to constant parameters for other building typologies.

12.10.8 *Indoor Air Quality and Thermal Comfort*

The procedures and standards mentioned in Section **3** shall be followed. If this ventilation procedure does not yield adequate results to contain a specific contaminant or if the contaminant levels shall be attained with lower ventilation rates, then as an alternative indoor air quality procedure (IAQP) may be used.

12.10.9 *HVAC Systems*

All HVAC system options available for any building typology shall be applicable for use in Tall Buildings. These include:

a) All air variable air volume (VAV) systems
b) Low temperature air VAV systems
c) Underfloor air systems
d) Air-water systems
e) Radiant ceilings
f) VRF drive fan coil units
g) VRF fan coils with 100 percent outdoor air ventilation

12.10.10 *Exhaust Fan Pressures*

There will be considerable wind pressures at the air intake and exhaust locations shall be calculated as follows:

P_s intake = C_p intake $[\frac{\rho_a U_H^2}{2g_c} / 2.152]$

P_s exhaust = C_p exhaust $[\frac{\rho_a U_H^2}{2g_c} / 2.152]$

(P_s intake – P_s exhaust) + ΔP_{fan} = $F_{\dot{S}ys} \frac{\rho Q^2}{A_L^2 g_C}$

$\Delta_{P_{wind}}$ = (C_p intake - C_p exhaust) $[\frac{\rho_a U_H^2}{2g_c} / 2.152]$

where,

ρ_a = Outdoor air density at height h
$U_{H\cdot}$ = approach wind speed at upwind height h (m/s)
$F_{\dot{S}ys}$ = System flow resistance
A_L = flow leakage area and
Q = system volume flow rate

12.10.11 *Water Distribution Systems*

A major consideration in the design of a piping system in a tall building is the hydrostatic pressure created by the height of the building. The design of piping shall take static pressure on the piping system due to the height of into consideration. The piping network is divided into zones vertically separated by pressure breaks and served by heat exchangers and pumps with main chiller located at the utility complex in basement or an adjacent service building. The building pressure break shall be at equal interval at different heights separated using heat exchangers and tertiary pumps. It is needed that consideration to be given for different vertical zones in chilled water temperatures at the inlet to heat exchangers in each zone. In a typical scenario of 4 zones to serve chilled water at 6°C at top of building following temperatures at each Heat exchanger will have to be maintained:

I Zone	1.5° C
II Zone	3.0° C
III Zone	4.5° C
IV Zone	6.0° C

Suggested piping materials shall be steel pipes schedule 40 with standard wall thickness for pipes up to 250 mm in diameter and for pipes 300 mm or larger a wall thickness of 9.5 mm. This by and large would accommodate the working pressures in tall buildings. However, a cross verification with accepted standard [8-3(41)] is preferred. Based on the working pressure valves and fittings also need to be selected. For steam condensate piping or for condenser water piping where corrosion is a possible concern pipe with heavier wall thickness shall be considered.

12.10.12 *Expansion and Contraction in Piping*

Design of piping shall take other factors including expansion and contraction and static and dynamic loads of the piping should be taken into consideration.

13 SPECIAL PLACES IN BUILDINGS

13.1 Cleanroom

The basic considerations in a cleanroom design are:

1) Cleanroom class.
2) Temperature
3) Relative Humidity
4) Sound Level
5) Vibration
6) Light spectrum
7) Electrostatic charge/ static electricity

NOTE – Number 4, 5, 6 and 7 are important for only selective cleanroom applications such as semiconductor, electronics and others.

13.1.1 *General Requirement*

a) Areas surrounding the cleanroom shall be less pressured than the cleanroom to avoid ingress of non-clean air to classified areas.
b) Airlock rooms shall be provided before clean room to maintain cleanroom integrity and reduce entry of contamination in classified areas.
   1) Separate change rooms shall be provided for male and female workers. multiple change rooms should be designed in series as per criticalness of application with primary change rooms designed as controlled not classified (CNC) and secondary change rooms (opening in cleanroom areas) designed under classified category.
   2) A suitable door interlocking shall be used to ensure that both doors of airlock do not open "simultaneously" during usual operation time (except during emergency situations).
c) Air shower shall be used to reduce particles entry during human movement.
d) Dedusting tunnels or pass box should be used to reduce particles entry during material movement.
e) Existing Windows, cleanroom wall/ ceiling panel joints shall be closed permanently using suitable sealants to avoid cross contamination.
f) Good smooth and scratch resistant flooring with skirting shall be provided.
g) All Corners and edges (ceiling to wall, wall to wall and wall to floor) shall be provided with coving to avoid dust accumulation and for easy cleaning
h) The room shall be considered a restricted area. Only authorized personnel shall be allowed to enter during operation.
j) No paper products / cotton buds shall be allowed inside the cleanroom.
k) All personnel entering the clean room facility shall use "cleanroom compatible gowning and shoes".
m) All personnel / visitors shall wear cleanroom garments while entering Cleanroom

n) Cleanroom garments shall be stored properly in a laminar air flow storage cabinet
   1) The cleanroom cleaning protocol shall be designed as per the product nature and contaminations to be removed. The cleaning agents shall also be compatible with cleanroom architecture.
   2) Movement of materials from and to the cleanroom shall be as optimum as possible.

13.1.2 Selection of airborne particulate cleanliness classes for cleanrooms and clean zones as per special publication is given in table 27:

Table 27 Airborne Particulate Cleanliness Classes for Cleanrooms and Clean Zones
(*Clause* 13.1.2)

Sl. No.	**ISO Classification Number**	**Maximum concentration limits (particles/m^3 of air) for particles equal to and larger than the considered sizes shown below:**					
		≥0.1µm	**≥0.2µm**	**≥0.3µm**	**≥0.5µm**	**≥1µm**	**≥5.0µm**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	ISO Class 1	10	2				
ii)	ISO Class 2	100	24	10	4		
iii)	ISO Class 3	1000	237	102	35	8	
iv)	ISO Class 4	10000	2370	1020	352	83	
v)	ISO Class 5	100000	23700	10200	3520	832	29
vi)	ISO Class 6	1000000	237000	102000	35200	8320	293
vii)	ISO Class 7				352000	83200	2930
viii)	ISO Class 8				3520000	832000	29300
ix)	ISO Class 9				35200000	8320000	293000

NOTE – Special publication may be ISO 14644-1.

The meanings of the cleanrooms classification is given in table 28:

Table 28 Meanings of the Cleanrooms Classification
(*Clause* 13.1.2)

Sl. No.	**Class**	**Description**
(1)	(2)	(3)
i)	Class 1:	This Cleanrooms class is mainly used within the microelectronic industry when manufacturing integrated circuits which requires submicron resolution.
ii)	Class 10:	This Cleanroom class is mainly used within the semiconductor industry using band widths below 2 micrometer.
iii)	Class 100:	This cleanroom class is, according to many, the most useful critical cleanliness class. Cleanrooms class 100 are often, incorrectly, known as

Sl. No.	**Class**	**Description**
(1)	(2)	(3)
		sterile rooms and are used when >bacterial free < and /or >particle free< environments are required. Cleanroom class 100 is used in aseptic manufacturing within the pharmaceutical industry, for example. This cleanroom class is frequently used during the manufacture of integrated circuits; and also during isolation and treatment of patients who are especially sensitive to bacterial infections, for example, after bone marrow transplantation.
iv)	Class 1000:	This cleanroom class is mainly used when producing high quality optics; When carrying out mounting work and testing of gyroscopes for aircrafts; and also, when mounting high quality miniature bearings.
v)	Class 10000:	Clean rooms of class 10000 are used for mounting procedures in hydraulic or pneumatic equipment and on some occasions are also used within the food and beverage industry. Class 10000 cleanrooms are also commonly used within the pharmaceutical industry.
vi)	Class 100000:	This classroom class is used by many industries, for example when working with optical products, when building large electronic systems based on smaller components, when building hydraulic and pneumatic systems and also within the food and beverage industry. The pharmaceutical industry also makes frequent use of this class of cleanrooms.

Air velocities and air changes in cleanrooms is given in table 29:

Table 29 Air Velocities and Air Changes in Cleanrooms
(*Clause* 13.1.2)

Sl. No.	**Class of Cleanroom**	**Airflow type**	**Average velocity** (m/h)	**Air Changes per h**
(1)	(2)	(3)	(4)	(5)
i)	ISO 8 (100,000)	N/M	18-146	5-48
ii)	ISO 7 (10,000)	N/M	183-274	60-90
iii)	ISO 6 (1,000)	N/M	457-732	150-240
iv)	ISO 5 (100)	U/N/M	732-1463	240-480
v)	ISO 4 (10)	U	914-1646	300-540
vi)	ISO 3 (1)	U	1097-1646	360-540
vii)	Better Than ISO 3	U	1097-1829	360-600

NOTES
1 Air Changes per hour= Average airflow velocity x room area x 60 min/h
2 Room Volume
3 N=non unidirectional; M= mixed flow room; U= Unidirectional flow.

The classification of filters given in table 30 should be applicable.

Table 30 Classification of Filters

(*Clause* 13.1.2)

Sl. No.	**Filter Class**	**Overall Value Efficiency** (percent)	**Overall Value Penetration** (percent)	**Leak test Efficiency** (percent)	**Leak test Penetration** (percent)
(1)	(2)	(3)	(4)	(5)	(6)
i)	H 10	85	15		
ii)	H 11	95	5		
iii)	H 12	99.5	0.5		
iv)	H 13	99.95	0.05	99.75	0.25
v)	H 14	99.995	0.005	99.975	0.025
vi)	U 15	99.999 5	0.000 5	99.997 5	0.002 5
vii)	U 16	99.999 95	0.000 05	99.999 75	0.000 25
viii)	U 17	99.999 995	0.000 005	99.999 9	0.000 1

Schedule of tests to demonstrate continuing compliance is given in table 31:

Table 31 Schedule of Tests to Demonstrate Continuing Compliance
(*Clause* 13.1.2)

Sl. No.	**Test Parameter**	**Class**	**Maximum Time Interval**
(1)	(2)	(3)	(4)
i)	To Demonstrate compliance by Particle Counting	≤ISO 5	6 months
		>ISO 5	12 months
ii)	Schedule of additional	All Classes	12 months
iii)	Air flow Velocity or Volume		
iv)	Air Pressure difference	All Classes	12 months
v)	Schedule of Optional tests	All Classes	24* months
vi)	Installed filter leakage		
vii)	Airflow Visualisation	All Classes	24* months
viii)	Recovery	All Classes	24* months
ix)	Containment Leakage	All Classes	24* months

* = Suggested time interval

13.2 Refrigeration for cold stores

13.2.1 *Key Elements and Components of Cold Room*

a) *Product quality* – Design and operation of cold storages is governed by the level of quality control parameters as per the individual products.

b) *Temperature of cold room* – During the entire storage period, the temperature should remain as constant as possible.

In case of some produces the rate of cooling for the freshly cooled products shall be considered, as per recommended cool down period. (Respiration loads, mainly from fruits and vegetables)

Shall avoid putting into a room a large amount of goods at a temperature too different from that of goods already in the room. The cold-production equipment should be checked to make sure it shall handle this extra load. Within one room the temperature should be as uniform as possible, as this affects not just products that are sensitive to temperature variations, but also those with recommended temperatures near 0°C. These optimum conditions shall be approachable without risk of freezing.

Dead zones and regular drafts shall be avoided. Temperature sensors should be placed around the room on the basis of the accuracy, as indicated by the manufacturer, of the automatic devices. Cold store temperature shall be either recorded or read at regular intervals. Thermometers should be protected from impact and yet be easily accessible. Temperature should be read at more than one location. Moreover, the temperature of the products themselves should be taken.

c) *Measurement of temperature of food* – A thermometer/ temperature measurement device that shall measure the internal temperature of food, like one with a probe that shall be inserted into the food is required. Food internal temperature shall be measured as the surface temperature may be warmer or cooler than the temperature of the rest of the food. The thermometer shall be accurate to ±0.5°C. The thermometer/temperature measurement device should be cleaned and sanitized before inserting it into food. The probe should be washed in warm water and detergent, sanitized according to the sanitizer instructions or the instructions that thermometer accompanies, and the probe should be allowed to air dry or thoroughly dried with a disposable towel.

13.2.2 *Typical Design Inputs for a Standard Cold Room*

The criteria involved in designing a cold room are similar to any warehouse, that is, storage capacity, facilities for receiving and dispatching goods, interior operating space, location of cold room, selection and location of refrigeration units. While designing cold room, the difference between room temperature and product temperature should be kept at a minimum value.

13.2.3 *Heat Loads*

Refrigeration load includes,

a) Transmission load, which is heat transferred into the refrigerated space through its surfaces;
b) Product load, which is heat removed from and produced by products when these are brought into and kept in the refrigerated space;

c) Internal load, which is heat produced by internal sources (for example, lights, electric motors, defrost mechanism and people working in the space);
d) Infiltration air load, which is heat gain associated with air entering the refrigerated space; and
e) Equipment related load. For example, Air-Cooling unit fan motors, fork lifts, etc.

The first four segments of load constitute the net heat load for which a refrigeration system is to be provided; the fifth segment consists of all heat gains created by the refrigerating equipment itself. Thus, net heat load plus equipment heat load is the total refrigeration load.

While other loads are quite similar to loads in regular HVAC system design, the product load includes the primary refrigeration loads from products brought into and kept in the refrigerated space, which includes,

1) Heat that shall be removed to bring products to storage temperature. In case of some produces the rate of cooling for the freshly cooled products shall be considered, as per recommended cool down period.
2) Heat generated by produces in storage such as respiration loads, mainly from fruits and vegetables.

In addition, another new aspect in heat load is the heat from defrosting where the refrigeration coil operates at a temperature below freezing and shall be defrosted periodically, regardless of the room temperature. In order to avoid system oversizing, and to take full advantage of load diversity, hour-by-hour load calculation or simulation method should be used.

13.2.4 *Considerations for Cold Room Selection*

The conditions within a closed refrigerated chamber shall be maintained to preserve the stored product. This refers particularly to seasonal, short shelf life, and long-term storage.

The four major concerns for product compatibility are temperature, moisture, ethylene, CO_2 and odour. Specific considerations include:

a) Uniform temperatures as much as possible in empty condition as well as with product loaded condition;
b) Length of air blow and impingement on stored product;
c) Effect of relative humidity;
d) Effect of air movement on employees working in cold store;
e) Controlled ventilation, if necessary;
f) Product entering temperature;
g) Expected duration of storage;
h) Required product shipping temperature when leaving cold store;
j) Traffic in and out of storage area;
k) Design of storage bins; and
m) Size of food product (L x W x H) or volume.

Rack systems are mostly related to retail store refrigeration and are not considered as part of building system.

13.2.5 *Installation and Maintenance of Cold Room*

All panels for thermal insulation of cold storage shall be as per the accepted standard [8-3(8)].

Refrigeration system has to be selected for a particular application based on a particular refrigerant Keeping in mind environmental issues. Thus, the refrigerant shall be a natural refrigerant like ammonia, carbon dioxide, hydrocarbons, or synthetic refrigerants, with very low GWP. System shall have either a) unitary system or b) DX systems or c) integrated single or d) two-stage system depending on the application temperature. The entire design has to be done as per proper standards.

Refrigeration system shall be assembled as per proper specifications to ensure that no refrigerant leakage. It is essential to have proper emergency measures in case of any accidental leaks. The building structure shall be designed with adequate safety factors and the thermal insulation has to be protected properly from any possible occurrence of fire. Emergency alarms should be provided in the cold store with switches in each chamber.

Safety is critical in the design, construction and operation of refrigeration systems for cold storage, especially with ammonia systems. Refrigeration system's safety standards shall meet requirements relating to safe design, construction, installation, and operation of refrigeration systems by establishing safeguards for life, limb, heath and property as per the applicable safety standards. This includes, but is not limited to, occupancy classification, restriction on refrigerant use, installation restrictions, design and construction of equipment and systems, and operation and testing. Equipment selection and their placement should be such so as to ensure safe and easy maintenance. A safety review of the engineered design and equipment layout is recommended with participation from the owner's site operations and maintenance (O&M) team. Personnel safety measures are required as part of the facility design. The designer should prepare a system safety plan with full hazard analysis.

13.2.6 *Cold Room Safety*

The cold temperatures inside a low temperature cold room shall cause increase in blood viscosity and risk to life unless proper precautions are taken. An audio alarm should be installed outside the cold room, powered through a UPS and the switch should be fixed prominently and within reach, inside the cold room. This will help any person trapped inside to alert those outside, for help.

The following safety provisions should be kept/taken care of, at the cold room site:

a) Firefighting equipment,
b) Safe handling of refrigerant leaks,
c) Safety devices, controls and alarm systems,
d) Emergency lighting in the cold chambers,
e) Lightning arrestor,

f) First aid kit,
g) Air filters/breathers,
h) Emergency assembly points,
j) Regular safety drills and training,
k) Water shower in ammonia plants, and
m) Avoiding ramps as they become slippery when wet or frozen.

13.2.6.1 *Precautions against getting trapped in freezing room*

In order to facilitate getting out of a person who may accidentally get locked in a cold room, emergency exits shall be provided. These shall have facility to be opened from inside, even when they are locked from the outside. In all cases, following shall be installed in the freezing room:

a) Doors which shall open manually both from the inside and the outside (for functioning during power shortages, etc). In case of rooms with large dimensions say more than 25 m, it is advisable to provide emergency doors with UPS/battery lit exit sign at both ends of the freezing room for easy exit.
b) A signage system outside the freezing room with a steady or blinking light, and a siren or buzzer, activated from the inside by pressing a UPS-lit button. This button should also be connected to the caretaker's apartment, where a monitoring board shows where the button has been pressed. These visible and audible alarms should always be connected to a self-contained electric circuit, operated with a permanently charged battery. The same circuit should also connect to an independent, battery-operated emergency lighting system or a phosphorescent signalling system, all the way to the nearest emergency exit from the area.
c) Electric or pneumatic sliding or manual doors, capable of being operated both from outside and inside by push button or pull cords, easily accessible, in case of large freezing rooms, to the persons inside/outside.

13.2.6.2 *Precautions against refrigerant leaks*

Safety measures shall be taken against leak of liquid or gaseous refrigerant. Consideration should also be given to installing gas detectors and shut-off valves. The safety of the people should be considered by installing in traffic and public areas with which the refrigerant supply shall be cut long before the refrigerant concentration reaches the level which would affect the people or the stored products. The gaskets around the cold storage door should be periodically inspected and corrected for any damage.

In refrigeration applications with ammonia (if used) as per standard practice, there is a risk of a high concentration accumulating in an enclosed room. With 15 to 28 percent by volume, and an ignition source (of 582°C), it is possible to create a fast-burning process which could be something like an explosion. So, a rapid dilution/containment system or an expulsion system that is emergency ventilation should be installed as per relevant standards.

Self-contained breathing apparatuses and protective clothing are essential for entering a building with a concentration of ammonia greater than 50 ppm. Ammonia clouds shall be neutralized with dry ice (CO_2) or transformed by fog nozzle, but there is then a risk of water pollution. For safety requirements for cold stores as also for refrigerant gas related safety, relevant standards shall be followed.

13.2.7 *Cold Room in Various Segments and Requirements*

The recommended temperature ranges for various applications/product categories to be stored in modular cold rooms are given below (temperature range is to be finally decided based on the product intended to be stored):

Application/Product category	*Recommended Temperature Range*
Horticulture (fruits and vegetables)	+2 to +8 ºC
Floriculture	+2 to +6 ºC
Hotels, restaurants, fast food chains	+2 to +6 ºC
Pharmaceuticals	+8 to -25ºC
Dairy	+4 to -25ºC
Ice cream	-20 to -25ºC
Ripening	+12 to +20ºC
Controlled Atmosphere	+1 to +3 ºC

The above temperature ranges are indicative only, and may tend to vary, based on specific application requirements and other conditions. The relative humidity in most of the cases are above 85percent to 90 percent range except pharmaceuticals, seeds, dry products and frozen products, or as required for a specific case by the user.

13.2.8 *Refrigeration Technologies for Cold Storage*

The prime considerations for selection should be life cycle cost, ease of maintenance and controls. Designers may select unitary or centralized systems that comprise unitary off the shelf products, DX units, centralized refrigeration system - air cooled or water-cooled.

13.2.9 *Ammonia Refrigeration System*

Ammonia is one of the most efficient applications, with the application range from high to low temperatures. With the ever-increasing focus on energy consumption, ammonia systems are a safe and sustainable choice for the future

Ammonia is the most environmentally friendly refrigerant. It belongs to the group of so called “natural” refrigerants, and it has both global warming potential (GWP) and ozone depletion potential (ODP) equal to zero.

Ammonia is a toxic refrigerant, and it is also flammable at certain concentrations. That is why it has to be handled with care, and all ammonia systems have to be designed with safety in mind. At the same time, unlike most other refrigerants, it has a characteristic odour that shall be detected by humans even at very low concentrations. That gives a warning sign even in case of minor ammonia leakages. In case it is necessary to reduce ammonia charge, combination of ammonia and CO_2 (as cascade or as brine) could be a good and efficient option.

13.2.10 *Freon Refrigeration System*

The refrigeration system shall be unitary and centralised systems. Condenser cooling may be either water-cooled and air-cooled.

13.3 Supermarket Refrigeration

Supermarket refrigeration systems include various types of equipment and condensing units designed for both remote and direct applications. The further clauses cover the different systems and components used in supermarket refrigeration.

13.3.1 *Type of Supermarket Refrigeration Equipment*

The following types of refrigeration equipment are commonly used in supermarkets, offering various configurations such as remote and plug-in systems:

a) Open multideck chillers, with remote refrigeration system
b) Glass door upright freezers and chillers with remote refrigeration system
c) Display cold room (Wall replaced with glass doors)
d) Plug and play solutions
e) Serve-over counters, plug-in type
f) Self-service counters, plug-in type
g) Stainless steel fish counters, plug-in type
h) Plug-in island freezers
j) Visi-coolers – plug-in type
k) Visi-freezers – plug-in type
m) Confectionery displays or cake showcase
n) Four-sided visi-tower
p) Four-sided visi-frozen tower / visi freezer
q) Glass top freezers with sliding glass (plug-in type)

13.3.2 *Remote condensing units for remote application*

Various types of condensing units are listed and explained below:

a) *Rack system for supermarkets* – The multi-compressor rack system comes with various types of reciprocating, scroll, or screw compressors. It should be compact, solidly built, and enhance performance with minimal pipe work. Also, the addition of an inverter in the rack enhances its efficiency and increases the life of the system.

b) *Individual condensing units* – Glass-door cold rooms, supermarket open or closed-door chillers and freezers shall be connected with a variety of condensing units. Their selection is based on cold room size, temperature and usage. The selection of these units is critical and should be verified ahead of installation.

Various types of Compressors are used in the condensing units as listed below:

1) *Air cooled systems* – These are generally for small to industrial applications, excessive pipe run or vertical lift distances and speciality blast chilling and freezing applications. They are highly efficient and perform tirelessly.

2) *Water cooled systems* – These are generally for medium to industrial applications, these types of units are very effective in malls, where units are required to be installed in the basement or in a hidden area, were fresh air and exhaust facilities in not available. These are also suitable for chilling and freezing applications. They are highly efficient but need treated water and regular maintenance.

13.4 Data Centre

13.4.1 *Location*

a) *Seismic considerations*

   1) *Seismic zone mapping* – Consult the latest seismic zone map of India {*see* accepted standard [8-3(30)} to accurately assess the risk level of the proposed location.
   2) *Structural Design* – Engage qualified structural engineers experienced in seismic design for data centres. Adhere to the latest codes and standards, incorporating base isolation or energy dissipation systems if necessary.

b) *Proximity to utilities*

   1) *Power grid stability* – Evaluate the historical reliability and voltage stability of the local power grid. Prioritize locations with minimal outages and voltage fluctuations.
   2) *Redundant power sources* – Having access to two independent power feeds from different substations for enhanced reliability.
   3) *Water availability* – Assess water availability throughout the year, accounting for seasonal variations. Consider water recycling and rainwater harvesting to reduce dependency on municipal supply.
   4) *Distance to utilities* – Minimize the distance between the data centre and power/water sources to reduce transmission losses and infrastructure costs.

c) *Connectivity*

   1) *Carrier diversity* – Ensure access to at least two diverse fibre paths from different carriers to avoid single points of failure.
   2) *Latency* – Consider the proximity to major internet exchange points (IXPs) and content delivery networks (CDNs) for low latency connections.
   3) *Future expansion* – Plan for future connectivity needs by choosing locations with ample capacity for additional fiber optic cables.

d) *Environmental factors*

1) *Flood risk* – Refer to flood zone maps and avoid areas prone to flooding. If unavoidable, implement appropriate flood mitigation measures (elevated platforms, watertight barriers).
2) *Cyclone and wind risk* – Consider the historical cyclone tracks and wind speeds in the region. Design the building to withstand wind loads as per local codes.
3) *Air quality* – Analyse the ambient air quality data to understand the levels of particulate matter (PM), dust, and other pollutants. Employ high-efficiency air filtration systems to protect sensitive equipment if required.
4) *Electromagnetic interference (EMI)* – Evaluate potential sources of EMI (power lines, radio towers, etc.) and implement shielding if necessary.
5) *Environmental clearances* – Understand and comply with all environmental impact assessment (EIA) and pollution control norms relevant to data center construction and operation.

e) *Temperature and humidity*

1) *Climate zone analysis* – Refer to India's climatic zone map (as per Part 8 'Building Services Section 1 Lightning and Ventilation') to identify regions with favourable temperature and humidity profiles for data center operations.
2) *Microclimate considerations* – Within a climatic zone, local variations shall exist. Investigate microclimates around the proposed site, accounting for factors like proximity to water bodies, elevation, and prevailing wind patterns.
3) *Historical weather data* – Analyse at least 10 years of historical temperature and humidity data for the location. Pay close attention to peak summer temperatures and humidity levels, which will drive cooling requirements.
4) *Wet-bulb temperature* – Evaluate wet-bulb temperature data as a critical indicator of evaporative cooling potential. Higher wet-bulb temperatures limit the effectiveness of evaporative cooling technologies.
5) *Climate change projections* – Consult climate change models and projections for the region to anticipate future shifts in temperature and humidity patterns. Factor these projections into long-term planning and design.
6) *Adaptive cooling strategies* – Explore the potential for free cooling or hybrid cooling systems that shall leverage favourable ambient conditions to reduce energy consumption.

f) *Accessibility and logistics*

1) *Transportation infrastructure* – Evaluate the quality and capacity of road networks, proximity to airports/railway stations, and availability of reliable freight transport for equipment delivery and maintenance.
2) *Manpower access* – Consider the ease of commute for staff and the availability of skilled IT professionals in the region. Plan to be in vicinity of a public transport infrastructure or provide common shuttle service.

3) *Expansion space* – Ensure sufficient space for future expansion of the facility or campus, including considerations for power and network infrastructure upgrades.

g) *Security and risk mitigation*

1) *Physical security* – Evaluate the overall security environment of the location, including crime rates and potential threats. Implement robust physical security measures for the data center premises.
2) *Cybersecurity* – Consider the proximity to potential cybersecurity risks and implement stringent network security protocols to protect data.
3) *Disaster recovery* – Develop a comprehensive disaster recovery plan that considers natural disasters, power outages, and other disruptions.

13.4.2 *Redundancy for Cooling Infrastructure*

a) *Chillers*

1) Implement N+1 redundancy for chillers, ensuring that the remaining chillers shall handle the full cooling load even if one unit fails. Consider 2N redundancy for critical facilities or those in hot climates.
2) Size chillers based on peak cooling load with a safety margin to accommodate future expansion or equipment upgrades.
3) Implement preventive maintenance schedules and conduct regular inspections to ensure optimal performance and reliability.

b) *Precision air handling units (PAHUs)*

1) Deploy N+1 redundancy for PAHUs, ensuring sufficient airflow even if one unit is offline for maintenance or repair.
2) Consider zoning the data center and assigning dedicated PAHUs to each zone for better control and redundancy.
3) Equip PAHUs with variable speed drives (VSDs) to optimize airflow based on real-time cooling demands, improving energy efficiency.

c) *Power distribution for cooling*

1) Provide redundant power feeds (A+B) to critical cooling equipment, including chillers, PAHUs, and pumps.
2) Utilize dedicated PDUs for cooling infrastructure with branch circuit monitoring to track power consumption and identify potential issues.
3) Implement emergency power off (EPO) functionality to safely shut down cooling systems in emergencies.

d) *Additional considerations for cooling redundancy*

1) If the climate permits, explore the use of free cooling (air-side or water-side economizers) to reduce reliance on mechanical cooling and improve energy efficiency.

2) Design chilled water and condenser water piping systems with redundancy to prevent single points of failure and ensure continuous circulation.
3) Implement N+1 redundancy for cooling towers or consider alternative cooling technologies like dry coolers or adiabatic coolers for water-scarce regions.
4) Deploy redundant chilled water and condenser water pumps with automatic switchover capabilities in case of a pump failure.

13.4.3 *Water Leak Detection (WLD)*

a) *Comprehensive coverage* – Install a water leak detection system with adequate coverage in all areas prone to leaks, such as under raised floors, near cooling systems, piping, and water entry points. Tailor the coverage to the specific layout and potential risks of each data center.

b) *Sensor types* – Utilize a combination of sensor technologies to ensure comprehensive detection.

   1) *Spot Sensors* – Rope sensors or point sensors for localized detection in critical areas like under racks and near equipment.
   2) *Zone sensors* – For broader coverage in areas like underfloor plenums or around piping systems.

c) *Sensitivity and response time*

   1) *Sensor selection* – Choose sensors with high sensitivity and rapid response times to enable early detection and minimize potential damage.
   2) *Calibration* – Regularly calibrate sensors and adjust sensitivity levels based on environmental conditions and potential risk factors.
   3) Alarms and Notifications:
   4) *On-site alerts* – Implement visual and audible alarms within the data center to immediately notify onsite personnel of a leak.
   5) *Remote Notifications* – Utilize remote notifications via email, SMS, or dedicated monitoring systems to alert responsible personnel even when they are off-site.

d) *BMS integration*

   1) *Centralized monitoring* – Integrate the WLD system with the BMS for centralized monitoring and control, enabling real-time visualization of leak locations and status.
   2) *Automated responses* – Configure the BMS to trigger automated responses to leaks, such as shutting off water valves or activating backup systems.

13.4.3.1 A few additional considerations to be taken are:

a) *Regular testing and maintenance* – Conduct periodic testing and maintenance of the WLD system, including sensor checks, cleaning, and calibration.

b) *Documentation* – Maintain detailed documentation of the WLD system, including sensor locations, alarm thresholds, and maintenance records.
c) *Emergency response procedures* – Develop and regularly review clear emergency response procedures for water leaks, ensuring staff are trained and prepared to act swiftly to mitigate damage

13.4.4 *Inside Acceptable Temperature and RH Condition*

a) *Temperature*

1) Maintain a temperature range between 18°C to 27°C for optimal performance and longevity of IT equipment.
2) Consider higher temperature setpoints (closer to 27°C) where possible to improve energy efficiency, ensuring equipment compatibility.
3) Minimize temperature fluctuations and avoid hot spots or cold spots through effective airflow management and cooling strategies.

b) Relative humidity (RH)

1) Keep RH within the range of 8 percent to 60 percent to prevent condensation on equipment and electrostatic discharge (ESD) that shall cause damage.

Note – The upper limit may be lower (50 percent or even 35 percent) depending on the presence of specific corrosive gases in the environment.

2) Monitor dew point temperature and ensure a safe margin between the dew point and the lowest surface temperature in the data center.
3) Employ humidification or dehumidification systems as needed to maintain RH within the desired range, especially in regions with fluctuating humidity levels.

c) Monitoring and control

1) *Real-time visibility* – Implement a monitoring system that provides real-time visibility into all critical infrastructure components, including power, cooling, security, and environmental conditions.
2) *Data granularity* – Capture and store granular data at frequent intervals to enable in-depth analysis and trend identification.
3) *Multi-protocol support* – Ensure compatibility with various communication protocols (SNMP, Modbus, BACnet) for seamless integration of diverse equipment and systems.
4) *Centralized management*
   i) *Unified platform* – Deploy a centralized management platform (BMS, DCIM) to aggregate data from all monitored systems, enabling holistic oversight and control of the data center environment.
   ii) *Remote access* – Provide secure remote access to the management platform, empowering authorized personnel to monitor and manage the data center from anywhere, anytime.

   iii) *User-friendly interface* – Choose a platform with an intuitive and user-friendly interface for easy navigation and efficient operation.

5) *Advanced analytics*
   i) *Predictive analytics* – Leverage AI-powered analytics to analyze historical and real-time data, enabling predictive maintenance, anomaly detection, and optimization of resource utilization.
   ii) *Machine learning* – Utilize machine learning algorithms to learn from data patterns and proactively identify potential issues or inefficiencies.
   iii) *Data visualization* – Employ data visualization tools to present complex information in a clear and concise manner, facilitating decision-making and troubleshooting.
6) *Automated control*
   i) *Threshold-based actions* – Configure the system to trigger automated actions based on predefined thresholds or events, such as adjusting cooling setpoints, initiating failover procedures, or sending notifications.
   ii) *Workflow automation* – Streamline routine tasks through workflow automation, reducing manual intervention and human error.
7) *Alarms and notifications*
   i) *Prioritized alerts* – Implement a multi-tiered alarm system to prioritize critical events and ensure prompt attention to potential issues.
   ii) *Multiple notification channels* – Utilize multiple communication channels (email, SMS, phone calls, mobile app) to ensure timely notifications reach relevant personnel.
   iii) *Escalation procedures* – Define clear escalation procedures for critical alarms to ensure swift and appropriate action.
8) *Additional Recommendations*
   i) *Cybersecurity* – Implement robust cybersecurity measures to protect the monitoring and control systems from unauthorized access and potential threats.
   ii) *Data retention and analysis* – Retain historical monitoring data for long-term analysis and trend identification, aiding in capacity planning and optimization efforts.
   iii) *Training and skill development* – Provide comprehensive training to data center staff on the use and management of monitoring and control systems.

13.4.5 *Air Distribution Pattern with Positive Pressure*

a) Hot/Cold aisle containment

1) *Mandatory implementation* – Implement hot/cold aisle containment systems for all data centers to ensure efficient cooling and prevent hot air recirculation.
2) *Containment types* – Choose between physical barriers (for example, aisle doors, curtains, or rigid panels) or chimney rack systems based on space constraints, future flexibility requirements, and desired level of containment efficiency.
3) *Bypass airflow control* – Minimize bypass airflow (air leakage around containment systems) to the lowest achievable level, ideally below 5

percent. Employ blanking panels, brush strips, and proper sealing to achieve optimal containment.

b) *Positive pressure*

1) *Pressure differential* – Maintain a slight positive pressure differential of 2.5 Pa to 5 Pa between the data center and surrounding areas. This effectively prevents dust, pollutants, and other contaminants from entering the data center.
2) *Airlock systems* – Implement airlock systems at all entrances to further enhance pressure control and minimize air infiltration during door openings.
3) *Pressure monitoring* – Continuously monitor pressure differentials using differential pressure sensors and integrate them with the BMS for automated control and alarms in case of deviations.

c) *Computational fluid dynamics (CFD) analysis*

1) *Design optimization* – Utilize CFD modelling during the design phase to comprehensively optimize airflow patterns, identify potential hot spots, and ensure adequate cooling for all equipment under various operating scenarios.
2) *Validation and troubleshooting* – Use CFD analysis to validate the effectiveness of the implemented containment and airflow management strategies. It shall also aid in troubleshooting cooling issues and optimizing airflow distribution as the data center evolves and equipment densities change.

13.4.5.1 Following are some additional considerations to be taken for airflow management:

a) *Raised floor plenum* – Design the raised floor plenum with appropriate airflow tiles and perforated tiles strategically placed to distribute cold air efficiently to IT equipment intakes.
b) *Cable management* – Implement meticulous cable management within racks and under raised floors to avoid airflow obstructions and maximize cooling efficiency.
c) *Equipment placement* – Consider the airflow requirements of different equipment types during rack layout and placement within the data center to ensure optimal cooling for all components.

13.4.6 *Commissioning and Retrofitting Guidelines for Data Centers*

a) *General principles*

1) *Adherence to standards* – Follow the commissioning process and relevant industry standards for commissioning and retrofitting processes.
2) *Documentation* – Maintain thorough documentation throughout the project, including design intent, test plans, procedures, and results.
3) *Independent commissioning agent (CxA)* – Engage a qualified and independent CxA to oversee the commissioning or retrofitting process. The

CxA should be involved from the early design stages to ensure that the project meets its intended performance and efficiency goals.

4) *Collaboration and communication* – Foster effective collaboration and communication among all stakeholders, including the owner, design team, contractors, and CxA.

b) *Commissioning phases*

1) *Factory acceptance testing (FAT)*
   i) *Purpose* – Verify that equipment and systems meet specified requirements before shipment to the site.
   ii) *Scope* – Conduct functional and performance tests on major equipment (for example, chillers, UPS systems, generators, PAHUs) at the manufacturer's facility.
   iii) *Documentation* – Document test procedures, results, and any identified issues for resolution before shipment.
2) *Site acceptance testing (SAT)*
   i) *Purpose* – Verify that installed equipment and systems function correctly and meet performance specifications on-site.
   ii) *Scope* – Conduct comprehensive testing of individual systems and components (electrical, mechanical, controls, fire protection) after installation but before integration.
   iii) *Documentation* – Document test procedures, results, and any deficiencies for rectification before proceeding to the next phase.
3) *Integrated system testing (IST)*
   i) *Purpose* – Verify the proper interaction and performance of all systems and components as an integrated whole under various operating conditions.
   ii) *Scope* – Conduct tests under normal, peak load, and simulated failure scenarios to assess system redundancy, failover capabilities, and overall performance.
   iii) *Documentation* – Document test procedures, results, and any identified issues for resolution before final handover.

13.4.6.1 *Specific guidelines for retrofitting*

a) *Thorough assessment* – Conduct a detailed assessment of the existing data center infrastructure, including its current performance, energy efficiency, capacity limitations, and potential risks.
b) *Clear objectives* – Define clear objectives for the retrofitting project, focusing on areas such as energy efficiency improvements, capacity upgrades, reliability enhancement, or technology modernization.
c) *Phased approach* – Consider a phased approach to minimize disruption to ongoing operations, allowing for gradual implementation and testing of new systems while maintaining service continuity.
d) *Compatibility and integration* – Ensure that new equipment and systems are compatible with existing infrastructure and shall be seamlessly integrated into the current environment.

e) *Thorough testing* – Conduct rigorous testing of all retrofitted systems and components, both individually and in an integrated manner, to validate performance and ensure compliance with design intent.

13.4.6.2 A few additional recommendations for retrofitting are:

a) *Energy efficiency focus* – Prioritize energy-efficient technologies and design strategies during commissioning and retrofitting to reduce operational costs and environmental impact.
b) *Monitoring and control* – Implement comprehensive monitoring and control systems to enable real-time visibility, proactive management, and optimization of data center performance.
c) *Documentation and training* – Provide detailed documentation and training to data center staff on the operation and maintenance of new or retrofitted systems.

13.4.7 *Electrical Safety*

a) *Earthing and bonding* – Effective earthing and bonding are crucial for personnel safety and equipment protection.

1) *Earth resistance* – Achieve low earth resistance as per good practice [8-3(31)] for effective fault current dissipation. The specific requirements depend on voltage levels and earthing methods. Use multiple earth electrodes and ground enhancement techniques if needed. Regularly test and inspect the earthing system.
2) *Bonding* – Ensure proper bonding of all conductive elements to create an equipotential environment and prevent electrical hazards. Use low-impedance bonding conductors and regularly inspect connections.
3) *Lightning protection* –. Protect your data center from lightning strikes with a robust system complying with accepted standard [8-3(45)]. The LPS should include air terminals, down conductors, and earth termination networks. Install surge protection devices (SPDs) to safeguard sensitive equipment and ensure effective equipotential bonding for shielding effectiveness.
4) *Water pipes* – Avoid using water pipes as earth electrodes.

b) *Circuit protection* – Prevent overcurrent's and short circuits with appropriate circuit protection devices.

1) *Circuit breakers and fuses* – Install appropriate circuit protection devices (MCBs, MCCBs, fuses) with suitable ratings to protect against overloads and short circuits.
2) *Selective coordination* – Ensure selective coordination of devices to minimize disruptions caused by faults.
3) *Arc flash protection* – Conduct an arc flash hazard analysis and implement appropriate protective measures including appropriate personal protective equipment (PPE) and arc-resistant switchgear. (for example, arc-resistant switchgear, personal protective equipment) to safeguard personnel from arc flash incidents.

c) *Regular inspections* – Regular inspections are vital for identifying and addressing potential hazards.

1) *Scheduled inspections* – Conduct comprehensive inspections at least annually. Depending on the criticality of the equipment.
2) *Thermography* – Utilize thermography to identify hotspots and potential issues..
3) *Corrective actions* – Address any identified deficiencies or potential hazards promptly to maintain a safe electrical environment.

13.4.7.1 Some of the additional considerations to be taken for electrical safety are:

a) *Design and installation* – Engage qualified professionals for design and installation with accepted standards [8-3(32)] and [8-3(33)] and the National Building Code.
b) *Power quality* – Monitor and maintain power quality parameters (voltage, current, harmonics) within acceptable limits
c) *Emergency power off (EPO)* – Implement EPO systems for critical areas
d) *Training and awareness* – Provide regular electrical safety training to staff, including arc flash safety and lockout/tagout procedures.

13.4.8 *Periodic Maintenance / Predictive Maintenance*

a) *Preventive maintenance*

1) *Comprehensive schedule* – Develop and adhere to a comprehensive preventive maintenance schedule for all critical equipment, including:

i) *Electrical systems* – UPS, generators, switchgear, PDUs
ii) *Mechanical systems* – Chillers, cooling towers, pumps, CRAC/CRAH units
iii) *Fire suppression systems* – Sprinklers, gas suppression systems, fire alarm panels
iv) *IT equipment* – Servers, storage arrays, network switches

2) *Frequency* – Base the maintenance frequency on manufacturer recommendations, equipment criticality, and operating conditions. Generally:
i) *Quarterly or as per OEM recommendations* – CRAC/CRAH units, air filters, UPS batteries
ii) *Semi-annually or as per OEM recommendations* – Generators, electrical switchgear
iii) *Annually or as per OEM recommendations* – Chillers, cooling towers, fire suppression systems

3) *Qualified technicians* – Engage qualified and certified technicians for maintenance activities to ensure proper procedures are followed and equipment warranties are maintained.

4) *Documentation* – Maintain detailed records of all maintenance activities, including dates, tasks performed, and any observations or issues encountered.

b) *Predictive maintenance*

1) *Sensor deployment* – Install sensors on critical equipment to monitor parameters such as vibration, temperature, humidity, current, and power quality.
2) *Data collection and analysis* – Collect and analyze sensor data using advanced analytics platforms and machine learning algorithms to identify trends, anomalies, and potential failures.
3) *Early warning system* – Set up alerts and notifications to proactively identify equipment degradation or impending failures.
4) *Proactive maintenance* – Schedule maintenance activities based on predictive insights, minimizing unplanned downtime and optimizing equipment lifespan. Adhere to recommended maintenance intervals or as per OEM recommendations.

c) *Thermal imaging*

1) *Regular inspections* – Conduct periodic thermal imaging inspections of electrical connections, switchgear, and IT equipment to identify hotspots and potential overheating issues.
2) *Qualified thermographers* – Engage certified thermographers to perform inspections and interpret results.
3) *Corrective action* – Address any identified hotspots promptly to prevent equipment damage and potential fire hazards.

13.4.8.1 Some additional considerations to be taken for maintenance are:

a) *Spare parts inventory* – Maintain an adequate inventory of critical spare parts onsite to enable quick repairs and minimize downtime.
b) *Vendor support* – Establish strong relationships with equipment vendors and leverage their expertise for troubleshooting and support.
c) *Remote monitoring* – Utilize remote monitoring and management tools to gain real-time insights into equipment health and performance.
d) *Training* – Provide ongoing training to data center staff on maintenance procedures and predictive maintenance tools.

13.4.8.2 The specific considerations for the Indian context are:

a) *Dust and pollution* – In regions with high dust and pollution levels, increase the frequency of air filter replacements and AHU maintenance.
b) *High temperatures and humidity* – Pay close attention to the performance and maintenance of cooling systems during peak summer months.
c) *Power fluctuations* – Implement measures to protect equipment from power fluctuations and surges, which shall impact equipment lifespan.

13.4.9 *Design for Future Expansion and Technology*

To consider for the future expansions scalability in below dimensions to be considered:

a) *Capacity planning*

1) Conduct a detailed capacity planning exercise, factoring in:
   i) Projected IT load growth based on business forecasts and technology roadmaps.
   ii) Anticipated storage requirements, including data growth rates and retention policies.
   iii) Network bandwidth demands considering increasing traffic and application needs.
   iv) Time horizon for expansion planning (typically 5years to 10 years).
2) Utilize industry-standard tools and methodologies for capacity planning, such as data center infrastructure management (DCIM) software and power/cooling modelling.

b) *White space and power provisioning*

1) Design the data center with adequate white space to accommodate future rack installations and expansions.
   i) Consider factors like anticipated growth rate, rack densities, and desired aisle widths.
   ii) Leave room for future power and cooling distribution infrastructure.
2) Provision power capacity based on projected IT load growth and power densities.
   i) Factor in the power requirements of new technologies and potential increases in rack densities.
   ii) Account for inefficiencies in power distribution and cooling systems.

c) *Modular power and cooling*

1) Implement modular UPS systems, PDUs, and cooling units that shall be easily scaled up as IT load increases. This allows for incremental expansion and avoids upfront overinvestment.
2) Consider using modular power skids and containerized cooling solutions for flexibility and rapid deployment.

d) *Network infrastructure*

1) Design a flexible and scalable network architecture with ample capacity for future bandwidth requirements.
   i) Evaluate the need for higher-speed network technologies to accommodate future demands.
2) Deploy high-density fiber optic cabling and modular network switches to facilitate seamless upgrades and expansions.

14 VENTILATION SYSTEMS

Ventilation is the process of changing air in an enclosed space. A portion of the air in the space shall be continuously withdrawn and replaced by fresh air drawn from outside to maintain the required level of air purity, health, comfort and safety of building occupants.

Ventilation shall be done either by mechanical systems or through natural means. Mechanical ventilation usually consists of fans, filters (accepted standards [8-3(16)], [8-3(17)], [8-3(18)] and [8-3(19)]), ducts, air diffusers and outlets for air distribution within the building. Natural ventilation and natural exhaust are covered in Part 8 'Building Services, Section 1 Lighting and Ventilation' of the Code. The scope of this Section is therefore restricted to mechanical ventilation.

14.1 Types of Fans

Fans are broadly categorised as:

1) Axial fan; and
2) Centrifugal.

In axial fans, the direction of air flow is parallel to the fan's axis of rotation and in centrifugal fans, this direction is perpendicular. Each category encompasses further designs for example in centrifugal – forward curved, backward curved/inclined, aerofoil fans, plug/plenum fans and in axial – tube axial, vane axial and propellers. Fans have also been classified in terms of their application and special design for example roof ventilator, inline fan, jet fan, spark resistant fan, fume extract fan to name a few. These types may be available in both centrifugal and axial designs.

Recent advances in fan technology have led to the development of mixed-flow fans. These fans combine the high-pressure capability of centrifugal fans with the high flow rate of axial fans.

14.1.1 *Application*

Table 32 provides a general guideline on selecting the type of a fan for a given application, for example for kitchen exhaust, a backward curved centrifugal fan, for basement smoke ventilation, a high temperature rated fan and for laboratory ventilation, a fume extract fan.

Table 32 General Guideline for Fan Type and its Application
(*Clause* 14.1.1)

Sl. No.	General Fan Selection Guide	Double Inlet Centrifugal			Single Inlet Centrifugal			Plenum	Tube Axial	Vane Axial	Propeller	Mixed Flow	Tubular Centrifugal	Roof Ventilator	Spark Resistant	Fume Extract Fan	Jet Fan	Powerless Roof	High Volume Low Speed (HVLS)
	Application	**FC**	**BC/ BI**	**AF**	**FC**	**BC/ BI**	**AF**												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	Air Handling Units - Static less than 70mm	X	X	X				X											
ii)	Air Handling Unit - Static above 70mm		X	X				X											
iii)	Fan Filter Units	X	X	X				X											
iv)	Cabinet Fans	X	X	X				X											
v)	Basement Ventilation- Supply Fans	X	X	X				X	X	X									
vi)	Basement Ventilation- Exhaust Fans		X			X			X	X		X							
vii)	Ductless Basement Ventilation																X		
viii)	Kitchen Exhaust					X	X	X	X										
ix)	Smoke Extraction		X			X		X	X	X		X		X					
x)	Chemical Fume Extraction								X	X						X			
xi)	Wall Mounted Exhaust								X	X	X								
xii)	Roof Exhaust													X				X	
xiii)	Toilet Exhaust (Ducted)											X	X						
xiv)	Toilet Exhaust (Unducted)										X			X					
xv)	Ventilation of explosive environment														X				
xvi)	Ventilation of nuclear facilities		X	X				X	X										
xvii)	Ventilation of dusty environment		X			X		X	X										
xviii)	Tunnel Ventilation								X	X									
xix)	Large Volume Recirculation																		X

14.1.2 Selection and Operation

A fan consumes most of the energy in a mechanical ventilation system. To meet a given requirement of air flow rate and system pressure drop, the primary fan selection criterion shall be the overall fan system power consumption and efficiency, that is by the fan, the drive train, the motor and any electric controller such as a variable frequency drive (VFD). This is shown schematically in Fig. 9.

The fan energy index (FEI) is a measure of the overall fan system efficiency and relates the electric power input to the fan motor (or to the motor drive) with the aerodynamic power imparted to the air by the fan (for additional information special publication may be referred). FEI is an index (ratio) that compares the overall energy performance of the selected fan to that of a reference baseline fan. The baseline fan is a conceptual fan capable of producing the required airflow and fan pressure at a specified shaft input power using a V-belt drive and a 4-pole IE3 efficiency classification electric motor. The baseline fan does not include speed control. FEI of a selected fan at a desired duty point is defined as:

NOTE – Special publication maybe ISO12759-6:2024 ‘Efficiency Classification for Fans, Part 6 – Calculation of the Fan Energy Index’.

FEI = (Baseline Fan Electrical Input Power) / (Selected Fan Electrical Input Power)

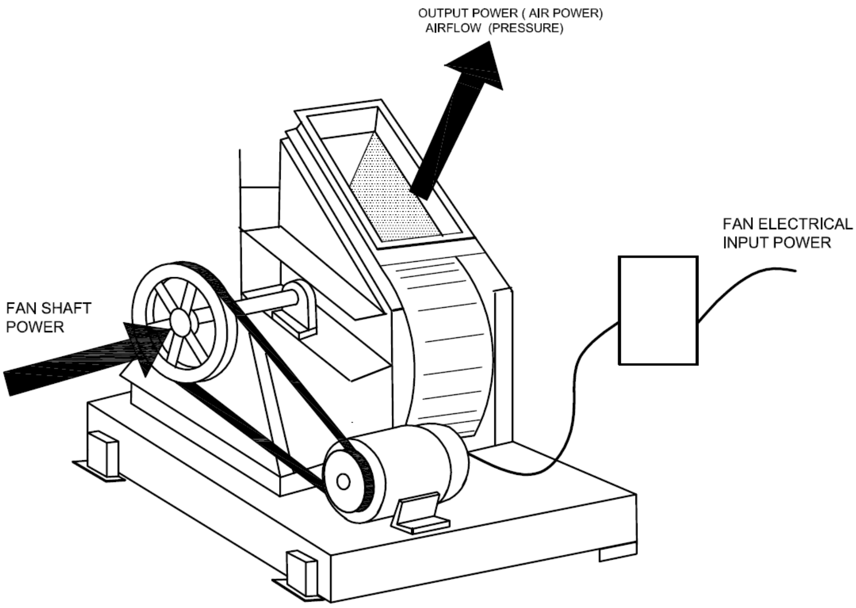


FIG. 9 FAN INPUT (ELECTRIC) POWER TO FAN OUTPUT (AIR) POWER

14.1.2.1 *Baseline fan*

The base line fan is a conceptual fan whose input power and efficiency values for a given duty point (flow rate Q and pressure P) are predefined and are used as a reference to calculate the FEI of any fan. The same reference fan is used to calculate FEI of various types of fans for a given duty point (Q, P).

Base Line Fan Shaft Power ($H_{\mathrm{i,ref}}$) at a given duty point of flow rate Q and Pressure P is defined as:

$H_{\mathrm{i,ref}}$ = (Q+0.118) x (P_t+100) / 0.66 Watts – For Ducted Outlet Fans
$H_{\mathrm{i,ref}}$ = (Q+0.118) x (P_s+100) / 0.60 Watts – For Free Outlet Fans

where P_t is total pressure, P_s is static pressure

Baseline transmission efficiency ($\eta_{t,ref}$) is defined as a function of baseline fan shaft power $H_{i,ref}$ as:

$\eta_{t,ref} = 0.96 \times [H_{i,ref} / (H_{i,ref} + 1.64)]^{0.05}$

Combining fan shaft power with transmission efficiency, the baseline motor output power shall be calculated as:

$= H_{i,ref} / \eta_{t,ref}$

Baseline motor efficiency ($\eta_{m,ref}$) shall be calculated from the baseline motor output power from the graph in Fig. 10.

By reading the value of baseline motor efficiency corresponding to the baseline motor output power, the baseline motor input power (or baseline fan electric power input) shall be calculated as under:

$= H_{i,ref} / (\eta_{t,ref} \times \eta_{m,ref})$

The baseline electric power input at a given duty point is the same irrespective of fan type and shall be used to calculate the FEI for any fan selected for the given duty point.

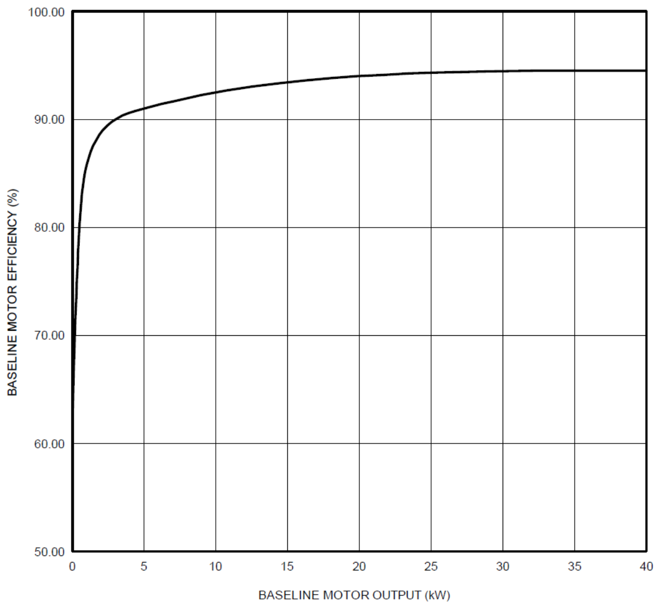


FIG. 10 BASELINE MOTOR EFFICIENCY AS A FUNCTION OF BASELINE MOTOR OUTPUT POWER

14.1.2.2 *Fan selection criteria*

The following selection criterion shall be used to select fan for various type of mechanical ventilation applications for a new building:

a) For axial fans requiring a shaft power of 2.0 kW or more, its FEI shall be 1.0 or more.
b) For centrifugal fans and mixed flow fan requiring a shaft power of 2.0 kW or more, its FEI shall be 1.1 or more.
c) The above prescribed minimum FEI values shall be applicable for all the duty points the fan is selected to operate at.

The choice of a fan type and its drive arrangement also depends on the nature of air to be handled and the type of application. If the fan has to handle dust laden or contaminated air, for example, industrial exhaust or kitchen exhaust, the fan drive arrangement (motor, pulleys, bearing and belts) shall be kept outside the air stream. The same applies to the temperature of air to be handled. For higher-than-normal air temperatures, for example in smoke ventilation, the fan shall be rated for high temperature application.

If fan noise is a concern, it shall be addressed by specifying acceptable limits of certified fan sound power ratings and not by arbitrary limits on fan speed or fan outlet velocity. Specifying fan noise in terms of fan sound pressure levels shall be discouraged.

14.2 Industrial Ventilation

In Industrial buildings, ventilation is needed not only to provide oxygen rich fresh air normally required for health and hygiene and to mitigate against thermal loads due to equipment, people and building heat gains, but also to remove and maintain the hazardous industrial pollutants within safe limits.

14.2.1 *Ventilation for Heat Control*

The required ventilation flow rate shall be calculated both for the sensible and latent heat load. In majority of cases the sensible heat load far exceeds the latent heat load, so the design rate usually shall be calculated on the basis of sensible heat alone. The sensible heat load includes solar heat gain, occupancy, lighting load, equipment load as well as other particular sources, if any.

The ventilation flow rate shall be calculated using the following equation:

$$Q_s = 3.462 \times \frac{H_s}{\Delta T}$$

where

Q_s = air volume flow rate, in m^3/h;
H_s = sensible heat load, in kcal/h; and
ΔT = allowable temperature rise, in °C.

Ventilation system shall be designed for air to flow through the hot environment in a manner that will effectively control the excess heat.

14.2.2 *General (Dilution) Ventilation Versus Local Exhaust Ventilation*

General exhaust ventilation (dilution ventilation) is appropriate when,

a) Emission sources contain materials of relatively low hazard (*see* Note);
b) Emission sources are primarily vapours or gases, or small, respirable size aerosols (those not likely to settle);
c) Emissions occur uniformly;
d) Emissions are widely dispersed;
e) Moderate climatic conditions prevail;
f) Heat is to be removed from the space by flushing it with outside air;
g) Concentrations of vapours are to be reduced in an enclosure; and
h) Portable or mobile emission sources are to be controlled.

NOTE – The degree of hazard is related to toxicity, dose rate, and individual susceptibility.

Local exhaust ventilation is appropriate when,

1) Emission sources contain materials of relatively high hazard;
2) Emitted materials are primarily larger diameter particulates (likely to settle);
3) Emissions vary over time;
4) Emission sources consist of point sources;
5) Employees work in the immediate vicinity of the emission source;
6) The plant is located in a severe climate; and
7) Minimizing air turnover is necessary.

Local exhaust ventilation normally requires lower air flows than general (dilution) ventilation.

Dilution ventilation is used to reduce the concentration of vapours from a given liquid solvent in the air to a safe level known as the threshold limit value (TLV) of the solvent expressed in ppm (parts per million). For a given solvent, the volume of air required to dilute its vapour concentration to below TLV shall be calculated by the following equation:

Air volume in m^3 per kg of evaporation $= \frac{(24 \times 10^6 \times k)}{M \times TLV}$

where

k = constant varying from 3 to 10 depending on the solvent, uniformity of air distribution, dilution of vapours in air and location of exhaust hood; and
M = molecular weight of the solvent.

A local exhaust ventilation system normally consists of a hood, a duct system, air cleaner, a fan and an exhaust stack. Such a system captures the contaminants at the point of generation through a properly mounted exhaust hood. The exhaust flow rate is determined from the area of the hood opening and capture velocity sufficient to prevent outward escapement of the contaminant. Table 33 lists the recommended range of capture velocity for various types of industrial contaminants.

Table 33 Recommended Capture Velocities for Industrial Contaminants
(*Clause* 14.2.2)

SI No. (1)	Condition of Dispersion of Contaminant (2)	Process Example (3)	Recommended Capture Velocity m/s (4)
i)	Released with practically zero velocity into still air	Evaporation from pickling tank, degreasing tank	0.25 - 0.5
ii)	Released at low velocity into moderately still air	Spray booth, intermittent container filling, welding, plating, low speed conveyor transfer	0.5 - 1.0
iii)	Active generation into zone of rapid air motion	Spray painting in shallow booth, barrel filling, conveyor loading, crushers	1.0 - 2.5
iv)	Released at high initial velocities into zone of very rapid air motion	Grinding, abrasive blasting, tumbling	2.5 - 10

The sizing of the ducts shall be determined considering the volume of air required and recommended duct velocity necessary to convey the contaminants with minimum possible pressure drop keeping in mind economics of installation and operation. Recommended duct velocity for exhaust ventilation system is given in Table 34.

Table 34 Recommended Duct Velocity for Exhaust Ventilation Systems
(*Clause* 14.2.2)

SI No. (1)	Nature of Contaminants (2)	Examples (3)	Recommended Duct Velocity m/s (4)
i)	Vapours, gases, smoke	All vapours, gases and smoke	5 - 10
ii)	Fumes	Welding	10 - 12.5
iii)	Air laden with very fine dusts	Litho powder, wood flour, cotton lint	12.5 - 15
iv)	Dry dust and powders	Fine rubber dust, moulding powder dust, cotton dust, jute lint, soap dust, leather shaving	15 - 20
v)	Average industrial dusts	Grinding dust, general material handling, clay dust, brick cutting, lime stone dust, asbestos dust in textile industry, dry buffing lint, granite dust, silica flour, shoe dust	17.5 - 20

vi)	Heavy dusts	Metal turnings, saw dust, sand blast dust, C.I. boring dust, lead dust, foundry tumbling barrels and shakeout	20 - 22.5
vii)	Heavy and moist dusts	Lead dust with small clips, moist cement dust, sticky buffing lint, quick lime dust	22.5 and above

The selection, installation and operation of fan shall be in accordance with the nature of contaminants. For dust and other industrial contaminant laden air, the drive arrangement (motor, belts and pulleys) shall be kept outside the air stream.

14.3 Underground Car Park Ventilation

14.3.1 *Requirement*

Ventilation is essential in enclosed car parking areas to dilute the level of toxic gases such as carbon monoxide (CO), oxides of nitrogen (NOx), presence of petrol/diesel fumes and smoke from engine exhaust. The ventilation rate will be such so as to ensure that the CO level is maintained within 40 mg/m^3 (35 ppm) for 1 h exposure, with a maximum of 29 mg/m^3 (25 ppm) for an 8 h exposure (as per best practices of special publication).

NOTE – Special publication may be ISO 10121-2.

14.3.2 *Ventilation Rate Requirement of Mechanically Ventilated Underground Car Parks*

For enclosed underground car parks without provision for natural ventilation, a minimum ventilation rate of 6 air changes per hour (ACH) shall be provided to keep contaminants within acceptable hygiene limits. In large basements, each compartment shall be independently ventilated at the minimum rate of 6 ACH.

14.3.3 *System Requirement*

The underground car park ventilation system shall be classified as supply-only, exhaust-only or a combination of the two. A system of ducts or impulse fans (jet fans) may also be used for proper distribution of air in the car park.

For underground car parking, the fans and the ventilation system used for normal CO level ventilation are also used for smoke ventilation during a fire. The extraction fans, ancillaries and the system should therefore be rated for high temperature operation including air changes per hour requirement, as specified in Part 4 'Fire and Life Safety' of the Code.

14.3.4 *Demand Control Ventilation Based on CO Level*

The ventilation air flow rate shall be varied according to CO level in order to conserve energy during off peak hours when vehicular movements is much lower than during peak hours. In multilevel basements as well as in large single level structures, independent fan system with individual control is required to take care of fire compartmentation requirements (see also Part 4 'Fire and Life Safety' of the Code).

14.3.5 *Location of Sensors*

The sensors for car park ventilation shall be placed in the following manner:

a) Maximum distance of any corner in the car park to the nearest sensor should be less than 25 m.
b) Sensors should be grouped according to the zone covered by the exhaust fan. The coverage area of each sensor should typically be 500 m^2.
c) Sensors should ideally be located between 0.9 m and 1.8 m above floor level. However, for practical reasons (in order to avoid vandalism), the sensors may be installed at just above 1.8 m height from floor.

14.4 Commercial Kitchen Ventilation

The basic purpose of a kitchen ventilation system (KVS) is to provide a comfortable environment in the kitchen and to ensure the safety of the people working in the kitchen and other building occupants, by effective removal of effluents which may include gaseous, liquid and solid contaminants produced by the cooking process and products of fuel and food combustion.

Heat and grease are the primary ingredient of kitchen effluents. 50 percent to 90 percent of the appliance energy input is released in the form of a rising convective thermal plume above the cooking surface; balance is released into the surrounding space through radiation. The exhaust hood shall be of sufficient size and placed at proper height to capture the whole plume. The hood exhaust flow rate shall be slightly higher than the plume flow rate. Extra exhaust capacity may be required to resist cross drafts.

14.4.1 *Hood Exhaust Flow Rate*

Kitchen hoods have been classified as two types, Type I and Type II. Type I hoods are used to collect and remove grease, smoke, steam and heat. Type II hoods only remove steam and heat. Thus, Type I hoods are fitted with some kind of grease collection device such as grease filters, baffles and a fire suppression system but a Type II hood typically does not have these devices. Appliances such as cooking ranges, fryers, broilers and griddles require Type I hoods whereas ovens, steamers and dishwashers shall work with Type II hoods.

Hood exhaust flow rates for different types of cooking equipment and exhaust hoods per linear meter of hood length shall be calculated as per Table 35. If more than one duty category appliance is placed under one hood, the hood exhaust flow shall be calculated on the basis of the heaviest duty appliance.

For Type II hoods, the prescribed exhaust flow rates are from 150 liters per second per linear meter of hood length to 460 liters per second per linear meter of hood length for oven hoods, and 460 liters per second to 770 liters per second for condensate hood.

Table 35 Hood Exhaust Flow Rates by Appliance Category
(*Clause* 14.4.1)

Sl No.	**Appliance Category Surface Temperature** °C	**Light** **200°C**	**Medium** **200°C**	**Heavy** **315°C**	**Extra Heavy** **370°C**
(1)	(2)	(3)	(4)	(5)	(6)
i)	Cooking equipment	a) Electric/gas ovens b) Electric/gas steamers c) Cheese melters d) Pizza ovens e) Food warmers	a) Hot Top/Element Ranges b) Griddles c) Fryers d) Pasta Cookers e) Conveyor Ovens f) Grill g) Rotisseries	a) Open Burner Ranges b) Broilers c) Wok Ranges	Appliances using solid fuels for example, wood, charcoal briquettes
ii)	Plume velocity (m/s)	0.25	0.43	0.75	0.93
iii)	Hood type	Hood exhaust flow rates per linear meter of hood length (litres per second)			
a)	Wall mounted canopy	309	463	618	850
b)	Single island	618	772	927	1080
c)	Double island (per side)	386	463	618	850
d)	Back shelf	463	463	618	–

14.4.2 *Good Hood Design and Installation Practices*

Wherever feasible, the following good hood design and installation practices shall be adhered to:

a) Increasing hood overhang increases capture volume which aids capture and prevents spillage. A minimum overhang of 150 mm on all open sides for all canopy hoods is prescribed. Increasing front overhang and use of inclined side panels (instead of side overhang) significantly reduces capture flow rates.
b) Deployment of side panels improves hood performance significantly. Side panels prevent the plume from spilling at the side, prevent cross drafts and increase velocity at the hood front.

c) Under a wall canopy hood, pushing the appliance towards the back wall significantly improves hood performance in two ways, increased front overhang and reduction in gap between the appliance and the back wall.
d) When using multiple duty category appliances in line under a single hood, the lowest capture rates are achieved when light duty appliance are at the end of the line. Therefore, hood performance is best when heavy duty appliances are placed in the middle of the line.
e) Hood shall be mounted at as low a height as practical above the appliance surface.

14.4.3 *Oil/Grease Removal*

The removal of oil/grease from the exhaust airflow is a very important part of commercial kitchen operation. Collection of grease in the duct system, in the fan, in roof top equipment and its emission in the environment poses not only pollution problems but is also a serious fire hazard. Grease shall be effectively removed in the hood exhaust system through the use of proper filtration device. The design and selection of proper filtration device shall ensure that the exhaust air is clean and in accordance with the applicable pollution control norms.

14.4.4 *Exhaust Duct Design, Installation and Maintenance Practices*

Kitchen exhaust ductwork carries hot grease laden air. The following general guidelines shall be followed in their design, installation and maintenance:

a) Ducts should be round or rectangular.
b) Ducts shall be grease tight and should be free of traps that shall hold grease.
c) Minimum sheet gauge should be 16-gauge mild steel or 18-gauge stainless steel.
d) All joints and seams shall be fully welded and made grease tight.
e) Ductwork shall lead directly to building exterior and should not be interconnected with any other type of building ductwork.
f) Horizontal duct runs should be minimized and pitch towards the hood or an approved reservoir for continuous drainage of liquid grease and condensate. The slope should be 2 percent for runs under 23 m. For horizontal runs greater than 23 m, 8 percent slope should be provided. A grease drain outlet shall be provided in form of a leg under a vertical riser.
g) Maximum velocities are limited by pressure drop and noise and should normally not exceed 12.5 m/s.
h) The minimum air velocity for exhaust ducts should be 2.5 m/s.
j) For new single speed fan system, a design duct velocity of 7.5 m/s to 9 m/s is appropriate.
k) Ducts shall be as per the requirements given in Part 4 'Fire and Life Safety' of the Code.
m) Access doors duly nut bolted with lead/fire rated gasket shall be provided for scavenging/grease removal during maintenance. This should be marked/provided in drawings as well as in actual duct work, so that nothing is built to block access to them.
n) It is recommended that duct cleaning at regular intervals be carried out so that the grease film thickness inside ducts (measured with a wet film thickness

gauge or equivalent device) does not exceed 180 microns. This will avoid accidental grease sparks and fire.

14.4.5 *Fan for Kitchen Exhaust*

Kitchen exhaust consists of hot, grease laden air with some solid particulate matter also. Fan shall be capable of handling this air and the motor and the drive train (shaft, bearings, belts, etc.) shall be kept outside the air stream. The kitchen exhaust fan shall consist of a backward centrifugal impeller.

14.4.6 *Terminations of Kitchen Exhaust System*

Kitchen exhaust systems shall be terminated so that,

a) Discharge direction shall be such as to minimize re-entry into fresh air intake. This not only requires a minimum separation between exhaust and fresh air intake but also knowledge of prevailing winds.
b) Grease shall be collected and drained into a closed container (a fire safety precaution).
c) Rainwater shall be kept out of the grease container.
d) Grease shall not be allowed to drain down the side of the building.
e) Discharge shall not be directed downward or towards pedestrian areas.
f) Roof top discharge shall de released a minimum 4 m above the roof surface.
g) For discharge from building sides, it shall be ensured that the discharge air is clean, free from odours and in accordance with the applicable pollution control norms.

14.4.7 *Replacement (Make-up) Air Considerations*

The air exhausted through a kitchen hood shall be replaced 100 percent with clean outside air. Kitchen room pressure shall be maintained slightly lower than the adjoining building space (for example, dining room) to allow conditioned air to transfer into the kitchen and to contain heat and odours within the kitchen. For kitchens adjacent to a building exterior wall, the kitchen pressure shall be slightly higher than outside to prevent ingress of dust, heat and insects.

14.4.8 *Energy Management Considerations*

Significant energy savings are possible with demand control ventilation (DCV) because the power consumed by a fan is proportional to the third power of its speed. Exhaust and supply air flow rates shall be controlled to cater to peak and off-peak periods by installing variable frequency drives (VFD) on the fan motors.

14.5 Laboratory Ventilation

Most laboratories are the source of chemical and biological contaminations which may be very harmful for the occupants. It is essential to provide effective ventilation to control the air quality and remove contaminants to protect the health and safety of laboratory personnel and surrounding environment.

14.5.1 *Ventilation of Chemical Laboratories*

a) The laboratory rooms shall have mechanically operated supply and exhaust air system. Exhaust air shall not be recirculated or short cycled through make up air.
b) Chemical laboratories shall have a minimum of 6 air changes per hour (as per best practices of special publication).
c) Fume hoods (*see* fig. 11) and/or local extractors shall be deployed for effective exhaust from localized processes. Face velocity at fume hood sash shall be sufficient to maintain the maximum allowable escape of contaminants at 0.01 ppm. This shall be verified by tracer gas tests post commissioning.
d) Laboratories shall be maintained at negative pressure with respect to surrounding corridors or less hazardous areas.
e) Ventilation system shall be capable of shutting down in case of fire.
f) Exhaust duct air velocity shall be maintained at 5 to 10 m/s to prevent condensation of fumes or accumulation of solid contaminants.
g) Eddies and cross drafts in the vicinity of fume hoods shall be minimized.

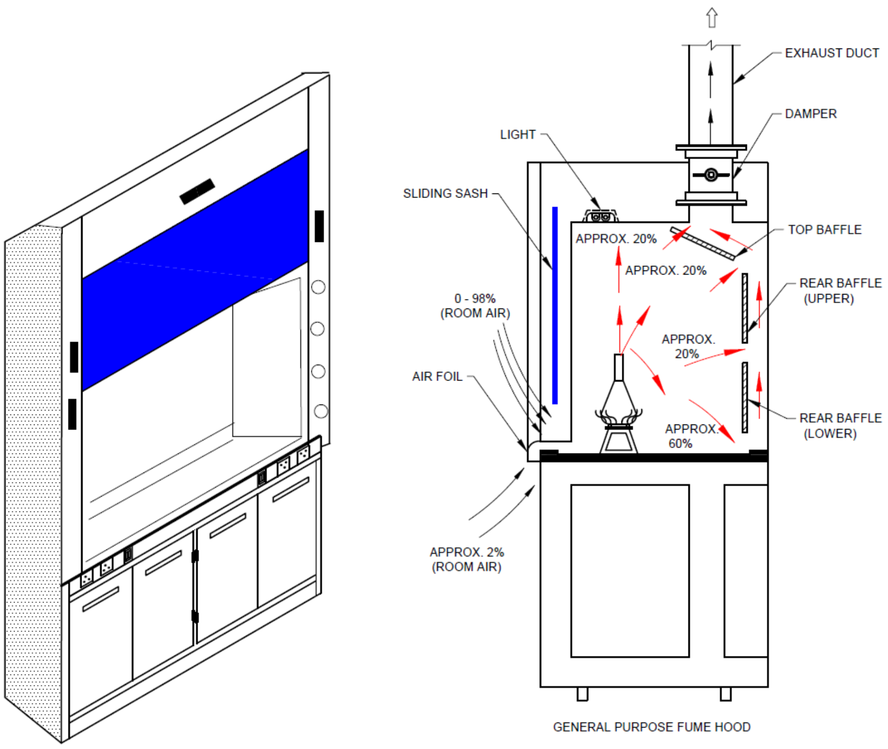


FIG. 11 GENERAL PURPOSE LABORATORY FUME HOOD

h) Certain minimum level of ventilation shall be provided even when the laboratories are not functional to evacuate the vapours generated from the chemicals in the laboratory.
j) Openable windows shall be prohibited to maintain containment and negative pressure in laboratory rooms.
k) Exhaust duct shall not be internally insulated for thermal or acoustic purpose. Sound attenuators or external insulation at source may be provided to control the noise.

m) Fume hood using heated perchloric acid shall be designed to have the entire exhaust path in spark and corrosion resistant construction as well as with a washing system to avoid explosion hazard.
n) Adequate makeup air shall be provided to compensate the air exhausted by the hoods or other exhaust system.
p) Air flow direction shall be from low hazard to high hazard areas.

NOTE – Special publication may be ISO 10121-2.

14.5.2 *Ventilation of Biological Laboratories*

Depending upon level of hazard and requirement of protection, biological labs are generally classified into four bio-safety levels (BSL), further categorized into BSL1, BSL2, BSL3 or BSL4 based on combination laboratories practices and techniques, safety equipment and laboratory facilities. General ventilation requirements of BSL3 labs are as prescribed below:

a) Minimum rate of 6 air changes per hour shall be maintained at all times.
b) Laboratories shall be maintained at negative pressure of 12.5 Pa or lower with respect to adjoining corridors, areas, other containment or pressure zones. Monitoring and control devices shall be installed to ensure that pressure differential is maintained at all time.
c) Ventilation system shall effectively remove heat, contaminants and odour from all equipment and laboratory spaces.
d) Visual readout devices and alarm should be provided at entry to containment space, in ante rooms and at entry to other individual rooms within the containment area.
e) Dedicated exhaust air system shall be provided. This system may not be connected to a common system or any other system serving the spaces outside the biocontainment space.
f) Exhaust system shall be provided with variable frequency drive with necessary airflow sensors and a standby fan for redundancy.
g) All duct work shall be with welded joints and in stainless steel construction.
h) It is highly recommended to provide the exhaust system for a BSL3 lab with high efficiency particulate air (HEPA) filters (accepted standard [8-3(20)], [8-3(21)], [8-3(22)], [8-3(23)] and [8-3(24)]). This filtration shall be provided as close as possible to the biocontainment area. The filtration system shall include bag-in / bag-out type filter replacement system so as to replace the filters without shutting down the exhaust system. Necessary arrangement shall be provided for full face scanning of HEPA filter integrity.
j) Necessary equipment such as laminar flow units, bio safety cabinets of required class, glove box etc. shall be used to ensure the protection of biologically delicate material or to contain bio hazard material during the experiment.
k) The airflow direction shall be from the clean area to the biocontainment spaces.

14.5.3 *Ventilation of Animal Research labs*

Properly designed ventilation system provides an adequate amount of oxygen to the lab personnel and animals, removes thermal load generated by animals, removes biological contaminants including allergens and airborne pathogens, controls the humidity of animal housing systems, dilutes the gaseous contaminations, maintains pressure differential between adjoining spaces, maintains micro environment in primary enclosure (housing cage) and maintains animal health.

Animal research facility shall be classified as under with respect to housing system:

a) Conventional animal facility with open type pan.
b) Modern animal facility with individually ventilated animal housing system.

14.5.3.1 *Animal lab with conventional system*

a) Shall be provided with minimum of 10 to 15 outside air changes per hour for animal biosafety level (ABSL) 1 and 2 labs and higher for ABSL 3 facility. System should be once through. Recirculation of air is generally not permitted.
b) Both, supply and exhaust air system shall be provided with HEPA filter to protect the animal from outside contamination and also to protect the environment from biological contamination.
c) System shall be designed to maintain required hygroscopic conditions as per animal requirement.
d) High velocity draft shall be avoided near animal housing pans to protect animals from wind chill effect.

14.5.3.2 *Animal lab with individually ventilated housing system*

a) Shall be provided with fresh air supply depending upon the total cage volume and number of air changes required by the system.
b) Necessary adjustment factor shall be considered while designing the HVAC system as the relative humidity in close cage will be 8 percent to 10 percent higher than in the room.
c) Shall ensure no air movement from contaminated area to clean area.
d) Ventilated caging system shall be selected and pressure gradients shall be adjusted in system itself according to different ABSL level requirements.

14.5.3.3 In addition:

a) The direction of air flow shall be from clean corridor to animal room to the service corridor. Necessary pressure gradient shall be maintained to ensure this all the time.
b) Both, supply and exhaust systems shall be designed for redundancy and shall be in operation all the time.
c) Animal experiment room shall be maintained under negative pressure with respect to clean area. Animal quarantine room and healthy animal rooms shall be maintained under positive pressure.
d) Use necessary isolation equipment to protect surrounding environment from infected animal or to protect immune compromised animals from surrounding environment.

14.6 Tunnel Ventilation

14.6.1 *General*

The tunnel ventilation system (TVS) for underground metro network is intended to provide,

a) An acceptable environment in the tunnel and station trackway for the operation of trains;
b) Pressure relief produced by the piston effect of train movement during normal operation;
c) Heat removal during congested/maintenance operation; and
d) An effective means of controlling smoke flows during emergency conditions for safe evacuation of passengers

14.6.2 *Operation Philosophies*

There are three design operating conditions for the tunnel ventilation system that is normal operation, congested operation and emergency operation.

During normal operation, that is when trains are running as per scheduled headway the main source of ventilation for the tunnel is airflow generated due to piston effect produced by moving train. Tunnel ventilation fans are not operated during train movement in tunnel. The trackway exhaust system (TES) at the station extract the heat from train air-conditioning or braking equipment when train is dwelling at the stations. The air extracted from the TES is either exhausted to the atmosphere or shall be used to recirculate to the station air-conditioning system as per the requirement. The trackway exhaust fans are generally provided with variable frequency drives to operate the fan at optimal speed to save energy.

In congested operation, the tunnel ventilation fans (TVFs) are activated for preventing the accumulation of warm tunnel air around idling train in the affected tunnel section. The tunnel ventilation design condition for congested train operation is maximum stratified tunnel air temperature (approx. 50°C) as per the design of the rolling stock.

In emergency operation, the TVS is set to operate to control the movement of smoke and provide a smoke-free path for safe evacuation of the passengers and for firefighting purposes. The ventilation system is operated in a ‘push-pull’ supply and exhaust mode with tube axial flow fans / nozzles. This enables driving tunnel air flows such that the smoke is forced to move in one direction, enabling evacuation to take place in the opposite direction. A typical ventilation system in tunnel during fire on a train is shown in fig. 12.

One of the most important factors in selection of the system is to generate the minimum critical velocities of air flow in the tunnel to prevent back-layering of smoke laden air in the tunnel.

14.6.3 *System Description*

The tunnel ventilation system (TVS) consists of tunnel ventilation fans (TVFs), trackway exhaust fans (TEFs), tunnel booster fans (TBFs), tunnel ventilation dampers (TVDs), tunnel ventilation nozzles and sound attenuators provided in the tunnel ventilation plant rooms at each end of the station and connected to both trackways and to outdoors through ventilation shafts.

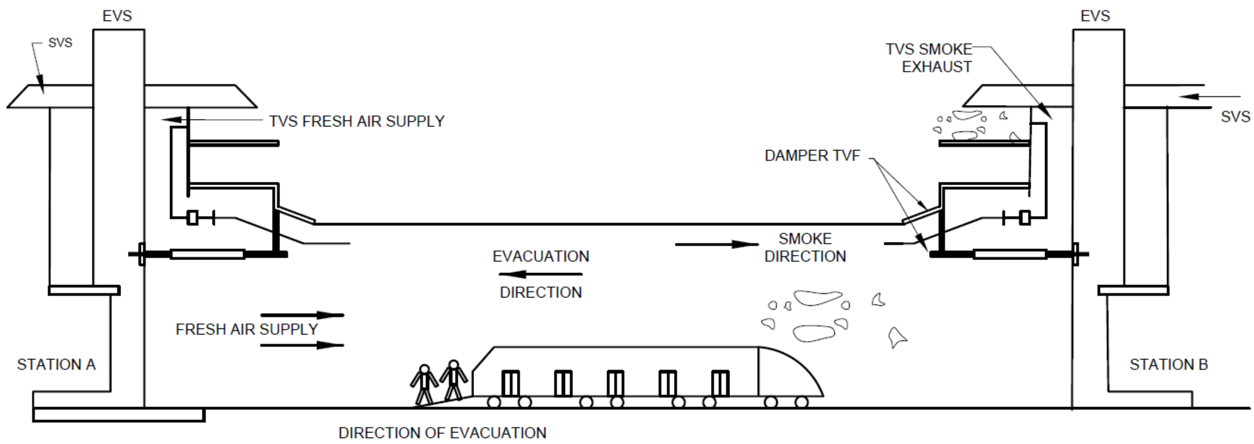


FIG. 12 VENTILATION IN TUNNEL DURING FIRE ON A TRAIN

Each tunnel ventilation installation has two fully reversible tunnel ventilation fans with fan isolation dampers. These dampers are closed when the fan is not in operation. In addition, there is a bypass duct with isolation dampers around the fan room, which acts as a pressure relief shaft when open during normal conditions and enables the flow of air to bypass the TVFs, allowing air exchange between tunnel and outdoor with flows generated by train movement.

The tunnel booster fans are installed at the crossover locations / at portals that is, where the train moves from underground to overground to provide thrust and to direct the flow in desired direction during congestion and emergency scenarios.

The trackway exhaust fans are located in separate plant rooms at each end of the station and connected to station trackway through under platform exhaust and over track exhaust ducts and to the outdoors through exhaust ventilation shafts, to enable heat removal from train AC system and braking system. The TEFs shall also be utilized for smoke extraction from the concourse/platform public areas with the help of dampers connecting the ducting system.

All the components of the tunnel ventilation system are rated minimum for 250ºC for one hour. The fire rating of the system shall be increased based on the requirements.

The specialized software tools such as subway environment simulation (SES), IDA tunnel software, computational fluid dynamics (CFD) analysis are used to evaluate the requirement and efficacy of the tunnel ventilation system.

A typical schematic of the TVS system installed at platform level is shown in Fig. 13.

14.6.4 *Control and Monitoring of TVS*

The TVS system shall be equipped with provisions for automatic, manual, local and remote controls so that the fans and damper motors shall be operated from a station control room (SCR) or from the operations control centre (OCC). At OCC, an integrated supervisory control and data acquisition system (SCADA), should be employed to control and monitor the TVS plant in each station, as the same are generally not attended locally.

The operation of the tunnel ventilation fans during congestion are integrated with the signalling system to identify the affected tunnel section or the ventilation zone. The fans shall be operated automatically or semi-automatic as per the requirements.

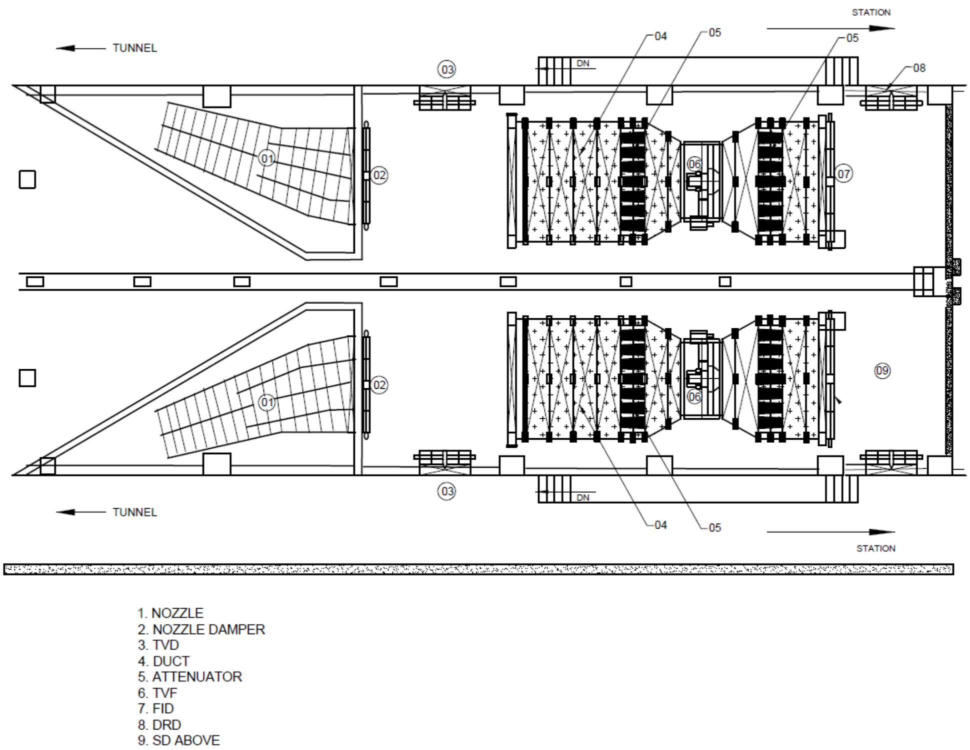


FIG. 13 TYPICAL SCHEMATIC OF THE TVS PLANT ROOM AT PLATFORM LEVEL

In case of unattended train operation, suitable means shall be provided to locate the fire on train for deciding the direction of operation of the ventilation system.

The SCADA for TVS shall be designed with a minimum safety integrity level that is SIL-2. The redundancy shall be provided for communication, processor and power supply.

15 AUTOMATION AND CONTROLS

In commercial buildings, there are various equipment and systems that consume a lot of energy in applications while delivering occupant comfort and achieving their functionalities. There are multiple aspects for operating these systems to deliver design conditions due to which automation and controls become inevitable. Systems are supposed to function at the set parameters throughout the year whereas ambient conditions vary throughout the operating hours of the building. Systems and equipment normally get designed for peak loads and demands but they operate at part load conditions for a majority of their operating hours. This aspect of operations under various outside as well as inside conditions impacts the operating efficiencies of these systems. To maintain various functionalities within the design conditions, systems should have proper controls incorporated in design as well as in operations. Nowadays equipment come with a lot of built in intelligence and it becomes very necessary to integrate them to a higher level of BMS to ensure owners and end users shall monitor and control the various systems to achieve operating efficiencies, safety, comfort and health of the building and its occupants. In addition to these aspects, the speed with which the digital technology is moving forward, internet of things (IoT) is becoming an integral part of equipment. Buildings shall incorporate futuristic design aspects of BMS in building design. This chapter addresses the various aspects of automation and control elements in a building for the various Systems as described below.

15.1 Roles and Requirements of Automation and Controls in a Building for Various Systems

Given below are the required roles for automation and control in building for various system:

15.1.1 *Heating, Ventilation and Air Conditioning Systems (HVAC)*

Automation and Controls should be designed for:

a) *Monitoring* – Should monitor air quality and thermal comfort parameters as specified in chapter.

b) *Control* – Controls shall Switch On/Off of the various equipment based on demand, and open/close or modulate valve actuators and HVAC dampers based on time schedule, occupancy or control parameters like temperature or RH or pressure or flow based on the application.

c) *Energy data management* – Should Provide energy consumption data to monitor and help create energy saving strategies

d) *Alarm management* – Should Provide better monitoring, control and early notification for predictive and preventive maintenance, optimize operational efforts and reduce downtime of the system.

e) *Building parameter data management* – Should provide historical data for analysis of system performance.

15.1.2 *Fire and Life Safety*

There is a lot of data exchange required between the fire alarm system and HVAC system for monitoring and controlling the pressurization systems in a building from the BMS. Life safety systems are always stand-alone systems but monitoring of all these systems from the BMS should be deployed critical for proper operation and monitoring of the buildings.

a) Automation for fire and life safety in commercial buildings, residential communities, public places and FAS and BMS should be seamlessly integrated.

   1) *Monitoring* – Shall monitor status of various equipment - water tank levels, primary pumps, diesel pumps, jockey pumps, fire sensors, smoke sensors, pressure across the system, leakages, fire-panel alerts and diesel fuel tank level, fire extinguishers.
   2) *Control* – It should have controls for automatic filling of water in fire tanks independently and proactive steps for managing alerts from the fire panel. should include predictive and preventive maintenance scheduling via automation for various components.
   3) The Wired or wireless technology for automation should be deployed based on the overall implementation of that project and budget.

b) Automation for life safety systems and monitoring of systems with interlinked logics and sharing of information with fire responders:

Application in buildings, communities, cities and towns, public places, industries, data centers, hospitality and hospitals etc.

   1) *Monitoring of fire alarm panels* – status monitoring - ON/OFF, alarm status /normal status this should be covered over IoT (Via Wi-Fi /4G/3G or wired). - Intend of this application - To have status monitoring locally and remote capability via IOT which shall be seen by fire responders.
   2) *Monitoring of hydrant system* – Pressure in hydrant pipes should be continuously monitored and remotely displayed, Change of Pump switch from auto/manual or vice versa, change in ON/OFF status of pumps. Calls and SMS/Or mail alerts at all levels with escalation matrix defined.
   3) The Wired or wireless technology for automation should be deployed based on the overall implementation of that project and budget.

For real life saving impact we need to look at early detection methods. Wired and wireless technology shall be employed. Wireless IoT sensors and applications should be programmed to provide 'Notifications' of critical events in small and medium sized buildings that do not have a complete BMS system.

15.1.3 *Electrical*

The following sub systems should be connected with the BMS for monitoring purposes. BMS should monitor:

a) Critical parameters of DG
b) Fuel levels of day fuel tank
c) Electrical breakers for risk free operation of the system
d) Various parameters from energy meters to ensure that energy consumption levels are trended and logged for proper analysis of the usage of energy and taking corrective action at the appropriate time to save the energy consumption levels in buildings
e) Vertical and horizontal transportation (VHTs) from a single platform

The integrated building management system (IBMS) should create necessary dashboards for easy access to the operating personnel.

Medium size buildings should use independent wireless IoT based energy monitoring device to monitor and control energy usage of VRF and ducted split units.

15.1.6 *Controls Requirement for Significant Components of Building*

Based on the above details of requirements of various systems for control and monitoring functionalities, following Table 36 defines compliance requirements for significant components of BMS at equipment level and system level.

Table 36 Controls Compliance Requirement for Significant Components of Building
(*Clause* 15.1.6)

Sl No.	**Discipline**	**Control and Monitoring Level**	**Equipment / System**	**Control / Monitoring - base level**	**Control / Monitoring - energy intensive buildings**	**Control / Monitoring - for critical buildings**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	HVAC					
i)	HVAC	Equipment Level	DX IDU/ODU	Stand Alone	Stand Alone	Stand Alone
ii)	HVAC	Equipment Level	DX VRF	Stand Alone	Stand Alone	Provide networked controllers
iii)	HVAC	Equipment Level	CHW FCU	Stand Alone	Individual Timeclock Control using Controller	Provide networked controllers
iv)	HVAC	Equipment Level	CHW AHU	Stand Alone	Individual Timeclock Control using	Provide networked controllers

Sl No.	**Discipline**	**Control and Monitoring Level**	**Equipment / System**	**Control / Monitoring - base level**	**Control / Monitoring - energy intensive buildings**	**Control / Monitoring - for critical buildings**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
					Programmable Controller	
v)	HVAC	Equipment Level	CHW Pumping	Stand Alone	Provide group controls for all the pumps	Provide networked controllers
vi)	HVAC	Equipment Level	Cooling Tower Fan	Stand Alone	Stand Alone - as per ECSBC	Provide networked controllers
vii)	HVAC	Equipment Level	Extract Fan	Stand Alone	Stand Alone	Provide networked controllers
viii)	HVAC	Equipment Level	Pressure Control (Air side)	Stand Alone	Stand Alone	Provide networked controllers
ix)	HVAC	Equipment Level	CT Level Control	Stand Alone	Stand Alone	Provide networked controllers
x)	HVAC	Equipment Level	Basement Ventilation	Stand Alone - as per ECSBC	Stand Alone - as per ECSBC	Provide networked controllers with all monitoring points in the dashboard screens
xi)	HVAC	Equipment Level	Energy Recovery (Airside)	Stand Alone - as per ECSBC	Stand Alone - as per ECSBC	Provide networked controllers
xii)	HVAC	System Level	CHW Pumping	Stand Alone	Stand Alone	Provide networked controllers
xiii)	HVAC	System Level	Variable Air Volume	Stand Alone	Stand Alone	Provide networked controllers
xiv)	HVAC	System Level	Pressure Control	Stand Alone	Stand-alone	Provide networked controllers
xv)	HVAC	System Level	Demand Control Ventilation	Stand Alone as detailed in ECSBC	Stand Alone as detailed in ECSBC	Provide networked controllers
xvi)	HVAC	System Level	Economizer	Provide controls as per ECSBC	Provide controls as per ECSBC	Provide networked controllers

Sl No.	Discipline	Control and Monitoring Level	Equipment / System	Control / Monitoring - base level	Control / Monitoring - energy intensive buildings	Control / Monitoring - for critical buildings
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xvii)	HVAC	System Level	Chillers and Chiller Plant Control	Chiller Plant Control as per ECSBC details	Chiller Plant Control as per ECSBC details	Provide networked controllers with data for analysis
	LIGHTING					
xviii)	Lighting	Equipment Level	Lux level control	as per details given in ECSBC	as per details given in ECSBC	as per details given in ECSBC
xix)	Lighting	System Level	Lighting Management System (LMS)	-	-	Integrate LMS with BMS; share occupancy/unoccupancy mode data; based on based on which, VAVs to switch to occupied/unoccupied modes
	ELECTRICAL AND VERTICAL TRANSPORTATION					
xx)	Electrical and Vertical Transportation	Equipment Level	Transformers, Breakers, VHT	-	-	Monitor healthy status of the equipment
xxi)	Electrical and Vertical Transportation	Equipment Level	Energy Meters	Record energy value at all meters for monitoring purposes for all utilities	Digitally connect all utility energy meters; track energy consumption for analysis	Digitally connect all utility energy meters; track power and energy consumption data for analysis
xxii)	Electrical and Vertical Transportation	System Level	Building Level	-	Comply as per ECSBC	Comply as per ECSBC
	WATER MANAGEMENT					
xxiii)	Water Management	Unit/Equipment Level	PHE Equipment	Provide stand-alone control for equipment functioning as per Section 8 on	Provide stand-alone control for equipment functioning as per Section 8 on	Track parameters at the dashboards

Sl No.	Discipline	Control and Monitoring Level	Equipment / System	Control / Monitoring - base level	Control / Monitoring - energy intensive buildings	Control / Monitoring - for critical buildings
(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Water Management	Water Management	
xxiv)	Water Management	Equipment Level	STP System	Stand-alone control	Stand-alone control	Track parameters at the dashboards
xxv)	Water Management	Equipment Level	Water Meters	Recording of Water Consumption data;	Recording of Water Consumption data;	Recording and trending of water consumption data

NOTE – Details of for abbreviations mentioned in column under equipment/system are provided below - this matrix is part of chapter 13 of ECSBC and shall be referred also from ECSBC.

DX IDU/ODU	DX Split Unit
DX VRF	DX Variable Refrigerant Flow Unit
CHW FCU	Chilled water Fan Coil Unit
CHW AHU	Chilled Water Air Handling Unit
CHW Pumping	Chilled water Pumping
CT Level Control	Cooling Tower Level Control
PHE equipment	Public Health and Engineering equipment
VHT	Vertical and Horizontal Transportation

15.2 Building Management System (BMS) and Internet of Things (IoT)

The following points outline the various components and functionalities associated with BMS and IoT in modern buildings

15.2.1 *BMS System Architecture*

a) Control Systems in a building shall have a system architecture that ensures control and monitoring of various operating parameters at the following levels:
   1) Unit/equipment Level for equipment performance, monitoring, control and energy optimization as per the control logic developed to achieve the design objective. Necessary and appropriate field devices shall be used at this level to capture various parameters that need to be controlled and monitored. (Refer Table 36).
   2) System and automation level shall ensure coordinated and integrated control logic between the various sub systems as per the design intents.

   3) Management Level shall contain necessary workstations with software and dashboard screens as detailed in **13.2.7** to provide macro level parameters of various high-level systems to monitor trend and analyse the various data.

b) System shall bring in all mechanical, electrical and public health engineering (MEP) equipment and systems under its architecture.
c) Control system shall be constructed to achieve energy optimization based on the level of intelligence and functionalities in-built in the equipment.
d) A matrix of equipment and parameters that shall be controlled and monitored shall be drawn (*see* Table 36 for various building systems). In addition to Table 36, critical parameters namely, temperature, pressure, voltage, current, energy, and others shall be recorded and monitored and shall be made available for the operations team for corrective action either through stand-alone controls or networked controls.
e) Based on point (d) above, detailed Input/output point summary (IOP Summary) shall be developed.
f) Control schematics and sequence of operation shall be developed for various control loops based on the respective design philosophy and intent of the building by the concerned design team.
g) The controls system architecture shall be developed to effectively integrate and manage various building systems and technologies. The key requirements shall include:
   1) Scalability and flexibility – Allowing for future expansion and adaptation.
   2) Interoperability
   3) Real-time data acquisition and analysis
   4) Security and privacy
   5) Redundancy and fault tolerance
   6) Energy efficiency and sustainability
   7) Centralized management for control and monitoring

15.2.2 *Protocols*

All unit level and system level controls shall have industry standard open protocols adopted for connecting various equipment/controllers/3rd party devices that have built-in intelligence in their controllers and factory installed field devices / equipment like chillers, diesel generating sets, energy meters, and variable speed drives. Other industry standard open and accepted protocols such as OPCopen platform communications (OPC), message queuing telemetry transport (MQTT), zigbee, Wi-Fi, modbus, meter-bus (M-Bus), global system for mobile communication/ general packet radio services (GSM/GPRS), Z-wave, device language message specification (DLMS) shall be used for connecting devices.

15.2.3 *Controllers*

For various applications, controllers with built-in logic or programmable control logic shall be used to achieve the desired design intents and controllers shall meet the requirements of **15.3.1.2** for protocol compliance.

Depending upon the building application and criticality, networked controls shall be used.

a) All networked controller systems shall comply with **15.2.2** for protocols used.
b) Critical parameters namely, temperature, pressure, voltage, current, energy, and others shall be made available for effective monitoring and control of the system through networked centralized control system. (Table 36 shall be referred for various parameters to be considered based on the application.)

15.2.4 *Internet of Things (IoT)*

IoT devices and automation optimize building performance by providing data on core building operational systems and enabling automatic control of the building's main operating functions. IoT devices, when implemented, shall be able to connect via standard building and industry protocols as mentioned in **15.2.2**.

For IoT devices to be accessed and configured on the field and / or remotely shall have hardware interface and software or wireless interface for remote configuration.

Integrating IoT with BMS represents a significant advancement in building management, offering improved efficiency and enhanced user experiences. While implementing systems with IoT enabled controls, following aspects have to be taken care of in the design:

a) *Interoperability* – This is to ensure different IoT devices and systems work together seamlessly. For medium sized buildings, all applications for devices should be accessible from the same screen. Use of higher-level local servers running continuously are to be considered to achieve interoperability when stated in OPR.
b) *Data privacy* – Safeguarding the personal data collected by IoT devices is important. Use of VLAN and Privacy Levels to be as per requirement detailed in OPR. For medium sized buildings WPA / WPA2 will otherwise be the minimum level.
c) *Scalability* – Ensure the system is scalable and adaptable to changing needs within the same platform.
d) *Security* – Protect the system from cyber threats by ensuring that remote access to all IP and other applicable devices have USER configured usernames. Default usernames and passwords shall not be retained and device shall not be accessed by use of default username and password. Security levels to be as per requirement detailed in OPR. For medium sized buildings WPA / WPA2 otherwise accepted as the minimum level.

15.2.5 *Cyber Security*

Vulnerabilities in the IT based systems are diverse. Due to their physical location across all parts of a facility and connectivity with open protocols, systems are prone to technical and physical attacks at all architectural levels. System shall take care of all aspects of cyber security.

15.2.6 *Software*

The BMS workstation software that brings in all the data and the graphics including all the functionalities and sequence of operation and logic to the operator workstation shall have the following options depending upon the criticality and application of the building and also based on owner's project requirements (OPR).

a) Computer workstation software or server based software depending upon the number of data points for monitoring and control.
b) Optional server based on premise or remote depending upon the scale and application of the building.
c) IoT and cloud based system as per OPR.

15.2.7 *Integrators/Gateways*

a) High level integrators/gateways shall be used to ensure conversion of various protocols mentioned under **15.2.7 c)**.
b) Protocol conversion for 3rd party devices integration of various equipment in a building shall happen when various equipment is connected through soft link to bring in the various parameters residing at the equipment to the BMS platform without installing any additional field devices.
c) Conversion from one protocol to another protocol
   1) BACnet MSTP to BACnet/IP
   2) MODBus RTU– BACnet/IP
   3) MODBus TCP/IP - BACnet/IP
   4) M-Bus to BACnet-IP
   5) MODBus – GSM / GPRS

   NOTE – The above are not exhaustive and other conversions may also be required as per the equipment and protocols installed.

15.2.8 *Dashboard*

High level parameters of various sub systems shall be captured on the dashboard screen and customized based on the OPR.

1) HVAC
2) Electrical
3) Energy management – consumption, generation
4) Water management – levels, volume, consumption
5) Sewage treatment plant

6) Lighting management – power consumption, circuits status, luminaire fused status circuits status, luminaire fused status
7) Fire – status of alarms / alerts
8) IEQ / IAQ
9) Waste management
10) Occupancy status
11) UPS / battery Management

15.3 Instrumentation and Field Devices

Instrumentation in automation and controls shall be provided to measure various parameters and communicate the same to the next level in the system architecture.

a) *Monitoring* – Status monitoring of multiple aspects of buildings like;

   Utilities (water, lighting, energy, gas), water quality (WTP, STP, ETP), air quality, ventilation (HVAC, mechanical), VHT (lifts, elevators, escalators, travellators), fire and life safety, UPS (power consumption, battery management), DG set, parking, security (cameras, boom barriers, access control, intrusion detection), plumbing etc.

b) Control of critical / non-critical areas as defined in OPR

c) *Instrumentation considerations* – These devices range from field devices, loggers, aggregators, controllers - sensors, PLCs, controllers (PID, IoT), mechanical (actuators, valves, dampers etc.), internal and external communication devices and any special purpose instruments. These shall be of analogue or digital type. Communication protocols like analogue (V, A), digital, serial, TCP/IP etc. based on the application shall be considered.

d) *Technology* – A combination of wired and wireless field devices shall be used based on the overall application of the project and OPR.

15.4 Sequence of Operation and Control Logic

Sequence of operation and the control logic of any control loop shall be developed in the BMS based on the design logic of that particular discipline and application. This is to be developed by the concerned design team and the same will be used in developing the Input/output point summary as well as for determination of necessary field devices to be installed for capturing the parameters to be controlled and/or monitored.

15.5 Data Gathering for Analysis and Performance Improvements

This is a very important part of the BMS where all the data that are gathered through the field devices as well as those processed at the controllers, data stored through various trending and logging from the various equipment and system shall be stored in a PC workstation or a server depending upon the number of data points.

This data shall be made available for analysis by the facilities and operations team for making performance improvements in the system as well as comparing through a range of time spans to understand the behaviour of the building. These data will also be useful in making informed decisions like the life of the equipment, for drawing up replacement schedules, comparing performances for various buildings etc.

15.6 Energy Savings – Optimization for Decarbonization

To effectively use the data from the BMS for measuring the sustainable level of operations of a building, following dashboard screens, at the minimum shall be made in addition to those listed under **15.2.6**. These will not only help the facilities and operations team for trending and analysis but also for measuring the carbon footprint of the building and the decarbonisation levels of the building. These will help the owner in understanding the carbon emissions and help in migrating towards net zero goals.

Dashboard screens shall be developed for the following:

a) Energy
b) Environment
c) HVAC system
d) Lighting control system
e) Water management system
f) Electrical and VHT systems

For example, energy consumption data to monitor and help create energy saving strategies, energy dashboards shall provide energy data to building and asset management team in graphical form for easy understanding and implementation.

15.7 Installation and Commissioning of Control Systems

15.7.1 *Field Devices*

Field Devices like temperature sensors, RH Sensors, pressure transmitters, flow meters and transducers, level sensors and switches, IAQ Sensors shall be installed as per manufacturers installation manual and recommendations. Necessary precautions shall be taken during installation of the field device for measuring the parameter that is detailed in the input/output point summary and the sequence of operation and control logic diagrams.

15.7.2 *Enclosure Panels*

The controllers, integrators and other components of BMS shall be housed in an enclosure panel that is appropriately rated (electrically) for the ambient conditions at which they are surrounded by so that the control components are neither damaged nor communicate incorrect data to the system. Since most of the controllers and field devices operate with 240V AC / 24V AC / 24V DC (as per manufacturers data sheets and installation manuals), necessary transformers have to be installed in the enclosure panel to supply the voltage as per the requirements. The transformers shall be rated to take care of the necessary VA ratings of the field devices and the relays being operated by the controller. Proper earthing etc, shall be provided as per the relevant sections of the accepted standard [8-3(46)] and Part 8 'Building Services Section 2 Electrical Installations' of this code. These enclosure panels shall be suitably IP rated depending on their installation environment.

Relevant sections concerning electrical components in NBC shall be followed for proper compliance.

15.7.3 *UPS Power Supply*

Necessary uninterrupted power supply shall be provided to the controllers and other control components of the BMS through proper electrical distribution system. Necessary earthing etc., shall be provided as per the relevant sections of the accepted standard [8-3(46)].

Relevant sections concerning electrical components in accepted standard [8-3(46)] shall be followed for proper compliance.

15.7.4 *Field Cabling and Containment*

Field cabling shall be provided between the various control components like the field devices, sensors, transducers, controllers, starter panels, 3rd party equipment for integration as per the relevant sections of the NBC code and as per the recommendations of the manufacturer of the control system. Control cables, integration cables and field cables shall be screened, twisted, shielded and the sizing shall be as per the recommendations of the controls' contractor and OEM. There shall be a detailed cable schedule drawn up based on the input/ output point summary before carrying out this work. Necessary earthing etc., shall be provided as per the relevant sections of the accepted standard [8-3(46)]. Containment of cabling shall be carried out as per the relevant sections of the accepted standard [8-3(46)] and as per the details of the projects approved documents. Necessary drawings have to be made for the entire system and approvals taken from concerned Engineer-in-charge

15.7.5 *BMS PC Workstation / Server*

The PC Workstations or servers, depending upon the number of data points and based on the application of the building and OPR, shall be installed in an air-conditioned room. These along with either the monitoring station or display units shall be accessible by the facilities and operations team. UPS power supply shall be provided for these components since these will have to handle data from the entire BMS online and have to store data as well for use.

Necessary network components like network switches and accessories shall be installed based on the control manufacturers recommendations and drawings.

15.7.6 *Programming and Commissioning of BMS*

The entire BMS system shall be properly installed, field cabling all checked for continuity prior to the commissioning of the system.

Based on the control logic and the applications, necessary programming shall be developed by the controls contractor and the same shall be downloaded to the various controllers or configured based on the type of control system (wireless or wired).

Various control parameters that are measured through the field devices are to be mapped onto the controllers and checked for consistency. Various set points need to be determined based on the applications and the programs have to be test run and observed for proper operations and necessary fine tuning needs to be done on various control parameters like – PID gains, range etc., for trouble free and accurate operation of the programs.

With all the above completed and as-built drawings, the BMS system needs to be handed over to the end user with as-built drawings and all IOMs for the entire system.

16 HYDRONIC PIPING SYSTEMS

This code establishes uniform standards for the design, installation and maintenance of hydronic and refrigerant piping used in heating, ventilation and air conditioning (HVAC) systems. By adhering to these standards, practitioners shall enhance system performance, reduce operational risks and meet regulatory compliance.

This section covers topics including material selection, sizing criteria, installation practices, testing procedures and maintenance guidelines for HVAC and refrigerant piping.

16.1 General Hydronic Piping Systems

In HVAC systems, piping systems play a crucial role in transporting fluids such as water and refrigerants throughout the building. Some general type of hydronic systems commonly found in HVAC system are:

a) *Chilled Water Piping System* – Network of pipes designed to distribute chilled water from a central plant to various points of use within a building or facility. Primarily used for air conditioning, refrigeration, and industrial cooling applications.

b) *Hot Water Piping System* – Network of pipes designed to distribute heated water from a central heating source to various points of use within a building or facility. Primarily used for space heating, domestic hot water supply, industrial processes, and other applications requiring heated water.

c) *Condenser Water Piping System* – Network of pipes designed to circulate water between a chiller's condenser and a cooling tower or other heat rejection equipment. It's a crucial part of a water-cooled HVAC system, commonly used in large commercial buildings for air conditioning and refrigeration.

d) *Condensate Drain Piping System* – Network of pipes designed to collect and remove condensate water generated by cooling equipment, such as air conditioners, refrigerators, and dehumidifiers. Condensate forms when warm, moisture-laden air comes into contact with a cold surface, causing the water vapor in the air to condense into liquid water.

16.1.1 *Open and Closed HVAC Piping Systems*

a) *Open and closed system* – An open system is one in which the water enters a reservoir that is exposed to the atmosphere such as collecting tanks, air washers, and cooling towers. A closed system is one in which the water flow is never exposed to the outside environment except at expansion tank part.

b) *Once – thru and recirculating* – Piping system shall be once through that is, when water is released from system, it only goes through the machinery once. Water circulates in a recirculating system by going through the refrigeration equipment, the heat exchanger, and back again instead of being discharged.

16.1.2 *Selection of Pipe and Fitting Materials*

Selection of right HVAC pipe material shall be done considering fluid type, pressure and temperature range, system layouts, space constraints and special requirements if any (flexibility / corrosion resistance).

a) Material options for HVAC pipe

1) *Steel pipe* – Carbon steel or stainless-steel pipes should be used in HVAC systems for their strength, durability, and resistance to corrosion. They are suitable for high-pressure applications such as chilled water, hot water, and steam distribution.
2) *Copper pipe* – Copper pipes have excellent thermal conductivity, corrosion resistance, and ease of installation. They should be used for refrigerant lines, domestic water supply, and hydronic heating systems.

3) *Polyvinyl chloride (PVC) pipe* – PVC pipes are lightweight, cost-effective, and resistant to corrosion. They may be used for low-pressure applications such as drainage, venting, and condensate lines in HVAC systems.
4) *Cross-linked polyethylene (PEX) pipe* – PEX pipes are flexible, durable, and resistant to corrosion and scale buildup. They may be used for radiant heating systems, and hydronic piping systems in HVAC.
5) *High-density polyethylene (HDPE) pipe* – HDPE pipes are highly resistant to corrosion, abrasion, and chemical damage, making them suitable for outdoor or underground applications in HVAC systems, such as geothermal heat pump systems and chilled water distribution.

b) *Pipe fittings terminology*

1) *Elbows* – Elbows are used to change the direction of flow in a piping system. They are available in various angles (for example, 45 degrees, 90 degrees) to accommodate different piping layouts.
2) *Tees* – Tees create branch connections in a piping system, allowing fluid to flow in multiple directions.
3) *Reducers* – Reducers connect pipes of different sizes, allowing for a smooth transition between different sections of the piping system.
4) *Couplings* – Couplings join two pipes together end-to-end, providing a leak-tight connection.
5) *Flanges* – Flanges connect pipes to valves, fittings, or equipment. They provide a secure and leak-proof connection and allow for easy disassembly when required.
6) *Unions* – Unions are similar to couplings but allow for easy disassembly of pipe joints for maintenance or repairs.

A significant portion of the pressure drop in the piping system is caused by elbows. Elbows with a longer radius shall be provided wherever feasible. Whenever possible, 45° elbows shall be provided over 90° elbows when arranging offsets.

c) *Piping connection methods*

1) *Soldering/brazing* – Soldering or brazing is commonly used to join copper pipes and fittings together in HVAC systems. It involves heating the joint and applying solder or brazing material to create a strong and leak-free connection.
2) *Threaded connections* – Threaded connections are used with threaded pipes and fittings, allowing for easy assembly and disassembly without the need for soldering or welding. This is usually recommended for low pressure system up to 6.9 kPa. (*see* Fig. 14)
3) *Grooved connections* – Grooved connections use grooved pipes and fittings with rubber gaskets to create a tight seal. They are quick and easy to install and are commonly used with steel pipes in HVAC systems. (*see* Fig. 14)

4) *Flanged connections* – Flanged connections use flanges to connect pipes to valves, fittings, or equipment. They provide a secure and leak-proof connection and allow for easy disassembly when required. (*see* Fig. 14)
5) *Welding* – Welding is used to create permanent connections between pipes and fittings in HVAC systems. It involves melting the edges of the pipe and fitting and fusing them together with heat. This type of fitting is recommended on high pressure system and larger diameter pipes.

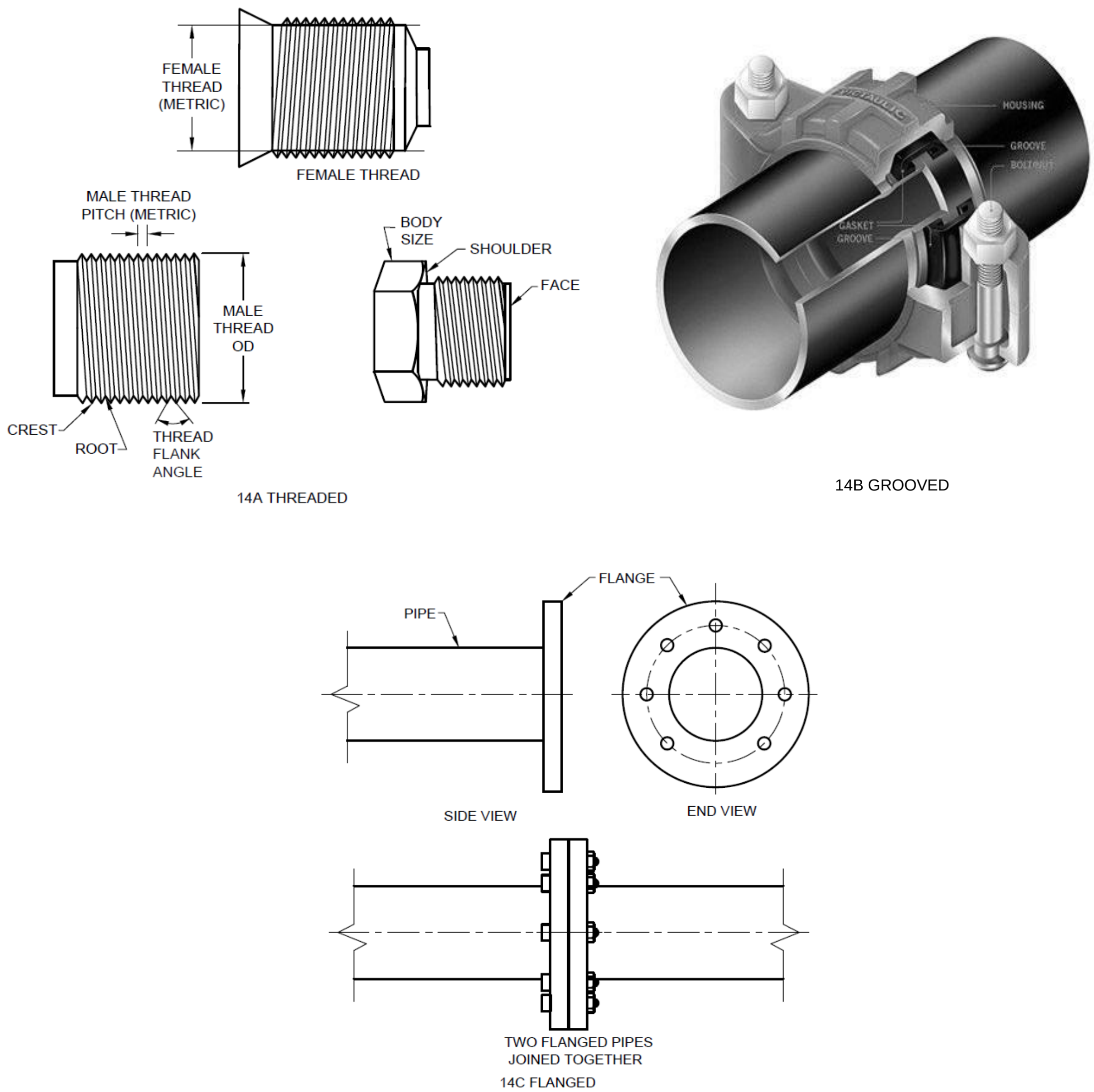


FIG. 14 PIPING CONNECTION METHODS

16.1.3 *Piping Supports*

a) Pipe supports shall be selected to ensure strong anchoring, absorbing vibrations, providing flexibility and reducing noise transmission.

b) Rigid supports / spring hangers and supports/neoprene pads and inserts/ vibration isolators shall be selected based on load capacity to bear the combined weight of the insulation, pipe, fittings, valves, and fluid in the pipe accounting for static and dynamic loads.

c) Manufacturer’s guidelines and specifications should be referred for recommended support type based on pipe material, size and system dynamics.

d) Consultation with HVAC engineers, vibration specialists or manufacturers to tailor support selection is recommended for specific project requirements.

16.1.4 *Expansion Loops*

a) Expansion loops should be installed in straight runs of pipe or at points where significant temperature changes occur, such as near equipment or in outdoor installations. They prevent damage to piping, equipment, and surrounding structures caused by thermal expansion.

b) Expansion loops shall be fabricated from standard piping fittings such as elbows and tees, or they shall be custom-designed to meet specific project requirements.

16.1.5 *Valves – Types and Applications*

a) *Gate valve* – Gate valves control flow by raising or lowering a gate (wedge-shaped disk) to allow or restrict fluid passage. When fully open, the gate is lifted entirely out of the flow path, minimizing flow restriction. Gate valves may be used for ON/OFF control in HVAC systems where full flow or shut-off is required. They may also be provided for isolating equipment/ piping sections for maintenance

b) *Globe valve* – Globe valves feature a globe-shaped body with a movable plug (the "disc") that regulates flow by moving up and down. As the disc moves, it alters the size of the flow opening, allowing for precise flow control. Globe valves may be used for pressure balancing, throttling or regulating flow in HVAC systems, such as controlling the flow of water or steam in heating and cooling applications. They may also be used for isolation of equipment /piping sections.

c) *Ball valve* – Ball valves feature a spherical disc (the "ball") with a hole through the center that controls flow. The ball rotates within the valve body to open or close the flow path. Ball valves may be used for on/off control, isolation, and emergency shut-off.

d) *Butterfly Valve* – Butterfly valves use a circular disc (the "butterfly") mounted on a shaft to control flow. The disc rotates perpendicular to the flow direction to open or close the valve. Butterfly valves should be used for large-diameter pipes in HVAC systems for ON/OFF control.

e) *Check Valve* – Check valves allow fluid to flow in one direction only, preventing backflow or reverse flow. They typically consist of a movable disc or flap that opens to allow forward flow and closes to prevent reverse flow. Check valves should be used in HVAC systems to prevent damage to equipment, maintain system efficiency, and ensure proper flow direction in piping systems.

f) *Balancing Valve* – Balancing valves should be used in hydronic systems to achieve proper flow distribution and maintain system balance.

g) *Control Valve* – Control valves regulate fluid flow based on signals from a control system, such as a thermostat or building automation system. They modulate the flow by adjusting the position of a valve plug, disc, or ball in response to changing system conditions. Control valves should be used in HVAC systems for precise temperature control, flow modulation, and energy management in heating, cooling, and air distribution systems.

h) *Pressure Independent Control Valve (PICV)* – A PICV is an advanced type of control valve used in HVAC (Heating, Ventilation, and Air Conditioning) systems for precise flow control and temperature regulation. It combines the functions of a control valve, differential pressure regulator, and flow limiter into a single device. This is recommended to be used to replace balancing and control valve in the system. (*see* Fig. 15)

j) *Triple Duty Valve* – A triple duty valve is a multifunctional valve and combines the functions of a check valve, balancing valve and an isolation valve into a single unit. Use of these valves simplify installation, save space and improve system efficiency. These are recommended to be used in hydronic chilled water and hot water systems (*see* Fig. 16).

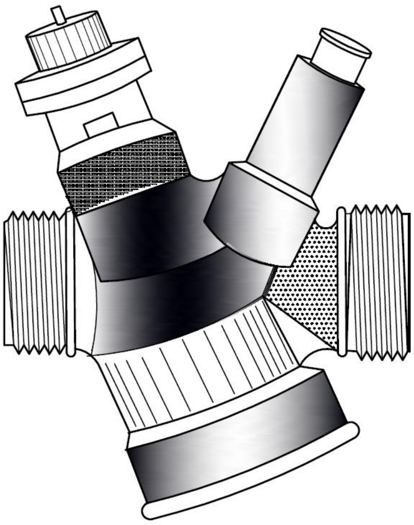


FIG. 15 PICV VALVE

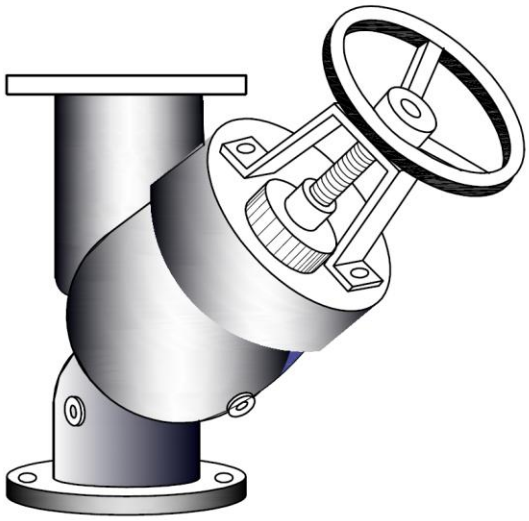


FIG. 16 TRIPLE DUTY VALVE

16.1.6 *Buried Piping Systems*

The following points cover the key aspects of buried piping systems:

a) *Design considerations* – Thermal expansion, corrosion protection and accessibility should be considered in buried piping design. Corrosion-resistant materials like HDPE, steel with protective coatings, ductile iron, or PVC should be selected. These materials shall withstand corrosive environments and prolong the service life of the piping system. Access points like valve boxes, manholes, or cleanouts should be planned along the pipeline route for maintenance.

b) *Material options* – These are material options recommended to be used;

   1) *High-Density Polyethylene (HDPE)* – HDPE pipes may be used for buried piping due to their lightweight nature, flexibility, and excellent resistance to corrosion, abrasion, and chemical damage.

   2) *Steel* – Steel pipes with corrosion-resistant coatings like epoxy or polyethylene may enhance their longevity in buried applications.

   3) *Polyvinyl Chloride (PVC)* – PVC pipes are lightweight, cost-effective, and resistant to corrosion, making them ideal for low-pressure applications in buried piping systems.

c) *Installation considerations* – Proper installation is crucial to ensure the efficiency, safety, and longevity of systems and equipment. The following points highlight key considerations for installation:

   1) *Trenching* – Excavation of trenches shall be carried out to the required depth and width to accommodate the piping system. Trench dimensions should be determined based on factors such as pipe size, soil conditions, and local building codes.
   2) *Bedding and backfilling* – A layer of bedding material such as sand or gravel should be placed at the bottom of the trench to provide support and stability for the pipes. After installation, the pipes to be backfilled with soil, compacted in layers to prevent settling, and ensure proper support.
   3) *Protection* – Buried pipes may be wrapped with protective materials such as geotextile fabric or insulation to shield them from damage due to abrasion, soil movement, or external forces. This protective layer helps preserve the integrity of the piping system over time.
   4) *Marking and identification* – Buried piping systems shall be marked and identified with durable markers or tape along the pipeline route to indicate the location, type of pipe, and purpose of the system. This facilitates future reference, maintenance, and repair activities.

16.1.7 *HVAC Piping in High Rise Buildings- Design Considerations*

Designing of HVAC Piping systems for high rise buildings should consider efficiency, reliability and safety aspects. Material selection shall be suitable for building's structural and environmental conditions. Factors such as corrosion resistance, thermal expansion and fire safety ratings should be considered. HVAC piping in high rise buildings should be designed to handle the required pressure ratings. Accounting for pressure drops due to friction losses, fittings and changes in elevations. Design should facilitate ease of maintenance and future expansion. Few recommendations are:

a) Ensure valve controls and access points are easily available for servicing and repair.
b) Implement measures to mitigate noise and vibration transmission through HVAC piping
c) Comply with fire safety regulations by using fire rated materials and design pipe routes to minimize fire spread and maximize compartmentation.

16.1.8 *HVAC Piping in Radiant Cooling Systems-Design Considerations*

Designing piping systems for radiant cooling involves several critical considerations;

a) *Pipe material selection and sizing* – Piping with high thermal conductivity such as cross-linked polyethylene, copper or specialized composite pipes should be used. Select pipe sizes based on flow rates required to meet cooling/ heating demands. Zoning strategies should be implemented to allow different areas to be heated or cooled independently based on occupancy and usage patterns.
b) *Floor construction and thermal mass* – The type of floor construction should be assessed (for example, concrete/wood) to determine its conductivity for efficiency of radiant system. Ensure proper insulation beneath the radiant pipes to minimize heat loss downward.
c) *Integration with building design* – Radiant piping layout to be coordinated with other services like electrical, plumbing and structural components.
d) *Maintenance and accessibility* – Access to manifold stations and control valves should be planned for maintenance and repair.

16.1.9 *HVAC Piping Testing, Commissioning and Maintenance Guidelines*

Testing, commissioning, and regular maintenance of HVAC piping systems are essential to ensure proper functioning and long-term reliability. The following points outline the guidelines for these processes:

a) *Testing procedures* – The periodic testing procedures recommended to ensure efficiency, longevity and reliability of HVAC piping system shall include pressure testing to check integrity of piping joints and connections; Leak detection tests to identify and repair any leaks; Flow tests to measure flow rates to check they meet design specifications and adjust as necessary.

b) *Balancing and commissioning process* – The piping system shall be balanced for even distribution of flow and pressure across all the branches. Verify system performance against design criteria and operational requirements. The commissioning procedure shall involve flushing, purging and filling the system with appropriate fluids.

c) *Regular inspection and maintenance* – A regular maintenance schedule should be established based on manufacturers recommendations and operational demands.

   1) This shall include but not limited to visual inspection for signs of corrosion, damage or leaks. Periodic cleaning of pipes should be done to remove any debris or build up to maintain optimal flow and efficiency.
   2) Valves operation shall be tested to ensure proper functioning and prevent sticking or seizing. Inspect and adjust pipe supports and hangers for any sagging or stress in joints

d) *Documentation* – Maintain comprehensive documentation of testing, balancing, commissioning activities including *test results.*

16.2 Refrigerant Piping

The following points outline key considerations for the design, installation, material, and maintenance of refrigerant piping

16.2.1 *Considerations in Refrigerant Piping*

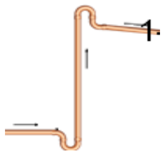
The refrigerant when flowing through these pipes, imposes friction with the inner piping wall due to the velocities. The friction reduces the system efficiencies and as such shall be maintained as low as possible. The norm is to maintain the pressure drops in these pipes, not exceeding an equivalent of 1.10°C which for most of the commonly used refrigerant works out to 1.3 kPa to 1.9 kPa for suction line and 4.0 kPa to 6.0 kPa for hot gas and liquid lines. This shall however be verified with the refrigerant pressure-temperature charts.

The second consideration is oil migration during operation. When refrigerant flows out of the compressor in vapor form, some amount of compressor lubrication oil escapes along with the refrigerant. The piping system shall be designed to ensure that the escaped oil is made to return back to the compressor after travelling through the system to ensure that the oil levels in the compressor is maintained. Following practices should be followed to achieve this objective:

a) The refrigerant velocities in suction line as well as hot gas line be maintained high enough so that it impels oil to move along the direction of the flow. The velocities in horizontal pipes should be minimum 3.8 m/s and that in vertical lines be maintained at a minimum of 7.6 m/s.

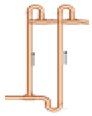
b) The suction line and hot gas line in horizontal traverse should be pitched downwards in the direction of the flow to ensure that the oil does not flow back. The recommended gradient is 1:200.

c) When the suction line and hot gas line traverse in vertical direction, the U-shaped trap shall be provided at the bottom and inverse U-shaped trap shall be provided at the top. The bottom trap provides holding space for the oil in vertical pipe and not allowing it to travel backward. The top trap prevents the oil that has reached the top from traversing back.



d) In the event of vertical pipe for suction line or hot gas line travelling upwards exceeds 3.5 m, a U-shaped oil trap should be installed at every 3.5 m.

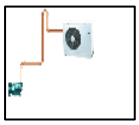
e) In the event the compressor has part load operation capabilities, the piping velocities in vertical risers may not be possible at the lowest capacity operations. In such events, a double suction risers should be installed in vertically upward pipes. One riser should be sized for the minimum capacity and the second riser should be sized for the balance capacity.



f) Since liquid refrigerant is perfectly miscible with the oil, the refrigerant velocity is not needed for transportation of oil. However, sudden closing of refrigerant flow shall result in liquid hammer effect. To minimize this impact and consequent damage to the piping system, the refrigerant velocities in liquid line should not exceed 1.5 m/s.

16.2.1.1 The third consideration is migration of liquid refrigerant during the system off cycle. When the system is not operational, the piping layout shall ensure that the liquid does not migrate either to the evaporator or the compressor.

a) When the relative position of compressor is at lower elevation than the condenser, the inverted U-shaped riser should be provided at an elevation higher than the condenser.



b) When the evaporator is at the lower elevation than the condenser, once again a similar inverted U-shapes riser should be employed. It is also a good practice to employ controls such that the system is switched on only after a time delay after the evaporator pump/fan is switched on.

c) Pump down control may be employed, particularly on the larger systems to shut off the flow of refrigerant by installation of solenoid valve so that when the system is off cycle, the most of the liquid refrigerant is stored in condenser or receiver.

16.2.2 *Piping Material*

Since the refrigerant in the system operate at high pressures, the piping material and thicknesses should be complaint with the subjected pressures. Following materials could be used for refrigerant piping.

a) Steel tubes and pipes.
b) Copper tubes and pipes
c) Aluminium tubes
d) Copper alloy tubes.

NOTE – For copper tubes and pipes, When the pipes are laid in an environment where pipes may be subjected to damage, soft annealed copper tubes should be avoided.

Any other proprietary material may be used provided they are rated for the subjected pressures as well as the verified data of pressure drops is well documented.

Post installation of piping the entire piping system should be pressure tested at 1.5 times the operating high pressure and joints tested for leaks. Post the pressure testing the system should be vacuumized to a pressure of 500 microns with holding of vacuum for the period of 4 h to 6 h to ensure that all non-condensable vapours are removed from the system and any trace of remaining moisture is removed.

The suction line pipes shall be adequately insulated. The insulation thickness should be calculated minimize the heat loss as well as to avoid condensation over the surface. Hot gas line insulation may not be deployed unless the pipes are laid in an environment where the hot gas temperatures may cause burns to occupants. Liquid lines may not be insulated. However, if the equipment is with reversible cycle such as heat and cool mode, all pipes need to be insulated. The insulated pipes should be protected from possible damages as well as the ultra violet exposures.

The piping system should be adequately supported. The supporting system should not damage or compress the insulation system integrity. Alternatively, the piping may be rested on well supported continuous trays.

16.2.3 *Refrigerant Piping Accessories*

The piping system should incorporate accessories which will either aid in proper operation of the system or may assist in trouble shooting.

a) *Oil separators* – Oil separators may be mounted in the hot gas line at the outlet of the compressor when piping lengths are excessively high or when the refrigerant velocities are on the border line. The refrigerant piping velocities however, should not be compromised.

b) *Receivers* – Receivers should be installed where the condenser volume is not adequate to store the entire refrigerant charge of the system. Receivers should be properly designed so that no flash vapor shall enter the liquid line.

c) *Filter dryers* – Filter dryers should be installed in the liquid line to ensure that all solid impurities are arrested prior to the entry of refrigerant in the expansion device. These devices also aid in removing minor amount of water vapor from the piping system that may have been left behind.

d) *Sight glass* – Sight glass may be installed in the liquid line to visualize the adequate flow of refrigerant as well as for to view adequate system dryness.

e) *Isolation valves* – Isolation valves either in form of hand shut-off valve or solenoid valve may be installed upstream and downstream locations of filter dryer for maintenance works.

17 INSTALLATION AND COMMISSIONING OF HVAC SYSTEMS/EQUIPMENT

The installation and commissioning of HVAC systems are critical to ensuring the system operates efficiently, safely, and in compliance with design specifications. The following points outline the objectives and planning considerations for the installation and commissioning process.

17.1 Objectives

The objectives for the installation and commissioning of HVAC systems and equipment shall be to fully meet the owner's project requirements, as detailed in **17.9.1.5**. The installation process must prioritize optimal energy efficiency, ensuring the systems operate reliably and maintain high-quality standards. Safety is a top priority, with all installations executed to the highest safety standards. Timeliness is essential to meet project deadlines, while also ensuring the optimum life cycle cost is achieved. In addition, the systems should be designed and commissioned to minimize noise and vibration, providing a comfortable and efficient environment.

a) Shall fully meet owner's project requirements (*see* **17.9.1.5)**
b) Optimal energy efficiency
c) Reliability/Quality
d) Safety
e) Speed/Timeliness
f) Optimum life cycle cost
g) Minimum noise and vibration

17.2 Planning the Installation

Meticulous planning results in a trouble-free installation at optimum time and cost with little chance of wastage and rework. Planning ensures safety during installation and commissioning.

Following factors are common across all types of equipment/systems:

17.2.1 Location of installation shall be selected with care. Location shall be such that there is adequate space to mount the equipment as well as to operate, service and maintain it. It shall be as close to the area to be served as possible. Good ventilation and natural lighting are important.

Where the installation is large, a separate utility block should be considered along with a service tunnel to house chilled and condenser water piping, electrical and control cabling and communication systems.

Equipment room floor shall be light coloured and finished smooth but non-slippery with epoxy paint coating. Where required, water proofing of plant/equipment room floor shall be done.

17.2.2 Noise generated by the equipment shall not be objectionable to surrounding spaces and any vibration generated shall not be transmitted to the building structure.

17.2.3 Equipment rejecting heat to surroundings shall be mounted in such a way that there is no obstruction to heat rejection and good ventilation and adequate top and side clearances are provided.

17.2.4 Location shall be such that proper access to material handling equipment such as crane, forklift etc is available not only during installation but also for its removal and replacement at a later date. When equipment has to be located in the basement of the building, service ramps or removable hatches shall be provided for this purpose.

17.2.5 Structure should be able to take the static and dynamic load of the equipment and transfer it to the ground.

17.2.6 Location shall be dust free and clean.

17.2.7 Equipment which needs drainage shall have the facility. For basement installations, provision shall be kept to pump out excess water from sumps provided. These sumps shall be coupled to alarms in case water level rises beyond set point. In no case shall the condensate water be left out in the open. It shall either be connected to the building drainage and if the installation is large, options for condensate recovery and re use shall be explored.

17.2.8 Locations of shafts, wall openings etc shall be planned in advance so that breakage/rework shall be avoided. Pipes may be supported from floor or ceiling slab as specified by designer. All floor and ceiling support for pipes, cable trays, ducts etc shall be suitably isolated from building structure to prevent transmission of vibration. The openings around service shafts shall be closed as specified. Openings in structural elements (beam, slab etc) shall not be made without the approval of structural engineer.

17.2.9 Equipment foundations shall be structurally designed and concrete foundation blocks shall be protected by epoxy coated angle nosing. Inertia blocks and seismic restraints shall be used where specified. Floor finish/slope shall be such that any water spillage does not stagnate around equipment foundations.

17.2.10 Fresh air intakes shall be planned taking into consideration required distance from exhaust outlets as well as other sources of contamination. All such intakes and exhausts which open outside the building shall be provided with wire mesh and bird screen on inside and louvres with rain protection or cowl piece on the outside. Where specified, intake air filters shall be used. When any duct is terminated on the roof, it shall have a swan's neck to prevent rain ingress.

17.2.11 Access to equipment rooms shall be through double leaf doors or rolling shutters of adequate width and height and fan room doors shall be airtight. Doors shall open outside and a sill provided to prevent water ingress.

17.2.12 It shall be possible to isolate equipment rooms in case of fire or distress. For provisions for compartmentation in case of fire, please refer to Chapter **19**. Escape routes shall be planned and clearly marked on site.

17.2.13 All equipment/materials delivered to site shall be compared with the documented and approved specifications and found correct. Test certificates shall be sought and verified for physical properties such as thickness, malleability, test pressure etc. Where independent testing is specified, third party test reports from labs [8-3(42)] accredited shall be produced. Agreed lot sizes shall be inspected at site before use. Where factory inspection is specified, same shall be carried out as provided in contract. Agreed quality assurance plan (QAP) shall be specified and test results recorded suitably. All instruments and gauges shall be calibrated, and valid calibration certificates shall be available.

17.2.14 All equipment's, materials and sub systems shall be cleaned prior to use. Installed sub systems such as duct and pipe work shall be cleaned as per an approved Standard operating procedure and shall be kept with all open ends suitably closed. All equipment shall be kept covered with tarpaulin /canvas cloth till they are ready to be commissioned. Shafts of electric motors and other rotating equipment, if stored for a long time, shall be rotated by hand once a fortnight so that grease applied on them do not solidify.

17.2.15 Testing of sub systems shall be carried out in sections as per an approved schematic drawing. Applicable standards and test pressures/duration of test shall be approved by the owner. Testing schedules shall be prior intimated to owner and tests shall be witnessed by owner's representative or by commissioning authority (CxA). Owner shall have the right to approve contractor's testing personnel regarding qualification and experience.

17.2.16 Number of test points for duct and pipe work shall be pre agreed between owner/CxA and the contractor. Once testing of individual sections are completed (with suitable isolation), the entire system shall be tested as a whole. Power and control cabling shall be tested as one single unit.

17.2.17 Receiving of equipment at site, its unloading, shifting to place of installation or interim storage shall be done with care and by using suitable tools and tackle. This requires advance planning and providing adequate lifting and shifting equipment at site. This is of special significance in case of heavy and bulky equipment such as chillers, fans etc to be installed in basement or building terrace. To the extent possible, heavy equipment shall be received at site only after its location of installation is fully ready and at the first instance the equipment should be located at the right place of installation. Multiple shifting of heavy equipment shall be avoided.

17.2.18 Source of power and water shall be provided as close to point of use as possible and shall be terminated with an isolator/valve. All electrical systems shall be properly grounded and electrical protections such as surge protectors/circuit breakers installed as required. When remote start/stop or control is specified, adequate provisions shall be made.

17.3 Specific requirements for Equipment/Systems

17.3.1 *Room (Window) Air Conditioner*

There shall be an opening of adequate size in the outer wall of the room (can be a window) and a wooden frame of suitable size shall be fitted therein. The air conditioner unit shall be placed inside the frame with its outer casing firmly fitted inside the wooden frame with metal screws keeping a slope of 6 mm to 10 mm for drainage of condensate. Drain line of adequate size shall be fitted to the back of the unit. Unit shall be properly levelled and any gap between the frame and wall/window shall be sealed off. Adequately rated electric power socket with on/off switch shall be provided close to the unit. Before fixing the front grill on the unit, it shall be ensured that supply and return air openings are properly isolated and short cycling of air does not happen.

In addition, the installation shall be as per the manufacturer specified installation requirements and instructions. In absence of manufacturer’s installation instruction and requirement.

17.3.2 *Split Air Conditioner*

The indoor unit (IDU) shall be located in the conditioned space at a suitable location away from any obstacles to airflow. IDU shall be accessible for regular filter cleaning and maintenance. Drilled holes in the wall to locate the IDU are best located with a template and a spirit level. A hole of adequate diameter shall be drilled in the wall close to the unit (adjacent to the refrigerant pipe connection side of the unit) through which supply and return refrigerant piping (both insulated), drain pipe to remove condensate water and power cabling to the outdoor unit (ODU) shall be carried. A PVC sleeve may be used to carry the lines and the annular space between the wall and the sleeve shall be filled with caulking material or sealant.

Refrigerant piping between the IDU and ODU shall be of copper with minimum number of bends and the minimum radius of each bend shall be 10 mm. Maximum piping length between IDU and ODU, difference in height between IDU and ODU and any additional refrigerant charge/lubricating oil charge that may be required shall all be specified by the equipment supplier. In cases where the IDU is located at the same level or above the ODU level, the suction line shall rise to the top of the IDU. This prevents the refrigerant liquid from migrating to the compressor during off cycle. horizontal suction lines shall be either straight or slightly sloped towards the ODU.A refrigerant trap shall be installed at the bottom of the vertical riser.

Where the ODU is located above the level of the IDU, a trap shall be installed at the bottom of the suction riser immediately after the IDU.

Pipes shall not be in direct contact with the building structure to prevent vibration transmission. Pipes shall be clamped to walls at suitable intervals and separation may be kept between pipe and clamp to prevent bi-metallic erosion.

ODU shall be placed on a flat firm surface which shall take the load of the unit. Vibration isolators or serrated rubber pads shall be placed below the unit. The ODU shall be located where air for cooling shall flow freely through the condenser coil. As far as possible, ODU shall not be exposed directly to sunlight. ODU shall be easily accessible for servicing. Where multiple ODUs are located, they should not face one another, and an adequate arrangement shall be made to prevent short cycling.

Once the piping between the ODU and IDU is completed, it shall be pressure tested at 21 Kg/cm^2 on the high side and 10 Kg/cm^2 (or 1.5 times the maximum operating pressure) on low side for minimum 6 h. Thereafter, the system shall be evacuated and a vacuum of 500 microns of Hg shall be maintained for 6 h before refrigerant is charged. Refrigerant charge/oil charge shall be as recommended by the manufacturer.

Condensate drain from the indoor unit tray shall be planned, routed and connected to the designated drain point.

Unit shall be started only by the supplier's authorised service personnel. All installation and start up checks shall be as per the manufacturer's/supplier's documented SOP.

In addition, the installation shall be as per the manufacturer specified installation requirements and instructions. In absence of manufacturer's installation instruction and requirement.

17.3.3 *Variable Refrigerant Flow (VRF) Systems or Multi Split Units*

All requirements detailed in **17.3.2** shall apply, since the same (set of) outdoor units serves multiple indoor units with varying lengths of piping, charging the correct amount of refrigerant and lubricating oil is important and manufacturer's instruction shall be followed. Communication wiring between all indoor units and the corresponding ODU shall be connected as per the manufacturer's instructions and communication cable shall be away at a distance minimum 300mm to avoid interference.

Allowable length of refrigerant piping and height between various IDUs and between IDU and ODU shall follow manufacturer's specification. Ball valves shall be installed for zoned refrigerant isolation. Evacuation shall be possible at each IDU and ODU. Start up by manufacturer/installer's authorised personnel shall include configuring and setting up of all control devices.

17.3.4 *Chiller (Air Cooled and Water Cooled)*

Chillers are heavy and built with either rotating or reciprocating equipment. adequate foundation system shall be provided to transfer the load to ground thru beams/columns and this shall be done in consultation with structural specialist. Dynamic loading shall be considered while designing the structure and shall be as per the accepted standard [8-3(34)]. Vibration isolation mounts or serrated rubber pads (as recommended by manufacturer) shall be placed between the chiller frame and the foundation. Where open type compressors are used, the alignment of the compressor with its motor shall be checked with a dial gauge.

Piping connections to the chiller shall be made only after the chiller is finally located in place and levelled. Piping ends shall have offsets for flexibility and piping shall be supported independent of the chiller. Coolers and condensers shall be connected through victaulic/equivalent couplings and suitable flexible connections as recommended by the manufacturer. Provision for fixing temperature sensor and pressure gauges shall be made immediately after the condenser and cooler at a distance of minimum 150 mm from the outlet.

Temperature at the location where chiller is installed shall be within the limits specified by the manufacturer. Where air-cooled chillers are installed open to atmosphere, a suitable cover over the roof panels is recommended. All electrical enclosures in case of open installations shall be IP 55 or higher as per accepted standard [8-3(43)]. Space for air circulation, people movement and maintenance shall be provided on all four sides.

Where the chiller is mounted above grade, a structural steel platform, capable of supporting the dynamic load of the chiller, shall be provided. A maintenance platform providing access to all parts requiring maintenance/attention shall also be provided. Service space shall include space for tube cleaning or for attaching the tube cleaning device.

Electrical isolation shall be provided not more than 2 m away from the chiller. Floor drain and water supply point near to the chiller shall be planned. Where accessories to chiller such as expansion tank, air separator unit etc are to be located in the plant room, adequate space for installing and servicing them shall be planned.

Where chillers are located inside the building, floor to floor height of the plant room shall be adequate to house the piping, valves, strainers etc. Height ranging from 3.6m to 4.5 m is recommended depending on chiller type. A guide rail arrangement is recommended over the chiller for easy removal of components in case of failure. The chiller concrete foundation base should be 150 mm to 200 mm above floor level.

17.3.4.1 Quality of water used for condenser circulation and chilled water make up greatly influences chiller performance as well as chiller life. Make up supply of soft water may be provided at a suitable height above the chiller allowing flow by gravity. Manufacturer's recommendation in this regard shall be strictly followed even for the water used for pressure testing and commissioning. The table 37 should be referred for the water quality requirements.

Table 37 Water Quality Requirements

(*Clause* 17.3.4.1)

Sl No.	**Properties**	**Limit**	**Circulating Chilled water**	**Make up water (Chiller)**	**Condenser Water**
(1)	(2)	(3)	(4)	(5)	(6)
i)	Total Hardness CaCo3	Max	80	50	200
ii)	Total Alkalinity CaCo3	Max	100	80	100
iii)	Chloride Ion ppm	Max	50	50	200
iv)	Iron as Fe ppm	Max	0.3	0.3	1.0
v)	Silica as SiO2 ppm	Max	30	30	50
vi)	Ammonia ppm	Max	0.2	0.2	1.0
vii)	Ph	Min-Max	7.2 -8.5	6-8	7.2- 8.5

17.3.5 *Packaged Air Conditioner (Air Cooled and Water Cooled)*

Installation of water-cooled packaged air conditioners (PAC) shall be similar to installation of water-cooled chiller whereas installation of air-cooled chiller shall generally follow the installation guidelines for split air conditioners as detailed in **17.3.2**. Following additional points are specific to PAC installation

a) While lifting and hoisting the unit with a sling, spreader bars shall be used to prevent damage to sides and top.
b) In respect of air-cooled PAC where piping length is more than 7 m, additional refrigerant/oil may require to be charged.

c) For duct connections, please refer **7.3.10**. Unit connections shall be through reinforced flexible connector.
d) Condensate drain with a water trap shall be installed next to the access panel of the unit.
e) Pre-filters shall be anti-bacteria and shall be washable. Unit shall not be operated without filter in place.

17.3.6 *Pumps*

Pump base frame shall be mounted on an adequately sized concrete block and there shall be cork or serrated rubber pads or anti-vibration mounts between the concrete block and plant room floor and shall be as per the accepted standard [8-3(34)]. Load shall be transmitted to beam or column as per advice of structural engineer.

More than one pump shall not be installed on a single base frame or concrete block. Factory supplied pumping systems mounted on common base frame is an exemption to this.

Foundation bolts where required shall be embedded correctly. Before grouting the bolts, the level of the base frame shall be checked.

Pump motor shall be mounted on the base frame, alignment checked and then only coupled with the pump shaft. Pump shall not run without its coupling guard. Pump alignment shall be checked once again after completing the suction and discharge piping in order to ensure that alignment is not disturbed after connecting the piping.

Before being test run, the pump shall be lubricated as per manufacturer’s instructions.

Suction and discharge lines shall be supported independent of the pump and shall be connected to the pump through flexible connectors. Isolation valves shall be provided on both sides (suction and discharge). Provision for pressure gauge connections at the inlet and outlet of the pump shall be made.

In-line pumps may be installed directly in the piping with pipe hangars adequately sized to handle the load of the pump and piping. For larger size in -line pumps, a flange support or floor support with saddles shall be used. All supports to floor and ceiling shall be vibration isolated.

Correct direction of rotation of the pump (which shall be indicated on the housing) shall be checked before start up.

A factory installed drain connection with a site fitted installation valve shall be used to drain the pump reservoir.

Where low temperatures are encountered, freeze up precautions shall be taken.

17.3.7 *Cooling Tower*

Cooling tower shall be located in such a way that noise as well as water drift are not objectionable. Tower location should not be close to leaf shedding trees.

Location shall be open and well-ventilated and manufacturer's instructions regarding side clearances for air circulation shall be meticulously followed.

If located on building terrace, the operating load shall be transferred to beams/columns as per advice of structural engineer. Cooling tower shall rest on adequately sized MS I-sections. These I-sections shall be hot dip galvanized to accepted standard [8-3(35)]. All welded joints shall be primer with corrosion resistant coated such as epoxy. Vibration isolation shall be provided between tower and the MS I-Sections.

Installation shall be such that the space below the cooling tower shall accommodate a strainer below the water level in the sump as well as a drain pipe with a valve. It shall be possible to completely drain the cooling tower sump when required.

A service platform may be constructed beside the tower so that all parts requiring cleaning or maintenance are easily accessible. Slope of the floor below the tower shall be such that water does not stagnate below the tower.

Make up and quick fill connections shall be done and uninterrupted water supply shall be made available. For water quality, water treatment and bleed off, please refer to the following section on operation and maintenance.

In case of multiple cooling tower installation at the same location, equaliser connections shall be provided. In case the pumps are at the same location as the cooling tower, the cooling tower sump shall be minimum 300 mm above the pump suction to ensure positive pressure while starting the pump.

The cooling tower basin shall be leak tested by filling up with water and holding it for minimum two hours.

17.3.8 *Air Handling Units (AHU)/ Heat Recovery Units (HRU)/ Fan Coil Units (FCU)*

Air Handling Units shall be either floor mounted or ceiling mounted. AHUs and FCUs shall be located close to or with in the area to be air conditioned so that duct runs are minimum. Location shall take into consideration the feasibility of running ducts, taking back return air to the unit (either through return air ducts, above the false ceiling or directly into the unit as well as provision of chilled water connections, provision of humidifiers, fresh air inlet as well as drain connections.

In a multi-storied building, it is advisable to locate the AHUs on above the other on each floor so that piping shall rise through the same shaft.

From fire safety considerations, individual AHUs shall not serve more than one floor. Similarly, it is advisable to have exclusive AHU for each fire compartment. In case, these are not possible, fire and smoke dampers shall be fitted on both the supply air and return air paths where floor crossing or fire compartment crossing takes place. Provision for pressure gauge and thermometer connections shall be made at inlet and outlet piping connections.

AHU/FCU shall be mounted in such a way that both the mechanical noise as well as the air noise does not disturb the occupants. This is specially emphasised for ceiling-suspended units. Duct mounted silencers and acoustic lining of supply air duct may be provided as specified. AHU/FCU shall not be mounted above electrical or IT rooms where water leakage shall lead to serious problems.

Adequate maintenance and service space shall be provided around AHU/FCU and trap doors for convenient access shall be available. Lamps inside the unit, belt guards, sight glass and door interlocks shall be ensured.

Floor mounted AHU/heat recovery unit shall be mounted on top of pre-cast concrete block to permit easy drainage of condensate and to facilitate cleaning below the unit. Such supports shall be adequate in number and also located suitably so that transfer of dynamic load to structure safely takes place. Serrated rubber pads or other vibration isolation material shall be placed between the AHU/HRU frame and the concrete support. Insulated condensate drain connection shall be with a U- trap and the floor slope shall be towards the floor drain. Slope of the drain pan connection shall also be towards the drain pipe connection. Chilled water piping to AHU shall have a manual air vent at the top most point in the coil circuit and a drain plug at the bottom of the coil.

Ducts shall be connected to the AHU/HRU with fire-proof connections to prevent transmission of vibration. Ceiling suspended AHUs/FCUs shall be hung from the ceiling with adequately sized rod and fasteners and shall be isolated from the structure by rubber or spring isolators. Illumination near the unit, drain point, water supply point and floor drain shall be provided.

17.3.9 *Air Washer Units (AWU) and Evaporative Cooling Units (ECU)*

Installation of AWU and ECU are similar to that of floor mounted AHU/HRU. They will have additional water connections to the spray- section with in-line recirculating pumps. Air washer units shall be preferably located on the summer wind-ward side. They shall be painted with reflective coating or thermally insulated. Large size air washers may be constructed with concrete basin. These shall have leak proof access doors as specified and basin shall be tested for water proofing integrity.

17.3.10 *Fans – Centrifugal, Axial Flow and Cabinet Type*

Fan performance is influenced by inlet and outlet conditions. 'Fan System Effect' which is the impact on fan performance due to inlet and outlet conditions as well as ways to mitigate them are described in **14**.

While rigging and hoisting heavy fans, manufacturer's instructions shall be carefully followed since the load is not uniformly distributed around the periphery.

Dynamic load of the fan, its distribution at different supporting points, vibration and noise shall be taken into account while designing the fan foundation.

Outlet connection to a duct (if provided) shall be by means of flexible fire-retardant connections.

17.3.10.1 *Centrifugal fans*

Where foundation bolts are provided, they shall be securely placed along with base plates while foundation is cast. Alternatively, fan may be mounted on suitable channel frame.

Vibration isolation base for fan and motor shall be an integral unit and shall be mounted on concrete foundation with anti-vibration mounts.

Safety screen shall be provided on fan suction side. Belt guard/coupling shall be provided and fan shall not be started without these protective devices.

17.3.10.2 *Axial flow fans*

Removable safety screens shall be provided on either side of the fan. Fans shall be properly grouted on the walls with vibration isolation material. Where the fan is suspended from the ceiling, vibration isolators shall be used.

17.3.10.3 Cabinet fans

A door interlock switch which shuts off the fan and switches on a bulk-head lamp mounted within the cabinet shall be provided. A water drain point shall also be provided within the cabinet. Transparent inspection windows of minimum 150 mm dia shall be provided.

17.3.10.4 For all type of fans, the sound generated is a major consideration which shall be taken care during the design/selection stage itself. Additionally, as specified by the fan manufacturer or system designer, acoustic silencers shall be mounted at inlet and outlet of the fan. Bird screen shall be provided at fresh air intake points and at exhaust outlet.

In all cases, adequate space for service and maintenance including removal and replacement of motor shall be provided.

Direction of rotation shall be verified on startup and field balancing shall be done where required. An electrical isolator or a push button switch shall be provided adjacent to the fan.

17.3.11 *Air Distribution and Ducting*

17.3.11.1 *Duct supporting/hanging systems*

Duct hanging system shall have 3 parts: Upper attachment to the building, the Hanger and Lower attachment to duct.

Upper attachments shall be concrete inserts which are cast into the structure, threaded concrete fasteners which are inserted into the cast slab or structural steel fasteners. Upper attachment method shall be selected with care and a safety factor of 5 is recommended. In case of steel structure, careful selection of primary and secondary supporting to be done on case-to-case basis.

Hangars shall be strips of galvanized steel or threaded round steel rods. Threaded portion of the rods shall be painted after installation.

Lower attachment is the connection between the hangar and duct section. Fasteners that penetrate the duct shall be sheet metal screws or rivets. All nuts, bolts and washers shall be zinc plated steel. Rivets shall be galvanized or made of magnesium-aluminium alloy.

Where ducts shall not be supported from the ceiling, wall brackets or other suitable support arrangements may be used.

Neoprene or other vibration isolation material of minimum 6 mm thickness shall be inserted between the ducts and the angle iron supports/brackets. Vertical ductwork shall be supported at each floor by suitable structural steel members.

Plenums where provided shall have access doors of 450 mm x450 mm.

Supporting details for rectangular ducting for static pressure up to 750 Pa are given in Table 38 and for static pressure above 750 Pa are given in Table 39. Supporting details for low pressure (Up to 750 Pa) rectangular ducting system are given below:

Table 38 Supporting Details for Low Pressure (Up To 750 Pa) Rectangular Ducting System
(*Clause* 17.3.11.1)

Sl No.	**Larger Side of Duct** mm	**Supporting Angle** mm	**Vertical Rod Diameter** mm	**Maximum Spacing between Supports** mm
(1)	(2)	(3)	(4)	(5)
i)	Up to 900	40 x 40 x 5	8	2 400
ii)	901 to 1 500	40 x 40 x 5	8	2 400
iii)	1 501 to 2 400	40 x 40 x 5	10	2 400
iv)	2 401 and above	65 x 65 x 5	12	2 400

Table 39 Supporting Details for High Pressure (Above 750 Pa) Rectangular Ducting System
(*Clause* 17.3.11.1)

Sl No.	**Larger Side of Duct** mm	**Supporting Angle** mm	**Vertical Rod Diameter** mm	**Maximum Spacing between Supports** mm
(1)	(2)	(3)	(4)	(5)
i)	Up to 1 250	50 x 50 x 5	12	2 400
ii)	1 251 to 2 100	65 x 65 x 5	12	2 400
iii)	2 101 and above	75 x 75 x 5	15	2 400

Alternatively, slotted galvanized brackets attached to the top two bolts of the four-bolt duct connector shall be used.

For round, oval and flexible ducts, galvanized steel straps, wire or rods shall be used and support details shall be as provided by manufacturer/installer and approved by Engineer-in-Charge.

Sheet metal ducts shall be fabricated from galvanized iron sheets with minimum 180 GSM zinc coating and of lock forming quality. Fabrication of ducts shall be carried out at a factory from coil stock or at site from cut sheets. Where the overall duct area for the project exceeds 600 Sq. m or where the external static pressure exceeds 250Pa, lock forming machines shall be used for fabrication.

17.3.11.2 *Pre-insulated ducts*

Pre-Insulated duct made of polyisocyanurate sandwich panels comprising of a rigid foam board faced on both sides by stucco embossed aluminium foil shall be joined with tiger connectors or with male-female jointing system up to 500 mm. Higher sizes shall be joined by cover corners which has a holding pin which goes inside the flange. Ducts shall have suitable fixtures made of polymer plastic or extruded aluminium for jointing as well as for fixing of accessories such as grills, diffusers etc. Duct work shall be installed using supports as specified by the manufacturer.

17.3.11.3 *Fabric ducting*

Tools and accessories for installation shall be provided by the Fabric duct supplier. Fabric duct shall be connected to fan/AHU with GI duct connectors. While laying the duct, care shall be taken to prevent twisting of the fabric. A ratchet strap may be used to secure the fabric to duct connector.

Once the fan/AHU is started, check the straightness of the fabric and adjust if necessary. Parameters like air flow and pressure shall be checked and validated.

17.3.11.4 Duct supports shall be designed to handle the load without bulging or buckling. Where seismic considerations are specified, they shall be followed. Support material shall be galvanized / coated steel or aluminium angle sections, chromium plated steel threaded rods and wire supports using stud anchors provided in ceiling slab or by threaded fasteners. Care shall be taken to ensure that the slab or structural members are not damaged. Where false ceiling is provided, ducts and false ceiling shall be supported separately. Collar Off-takes for supply air outlets shall be constructed and installed only after the false ceiling / boxing framework is done and frames for fixing supply air outlets / return air Inlets are installed. Flexible ducts may be used for terminal connections.

17.3.11.5 Where duct penetrates brickwork or masonry openings, treated wooden framework shall be provided within the opening and the crossing duct shall be provided with heavy flanged collars on either side of the wooden frame so that the duct crossing is made leakproof. Alternatively, the duct section passing through the structure may be suitably wrapped so that vibration is not transmitted to the structure. Where duct passes through a fire compartment partition, a fire barrier shall be created by installing a fire cum smoke damper.

17.3.11.6 When fans feed into a duct system, uniform straight flow conditions shall be ensured. Fan manufacturer's recommendation in regard to straight length of connecting duct both at inlet and outlet of the fan to obtain optimum fan performance needs to be followed. Similarly, pressure loss in a duct elbow or a volume control damper is minimum when air approaching the elbow /damper has a uniform velocity profile and positioning the elbow / damper after an adequate straight piece of duct is recommended. All elbows shall have adequate number of turning / guide vanes to ensure uniform air flow over the entire cross-section.

17.3.11.7 When duct is connected to an air handler or a fan, flexible connections made of rubberised canvas and 100 mm long shall be used between duct and AHU/fan and shall be securely bonded and bolted to the unit casing as well as the duct to prevent air leakage.

17.3.11.8 Turning vanes shall be provided at supply air outlet collars and at branch take-offs. They shall be fabricated from minimum 0.8 mm galvanized steel sheet and equally spaced on side runner and rivetted or bolted to the duct.

17.3.11.9 Take offs allow air from main duct to be diverted to branch ducts and take offs are fitted into circular or rectangular openings cut into the wall of the main duct and small metal tabs cut at the start of the take-off are bent to connect the take off to main duct. Alternatively, a snap-in attachment with an adhesive foam gasket shall be used, outlet of the take-off connects to branch duct.

17.3.11.10 Dampers shall be manually controlled or automatic. Dampers shall be rated for operation against 1.5 times the rated pressure class of ducting. Suitable links, levers and quadrants shall be provided for proper operation, control and setting of the dampers. Linkages shall be blade to blade and concealed in a jamb out of the airstream. Every damper shall have an indicating device showing the damper position and a locking device. Where Dampers are operated via an external gear train, these are to be constructed out of engineering polymers with self-lubricating properties, and, located out of the air stream. Leak resistant access doors next to the dampers shall be provided to facilitate attending to the dampers and duct cleaning.

17.3.11.11 Splitter dampers shall be installed in branches where a split takes place. They shall be made of aerofoil blades of minimum 1.6 mm thickness and hinged at downstream edge. Operation rod shall be accessible from outside with an airtight hub and locking screw. Splitter damper shall be enclosed in sheet steel ducting with flange at both ends and shall be aligned with the main ducting. Damper section shall be made of one size higher thickness than the upstream duct.

17.3.11.12 Louvre dampers shall be provided in all branches they shall be multiblade type of aerofoil construction or in triple vee grove construction, rotating in lubricated ball / roller bearings / delrin bushes. Blades shall be connected by a linkage for simultaneous operation by a rod extending outside the duct and terminating in a locking quadrant with damper position indicator. Damper shall be enclosed in sheet steel box made of one size thicker than upstream duct and shall have flanges at both ends for connecting to main duct.

17.3.11.13 Fire dampers and combination fire and smoke dampers shall be installed wherever a fire compartment partition exists. They shall be installed in ducts, return air passages and at all floor crossings. Access door shall be provided for each fire damper. Fire dampers may be motorized (activated by an electrical impulse from the fire alarm panel or a thermal trip element) or operate on a fusible link and shall shut off airflow completely. Wiring from AHU panel to the damper (in case of electrically operated damper) shall be carried out by damper installer. Dampers shall be suitable for vertical or horizontal mounting. Damper shall be installed maintaining fire integrity of the partition and all dampers at wall/floor crossings shall have a factory fitted sleeve. In such cases, the damper shall be a free float and the annular space shall be free to allow for expansion through a smoke seal. Please also refer to Part 4 'Fire and Life Safety' in this Code.

17.3.11.14 Any type of electrical heaters shall not be mounted inside ducts. The electrical heaters shall be allowed to be installed in locations identified and approved by competent authority.

17.3.11.15 Variable air volume (VAV) boxes shall be installed at specified locations. They may be supported from floor, wall or ceiling as specified and may be mounted in vertical or horizontal direction. Boxes shall be factory set for minimum airflow of 10 percent and maximum airflow of 110 percent of design flow. Access to the box shall be from below and shall be completely sealed but easily removable. Electrical supply point with an isolator shall be provided by others and step-down transformer wherever needed shall be part of the unit.

17.3.11.16 Grilles, diffusers and registers act as terminal units for supplying air from the duct system to the room or for collecting back air from the room either to exhaust or for return to AHU/fan. Terminal units may be fitted with air filters. Square or rectangular wall outlets shall have a flanged frame with outside edges turned and fitted with a flexible gasket between the concealed face of the flanges and the finished wall face. Core of supply air register shall have adjustable front loves parallel to the longer side capable of deflection and adjustable back louvres parallel to shorter side to achieve horizontal spread of air up to 45 degrees. Outer framework shall be made of 1.6 mm minimum thickness of aluminium sheet and louvres shall be of aero foil design of extruded aluminium section with minimum thickness of 0.8 mm. The vane ratio (ratio of gap between the vanes and vane depth) should not be less than 1 and should not exceed 1.2.

17.3.11.17 Square and rectangular ceiling outlets /intakes shall have a flange flush with the ceiling on which it is fitted. Outlets shall have an outer ring with duct collar and removable core assembly. Inner as well as outer rings shall be minimum 1.1 mm thick and diffuser assembly shall be 0.8 mm thick extruded aluminium section. Circular ceiling outlets shall be either flush or with an outer cone. Flush cones shall have the lower edge not more than 5 mm below the finished ceiling. All outlets / inlets shall be designed to reduce dirt deposit on the ceiling adjacent to the outlet.

17.3.11.18 Linear diffusers shall have a flanged frame with the outer edge turned 3.5 mm and shall have 1 to 8 slots as specified in design. These shall be constructed out of 1.6 mm thick extruded aluminium sheet. All supply air outlets shall have volume control device made of extruded aluminium.

17.3.11.19 Locations of air outlets and intakes shall be shown in the drawing and necessary openings and the wooden framework for fixing the grilles/diffusers shall be provided by the contractor.

17.3.11.20 While installing fresh air intakes, no fixing device shall be visible from the face of the frame. Where louvres are to be fixed to brick, masonry or concrete, fixing shall be with expanding plugs or raw plugs. Where louvres are to be fixed to wood or metal, nonferrous screws or bolts shall be used. A flanged frame made of rolled steel sections shall be provided on the front face to cover the gap between the louvres and the adjoining wall face. Frame shall be structurally rigid and corners shall be welded. Where the louvre length exceeds 1 250 mm additional intermediate and equally spaced supports shall be provided to prevent sagging/vibration. Louvres shall be made of 1.6 mm thick 100 mm wide extruded aluminium sections and fitted in an extruded aluminium frame. A bird screen made of 12 mm mesh in 1.6 mm steel wire held in angle or channel frame shall be fixed to the rear face of the louvre frame. Louvres shall be fixed 45 degrees to vertical and shall provide 60 percent minimum net opening. Louver design and spacing shall ensure that there is no water ingress and the lowest louver shall be suitably overlapped to prevent water being drawn in.

17.3.11.21 Test probes which shall be installed at every fan discharge and suction duct shall be of heavy-duty zinc alloy casting. Expansion plugs shall be neoprene and capable to withstand 80°C and 300 kPa pressure.

17.3.11.22 Kitchen exhaust ducting shall be of 16 G MS CRCA sheets and shall be of welded construction. Access doors shall be provided at 3 m intervals and the duct shall have a mild slope towards the kitchen hood. Laundry and dish washer extract ducts shall be of air and watertight construction and shall be of Aluminium sheets in accordance with accepted standard [8-3(3)]. Gasket used to be fire rated. Access doors to be provided at regular intervals and at critical points. The ducting shall be wrapped with high temperature grade EPDM, nitrile rubber or with fire wrap.

17.3.12 *Filters and Air Cleaning Devices*

The installation and commissioning of filters and air cleaning devices require strict adherence to these guidelines to ensure optimal performance and safety.

17.3.12.1 Filter elements shall be kept stored in original packing till they are ready to be installed with all upstream areas such as AHU rooms and upstream ducting is cleaned and made dust free.

17.3.12.2 Filters shall be installed with directional arrows pointing towards air flow direction. Filters shall be tightly fitted in the frames provided using gaskets with no gap between the filter and the frame.

17.3.12.3 Differential pressure gauge/switch is recommended to be installed across filters. After initial running of 48 h, if required, replace the filters (In case of pre filters only).

17.3.12.4 HEPA filters shall be handled with special care since the media is fragile and shall be installed with the gasket side of the filter facing the frame.

17.3.12.5 ESP filters shall be firmly fitted in a specially fabricated frame and wiring of the ESP filters shall be as per manufacturer's recommendation. A clear sticker "Caution – High Voltage Filters "shall be prominently displayed in front of ESP filters.

17.3.12.6 While installing ultra violet germicidal irradiation (UVGI) lamps, the layout provided by the manufacturer shall be followed. In AHUs, UVGI lamps may be installed downstream of cooling coil. Mounting frame for UVGI lamps may be at a distance of 300 mm from the cooling coil for optimum performance. After installation, the lamp surface shall be cleaned with a wick wetted with spirit.

17.3.12.7 Ballast of the lamps may be accommodated with in the UVGI electrical panel or may be tied to the UVGI mounting brackets as per manufacturer's recommendation and IP rating of ballasts.

17.3.12.8 Follow manufacturer's instruction for any shielding of drain pan, cable sheaths and conduits.

17.3.12.9 Safety guidelines provided by manufacturer shall be closely followed. If for any reason, AHU door needs to be opened while the lamps are "ON" person/s in AHU room shall wear PPE kit and protective goggles. Bare eye or skin shall not be exposed.

17.3.12.10 Upper zone irradiation units may be mounted on walls or hung from ceiling well above occupied zone (minimum 2.2 m from floor level). Baffles/ louvres shall be directed in such a way that the rays are not directed towards occupied zone. In respect of upper zone irradiation units, the occupied zone UVGI shall be measured periodically to ensure that it does not exceed 1 000 UV/m^2 to 2 000 UW/m^2.

17.3.13 *Installation of Piping Works*

The following are key points for the proper installation of pipeworks, ensuring alignment, sealing, support, and compliance with safety:

17.3.13.1 It shall be verified that pipes of correct specifications such as pipe class, length, thickness, straightness and surface finish are received at the project site. Pipe routing as per 'Good for Construction' drawing shall be verified at site and pipes may be cut to required lengths.

17.3.13.2 Edges of pipes shall be bevelled by grinding to make a 'butt' joint. Welding shall be done exactly to specifications (for example, accepted standard [8-3(36)]. Fabrication of supports shall be as per site requirements and specifications. Spacing between supports shall be as specified.

17.3.13.3 Overhead piping may be supported on walls/ columns with appropriately sized brackets or may be suspended from ceiling/roof truss with MS suspension rods or hangars. Anchor fasteners of adequate sizes shall be used for pipe supports. Vertical risers shall be supported by horizontal supports mounted at regular intervals.

17.3.13.4 Vertical pipes passing through floors shall be parallel to the wall and shall be straight (as verified with a plumb line).

17.3.13.5 Where pipes pass through floor slab or walls, gaps between the pipe and floor/wall opening shall be sealed as detailed in Part 4 'Fire and Life Safety' of this code.

17.3.13.6 Chilled water piping shall be supported on PUF or wooden gutties. Single gutties shall be used for horizontal runs and double gutties for vertical risers. While installing insulated pipes, care shall be taken that insulation is not unduly compressed.

17.3.13.7 Condenser water piping shall be placed on serrated rubber pads at each support and held in place by U Clamps.

17.3.13.8. Piping shall have expansion joints as required. Fittings, valves and instruments shall be as per approved drawings. Drain points and air vents shall be provided as required. Auto purge valves shall be provided at the highest point in each pipe loop with discharge piped out to nearest drain or sump. While T connections shall be permitted on suction side of pump, shoe connections shall be provided on the discharge side. Elbows / bends shall be minimum and reducers shall be eccentric type. Welding scale shall be removed before applying red oxide primer. Readymade fittings to specifications are recommended. Welder shall be competent and hydraulic pressure testing with 1.5 times the working pressure shall be done for 24 h.

17.3.13.9 Flanges shall be provided near each equipment connection and all flanges shall be with gaskets.

17.3.13.10 During installation process, open pipe ends shall be always kept closed.

17.3.14 *Insulation Works*

The following are key points for the proper installation of insulation works, ensuring correct material selection, proper fitting, and adherence to safety and performance.

17.3.14.1 *Thermal Insulation of Sheet Metal Ducts*

Duct surface shall be cleaned with wire brush to remove dust and grease. Two coats of cold setting fire resistant adhesive compound shall be applied over the duct surface. GI stick pins shall be used in case of glass wool/rock wool. Thermal insulation shall be wrapped around the duct with aluminium foil facing the outer side. All transverse and longitudinal joints to be sealed with aluminium tape. PVC strips shall be fixed at suitable intervals so that insulation remains in place. Insulation shall be covered with GI wire mesh (0.63 mm thick x 19 mm) netting on the outside where duct is open and exposed to weather and shall be additionally protected with tar felt or two coats of 10 mm sand cement plaster followed by two coats of water proofing chemical.

17.3.14.2 *Duct made of pre insulated boards*

Please refer to **17.3.11.2** for ducting

17.3.14.3 *Acoustic lining of duct*

Inside surface on which lining is to be provided shall be cleaned of dust and grease. Material used shall be 12/25 mm thick resin bonded fibre glass/rock wool rigid board with 48 kg/m^3 density. Board shall be fixed inside duct using fire retardant adhesive and covered with tissue paper. Insulation shall be covered with 0.5 mm thick perforated Aluminium sheet having polysurlyn lamination on inner side with minimum 20 percent perforation. Insulation board and aluminium sheet shall be secured with Cadmium coated bolts, nuts, cup washers and steel screws. Ends shall be securely sealed so that no lining material is exposed. Length of lining shall be as per approved drawing.

As an alternative to the above, open cell elastomeric foams of fire-retardant type specially formulated for sound attenuation may be used. These shall be fixed inside the duct with fire retardant cold setting adhesive.

17.3.14.4 *Acoustic lining of equipment rooms*

Where specified in drawings, inside walls and ceilings of equipment rooms may be lined with acoustic insulation. Surface to be cleaned with a wire brush. A frame work of U-shaped channel with height equal to proposed lining thickness made of 0.63 mm thick GI sheet shall be fixed to the walls by means of raw plugs. Similar frame work shall be fixed to ceiling by means of dash fasteners.

Resin bonded glass wool/rockwool cut to size shall be fitted in the framework and covered with tissue paper. Surface shall be covered with 0.5 mm thick perforated (minimum 20 percent perforations) aluminium sheet with polysurlyn lamination on the inside. These shall be fixed with brass screws.

17.3.14.5 *Pipe insulation*

Insulation of pipes shall be carried out with specified material. Pipe insulation material is available in pre-moulded half sections.

Pipe surface shall be cleaned of dust, rust and grease with wire brush. One coat of red oxide primer and two coats of cold setting, fire retardant adhesive compound shall be applied. After tightly fixing the insulation sections, joints shall be sealed with adhesive compound.

Piping within covered space shall be covered with aluminium cladding of specified thickness having polysurlyn lamination on the inside over a vapor barrier. Cladding shall have 50 mm overlap and shall be tied down with lacing wire.

Piping outside the building and exposed to weather shall be finished with vapor barrier and GI or Aluminium sheet cladding with polysurlyn lamination on inner side. Two layers each of 6 mm thick sand cement plaster each cured for minimum 48 h followed by two coats of water proofing chemicals or fixed with bitumen membranes with hot bitumen adhesive or cold quick setting fire resistant mastic compound.

Buried piping shall be covered with suitable gauge polythene faced hessian cloth (with polythene facing outward) with 50 mm overlap. Joints shall be sealed with bitumen. A layer of 0.5 mm thick x 20 mm thick sand cement plaster (1:4) shall be applied and water proofed by applying hot bitumen or cold quick setting fire resistant mastic compound with a layer of tar felt over the plaster. Final finishing shall again be with hot bitumen or cold mastic compound.

Alternatively, the insulation sections shall be protected with a 3 to 5 mm thick HDPE sheet cladding hot air welded and sealed at all joints.

In respect of pre insulated pipe sections, manufacturer’s instructions shall be followed. For pipes inside the building, the factory provided Aluminium foil lamination shall suffice both as vapor barrier and also as finishing material. Otherwise, GI or Aluminium cladding shall be provided with 1.016 mm (40 mil) polysurlyn coating on inside. After application with adhesives, all joints shall be sealed with Aluminium tape.

17.3.14.6 *Insulation of pumps, valves, expansion tank, fittings and pipe supports*

Pumps, valves, fittings and strainers in the chilled water line shall be insulated to the same thickness and using the same as the pipeline. Care shall be taken to apply the insulation in such a way that it shall be possible to dismantle the pumps and operate the valves without damaging the insulation. Moulded PUF insulation in sections may be used where access is desired. These shall be easily reset/ reinsulated after dismantling. Option is available to use pre insulated valves and flanges.

Expansion tanks shall be insulated with 50 mm thick TF quality expanded polystyrene or 40 mm thick polyurethane or poly-isocyanurate foam as specified. Surface shall be cleaned and two layers of hot bitumen or fire resistant cold adhesive compound shall be applied. Insulation slabs shall be placed abutting one another and joints sealed with same compound. Slabs shall be covered with 0.63 mm thick x 20 mm GI wire mesh netting to be fixed with brass/GI screws. Final finishing shall be with 0.5 mm thick Aluminium cladding with polysurlyn coating on inner side.

Chilled water pipe supports shall be insulated with high density (120 kg/m^3) phenolic foam of thickness equal to pipe insulation. Supports shall have same shape as the outside surface of the pipe. Shape/ dimensions of pipe supports shall be as specified.

Pipe bends shall be insulated with sections cut into bevelled lags and applied over the bends with fire retardant cold adhesive compound and all joints sealed with cut insulation pieces or factory-made shaped bends in two halves fixed with fire retardant cold adhesive compound and tied with lacing wire. Vapor barrier similar to that used for pipes shall be applied and the whole assembly may be clad with Aluminium sheet having 1.016 mm (40 mil) polysurlyn lamination on inner side. Cladding to have same thickness as pipe cladding. Joints in the cladding shall be grooved joints fixed with screws and sealed with aluminium tape or mastic compound.

17.3.14.7 *Under deck and over deck insulation*

Underdeck roof insulation shall be with phenotherm 35 kg/m^3 or polyisocynurate foam 32 kg/m^3 or resin bonded glass wool or rock wool 48 kg/m^3. Thickness shall be as specified and method of application same as that of acoustic insulation for equipment rooms (*see* **17.3.14.4**).

Overdeck insulation shall be with polyurethane foam 40 kg/m^3 to 45 kg/m^3 of specified thickness sprayed in multiple layers to form a jointless homogeneous surface. Geo – textile cloth shall cover the insulation followed by plaster and suitable water proofing system. Alternatively, extruded polystyrene slabs or polyurethane/ poly-isocynurate foam slabs shall be fixed over fully dried roof surface with fire resistant mastic and joints sealed with adhesive compound.

17.3.15 *Thermal Storage System*

Storage tanks shall be fabricated out of carbon steel of adequate thickness, hydraulically tested for 1.5 times the design pressure and shall be positioned at the location ensuring that its operating load is safely transferred. Tanks may also be fabricated on-site. Red oxide primer as per the accepted standard [8-3(37)] shall be applied to all exposed welds and edges. Tank shall be able to withstand freezing of water inside through repeated cycles without damage. Tank shall be thoroughly cleaned and flushed before use. External surface shall be insulated similar to that of expansion tank.

Where multiple tanks are installed adjacent to one another, minimum clearance of 600 mm shall be kept. Adequate height to allow for piping (minimum 1 m) shall be available above the tank. Each pair of manifold inlet/outlet connections shall include a shutoff valve to isolate the unit. Bypass circuit shall be installed with a 3-way modulating valve. Thermometer/pressure gauge shall be installed at inlet and outlet. Before start up, air shall be completely purged out from the system for which air bleed valves shall be located at the uppermost points in the piping network.

When glycol is used as the storage medium, add inhibitors as recommended by the manufacturers.

When tanks are located in the open outside the building, insulation shall be covered with a layer of 26 gauge aluminium cladding.

17.3.16 *Smoke Management Systems*

Purpose of smoke management is:

a) Inhibit smoke from entering stairwells and other means of egress, refuge spaces, elevator lobbies, elevator shafts etc.
b) Maintain tenable environment in refuge areas and egress paths during evacuation.
c) Provide conditions to enable emergency response teams to fight fire and conduct rescue operations
d) Protect life and property.

Smoke control systems shall be as per Chapter **19** as well as Part 4 'Fire and Life Safety' of this code.

Installation aspects of smoke and fire dampers is covered in **17.3.11.13** and installation of fans and ducting is covered in **17.3.10** and **17.3.11**.

17.3.17 *Installation of Electrical Systems*

These are the key provisions for the installation of electrical systems in electrical rooms and switchboards.

17.3.17.1 All the equipment used in the Electrical room shall be of sufficient current rating for its normal duty as well as during the fault current. The equipment shall be of sufficient mechanical strength to withstand the fault condition to ensure human safety.

17.3.17.2 Every switch board of medium or high voltage shall comply the following provisions:

A clear space of not less than 1 meter in width shall be provided in front of the switch board. If there is any attachment at the back of the switchboard, the space shall be either less than 20 cm or more than 750 mm in width from the farthest outstanding part of the switchgear. If the space behind the switchboard exceeds 75 cm in width, there shall be passage-way from either end of the switchboard clear to height of 1.8 meters.

All disconnect switches are to be identified and labelled stating the source of the circuit and the equipment / circuit it is feeding.

17.3.17.3 Insulation mat as per the accepted standard [8-3(38)] of proper grade to be used in front of 415 V and above electrical switchgears. All panel doors shall be locked, made vermin proof by sealing entry holes specially from cable entry points.

17.3.17.4 Bus coupler panel and its cubicle shall be handled with utmost care. Red painting of bus coupler, adaptor panel and tie feeder panel from all sides (front, top and back) for easy identification and treat Adaptor panel as a part of bus coupler.

17.3.17.5 Incoming barrier of power supply and phase barrier inside the switchgear panel to be ensured.

17.3.17.6 There should not be any loose wirings, exposed joints, distribution box or junction box in cover open condition in the workplace. No switchgear which has been kept disconnected, for period of six months or more for any maintenance job shall be energized without testing.

17.3.17.7 Over current protection to be provided to disconnect the supply automatically if the rated current of the equipment, cable or supply line is exceeded for a time which the equipment, cable or supply line is not designed to withstand. Earth fault or earth leakage protection to disconnect the supply automatically if the earth fault current exceeds the limit of current for keeping the contact potential within the reasonable value.

17.3.17.8 The operation of all electrical and mechanical interlocks on the switchgear shall be checked to ensure that they operate in a positive manner. All electrical connections shall be proved for mechanical integrity that is terminal tightness, shrouding etc. The panels, relays and control modules shall be visually inspected to ensure freedom from debris and mechanical damage.

17.3.17.9 Proper illumination in work area shall be ensured and no lone working shall be allowed inside HV/LV switch gear room

17.3.17.10 Please refer to Part 8 'Building Services Section 2 Electrical and Allied Installations' of this code for installation of all electrical equipment including motors and switch/control gear.

17.3.18 *Installation of Electric Motors*

These are the key provisions for the installation of electric motors

17.3.18.1 Motors shall be installed at a location compatible with its enclosure type as well as the ambient conditions.

17.3.18.2 Before installation, the insulation resistance shall be checked by applying 500 V-DC. If insulation resistance is low, the windings shall be dried out till the resistance increases to 5 megohms. While doing this, the frame shall be grounded and winding discharged against frame immediately after measurement.

17.3.18.3 Foundation details and bolting arrangements shall be as specified by the manufacturer.

17.3.18.4 For belt drives, the sheave pully shall be mounted close to motor housing and clearance may be provided for end-to-end movement of motor shaft. Drive shafts shall be parallel and belt tensions may be checked periodically during the first 24 hours of operation.

17.3.18.5 Lubrication shall be done with grease recommended by the manufacturer.

17.3.18.6 Terminal housing shall be of adequate size to allow minimum terminal spacing as per article 430 of accepted standard [8-3(46)]. Adequate earthing shall be provided. Minimum earth wire permitted is No. 14 standard wire gauge (SWG).

17.3.18.7 All motor connections and protections shall comply with accepted standard [8-3(46)].

17.3.19 *Installation of Instrumentation/Controls/BMS/IOT*

These are the key provisions for the installation of Instrumentation/Controls/BMS/IOT

17.3.19.1 Field devices such as temperature and RH sensors, pressure transmitters, flow meters etc shall be installed as per manufacturer's instructions. Components of the BMS System shall be housed in an enclosure suitable for the location where they are installed in respect of temperature, RH and IP rating. Where required, suitable transformers shall be installed in the enclosure and adequate earthing shall be provided. Uninterrupted power supply shall be provided to the BMS system.

17.3.19.2 Field cabling and containment shall be as per Part 8 'Building Services Section 2 Electrical and Allied Installations' of this code. Kept at a minimum distance of 300 mm from power cables. Field cabling shall be carried our with screened cables in conduits work stations/ servers shall be installed in clean and dust free rooms.

17.3.19.3 While installing IoT – Wireless field devices, availability of repeaters to form a mesh network shall be ensured.

17.3.19.4 Method statement for installation and commissioning shall be provided by the supplier/installer and pre- approved by the Engineer-in-Charge. If energy dashboard is part of the scope of supply, all screens shall be pre-approved by the Engineer-in-Charge. Where specified, IoT interface for specified equipment shall be provided and these shall be tested as part of the commissioning process.

17.3.19.5 All back up data for restoring the system functionally, in case of any failure, shall be provided and these shall be safely stored separately.

17.3.19.6 System shall be protected from cyber threats by ensuring that all remote access is password protected. Default user names/passwords shall not be retained.

17.4 Vibration Isolation and Seismic Protection

These are the key provisions to be considered for Vibration isolation and Seismic Protection

17.4.1 When machinery with moving parts rests on any support or foundation, vibration gets transmitted usually accompanied by noise. Objective of vibration isolation is to minimize the effect of the dynamic forces generated by the moving parts being transmitted to surrounding structure. When a resilient material is introduced between the machine and its foundation, it deflects due to the static load and by so doing establishes the natural frequency of the isolation system. Natural frequency f_n of the machine set on resilient material is a function of the static deflection of the resilient material under the imposed load.

This shall be expressed as: $f_n = (946.5/V) - d$

where,
d is the static deflection in mm.

The disturbing frequency of the machine is defined by the operating characteristics of the equipment. Efficiency of isolation (percentage of vibration isolated) may be calculated as:

$$E = 100.1 - 1/(f_d/f_n)^2 - 1$$

E represents the amount of reduction in the amplitude of the transmitted mechanical vibration. Based on the graph below (fig. 17) the static deflection required to attain the desired isolation efficiency shall be ascertained.

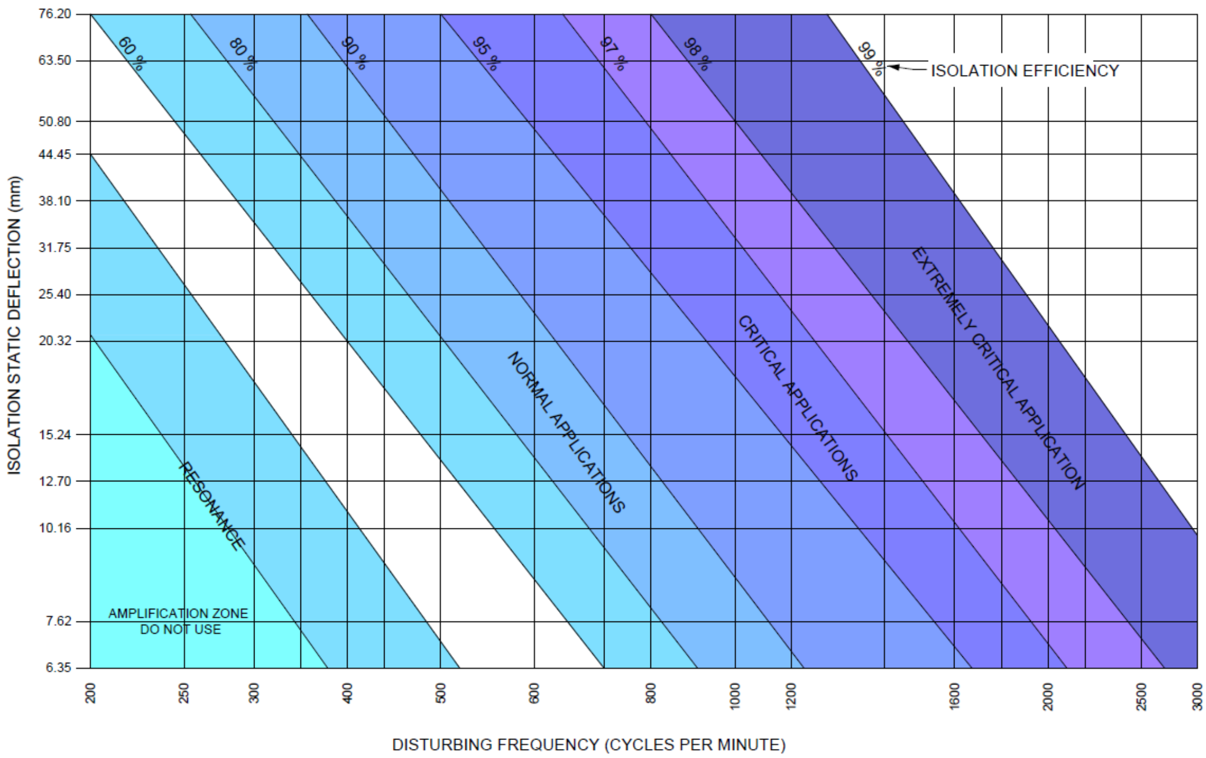


FIG. 17 STATIC DEFLECTION REQUIRED FOR DESIRED ISOLATION EFFICIENCY

17.4.2 Selection of isolator in a particular situation depends on:

a) Weight to be supported.
b) Disturbing frequency
c) Rigidity of supporting structure

17.4.2.1 Anti vibration mounts (AVMs) are generally elastomer based, springs, or fluid based. These need to be selected and positioned carefully since incorrect use shall worsen the problem.

17.4.2.2 *Selection of suitable AVMs involves the following steps:*

a) Estimating the weight distribution at each support which depends on its position relative to the centre of gravity of the total mass. This is best done by a computer program. If the equipment is placed on suspended supports, same shall be factored into the selection program.
b) Selecting the appropriate AVM based on type of equipment being supported, its operating speed, nature of supporting structure, environmental conditions and space availability.
c) The load rating of the mount shall be determined based on isolation efficiency derived from charts available for that purpose.
d) Usually, the AVM is selected for the next higher load rating than the one determined in point c.

17.4.3 *Seismic Isolation of Non – Structural Components*

These are the key provisions to be considered for Seismic Isolation of non- structural components

17.4.3.1 The non-structural components in the building which shall be affected by earthquake effects include:

a) Mechanical systems and components.
b) Electrical systems
c) Fire protection systems
d) Plumbing systems.

17.4.3.2 Seismic protection of the above systems shall ensure

a) The components are securely attached to the supporting structure.
b) Life safety equipment such as emergency lighting and fire suppression systems continue to function.
c) For critical applications, non-structural components continue to operate. Critical applications shall include:
    1) Health Care Facilities
    2) Airports
    3) Emergency Response Centres
    4) Critical defence installations
    5) Data Centres.

17.4.3.3 Performance objectives for seismic protection of non-structural components and how the objectives shall be met shall be as indicated below:

a) *Position retention* – Non-structural components shall retain their position under design level earthquake demands without consideration of frictional resistance produced by effects of gravity. This shall be validated by analysis of seismic calculations and such analysis shall also validate the non- structural anchorage, force resisting skeleton and attachments shall have position retention capacity equal to or greater than project specific design level demand for the installation location. Both, strength design and allowable stress design approaches shall be accepted in such calculations.

    The use of earthquake experience data may be used to establish non-structural position retention capacity. Seismic simulation testing may be used to establish non – structural position retention capacity.

b) *System interactive avoidance* – Unwanted interaction, under design level earthquake demands, between the non-structural systems and anything else that might be located in the vicinity shall be taken into account. This is to ensure that failure of one system or contact between systems shall not cause consequential damage to an essential system. This may also be validated through visual inspection.

c) *Active operation* – Following application of design level earthquake demands, active operational functionality of mechanical and electrical equipment and electrical distribution system shall be maintained.

17.5 Painting and Colour Codes

The following are guidelines for painting and colour coding in air conditioning installations:

17.5.1 All surfaces to be painted shall be thoroughly cleaned with a wire brush. One coat of zinc chromate primer shall be applied and after the prime coat is completely dry finish painting shall be done. Second coat of finish painting shall be done just before hand over with permission from Engineer-in-Charge. Galvanized steel ducts may be painted without a prime coat. Dry film thickness (DFT) of finished painting shall be 250 microns minimum.

17.5.2 Colour code shall be used for easy identification of various items in an air conditioning installation for correct interpretation and identification.

17.5.3 Colour band shall be 150 mm wide, superimposed on ground colour to distinguish type and condition of fluid. The spacing of band shall not exceed 4.0 m.

17.5.4 Further identification may also be carried out using lettering and marking direction of flow.

17.5.4.1 The scheme of colour code for painting of pipe work services for air conditioning installation shall be as indicated in Table 40.

17.5.4.2 In addition to the colour bands specified above, all pipe work shall be legibly marked with black or white letters to indicate the type of service and the direction of flow, as identified below:

Hot water	:	HW
Chilled water	:	CHW
Condenser water	:	CDW
Steam	:	ST
Condensate drain	:	CN

Table 40 Scheme of Colour Code of Pipe Work Services for Air Conditioning Installation
(*Clause* 17.5.4.1)

Sl No. (1)	Description (2)	Ground Colour (3)	Lettering Colouring (4)	First Colour Band (5)
i)	Cooling water	Sea green	Black	French blue
ii)	Chilled water	Sky Blue	Black	Black
iii)	Central heating	Dark Blue	Black	Canary yellow
iv)	Condensate Drain pipe	Black	White	
v)	Vents	White	Black	
vi)	Valves and pipe line fittings	White with black handles	Black	
vii)	Belt guard	Black yellow diagonal strips		
viii)	Machine bases, inertia bases and plinth	Charcoal grey		

17.6 Testing and Balancing

17.6.1 *Air System Balancing* – Air distribution system shall be balanced so that air quantities measured at fan discharge and at various outlets shall be within $\pm$10 percent of the design airflows. Branch duct adjustments shall be permanently marked after the balancing is complete. Throttling losses in the system shall be minimum. Tests shall be carried out for each fan and AHU. All dampers after adjustment shall be set and locked in position. All air and static pressure measurements shall be done with probe type meters. After balancing the fan speed shall be suitably adjusted. Duct leakages shall be tested and validated as specified.

17.6.1.1 Airflow balancing shall be carried out by adjusting the flow at each diffuser to match the right percentage of total airflow in the ductwork. Balancing shall be done based on the ratio between measured and designed flow rate. Following steps may be followed for proportional balancing:

1) Ensure all VCD, VAV and fire dampers are in fully open position.

2) Adjust the damper of each diffuser proportionately to the same ratio in each branch duct.

3) Adjust each branch duct VCD in each main duct so that each branch duct has the same proportion of airflow.

4) Adjust each main duct VCD.

5) Adjust fan speed (through VFD or belt pully) or the main VCD after the AHU to ensure that each diffuser has the right airflow rate.

6) Measure and record airflow rate at each diffuser and compare it with design airflow (within ± 10 percent)

17.6.2 *Water System Balancing*

The following are guidelines for testing and balancing in air and water systems:

17.6.2.1 Water balancing (of chilled water/brine) shall be done as under:

a) Keep all balancing, control and isolating valves in fully open position;

b) Measure the water flow across each balancing valve and compare it with design flow;

c) Identify the index value (lowest flow ratio) in each branch;

d) Keep index valve fully open;

e) Throttle the farthest valve to the same ratio and after that every valve in the branch starting from the lowest ratio;

f) Monitor index valve percentage after throttling each valve gradually. By the time the last valve is completed, the flow is balanced at all valves including the index valve;

g) Record the reading at all valves.

17.6.2.2 Where pressure independent balancing and control valves (PIBCV) are used, the proportional balancing described above is not required. Each valve may be set to correct water flow rate as per manufacturer’s instructions.

17.7 Cleaning/ Flushing of Duct/ Pipe work

The following are guidelines for cleaning and flushing of duct and pipe work:

17.7.1 In duct work, access doors shall be provided next to dampers and these access doors shall be used to clean the duct work. Prior to commissioning of the system, entire duct shall be cleaned. Where specified, such cleaning shall be done by duct cleaning systems using robots. Otherwise, the fans shall be run with only pre-filters in place (to protect coils) and the entire dust shall be blown off. After the cleaning, pre filters shall be replaced.

17.7.2 Pipe work shall be cleaned and flushed before commissioning. Flushing of system shall be done bypassing sensitive parts such as chiller and heat exchanger tubes. Before filling up the system with clean water, all shut off and control valves shall be kept fully open. Continuous air venting shall be done. Pump shall be started only after filling up and air venting is completed. Additional flushing pumps may be used over and above system pumps and the primary pump strainer basket mesh shall not be less than 3 mm when flushing starts. Flushing velocity from 1.0 m/s to 1.25 m/s is recommended. Pressure drop across pumps shall be monitored during the process so that pump cavitation is avoided.

17.7.2.1 Dynamic flushing in several steps is recommended. First the primary ring main may be flushed, thereafter the main pipes and lastly the horizontal mains in each floor. After each round of flushing, the strainer basket shall be changed. Each loop needs to be flushed till the water is clean and the strainer basket does not collect sediments. Flushing of horizontal main pipes shall start at the topmost floor and finish at the lowest floor. After flushing in sections is completed, full system flushing shall be carried out. After flushing is complete, the water sample shall be analysed to determine successful flushing.

17. 8 Commissioning, Testing and Balancing, Performance Validation, System Handover

The following are guidelines for effective commissioning, testing and balancing, performance validation, and system handover to ensure that all systems operate as per design intent and meet performance requirements:

17.8.1 Commissioning shall mean putting an equipment or a system into active service as intended by the owner.

17.8.1.1 In respect of unitary equipment such as room (window air conditioners), Non – ducted split units, package units or VRF, this process shall involve connecting the unit (after installation) to a suitably sized power outlet, switching on the unit and recording the temperature/RH/ air movement/air quality in different locations in the conditioned space. The process shall also involve whether the unit's contracted features are operational and whether the compressor switches off once the set temperature is achieved. Air flow from the unit as well as noise level shall be appropriately measured and recorded. Capacity/power consumption is verified with factory issued test certificates.

17.8.1.2 For a central air conditioning plant or a mechanical ventilation system, the process of commissioning shall follow a structured and documented process. This shall comply with special publication.

NOTE – Special publication may be ISHRAE Standard 10003-2020.

17.8.1.3 The commissioning flow chart given below in fig. 18 sets out the stages of this process.

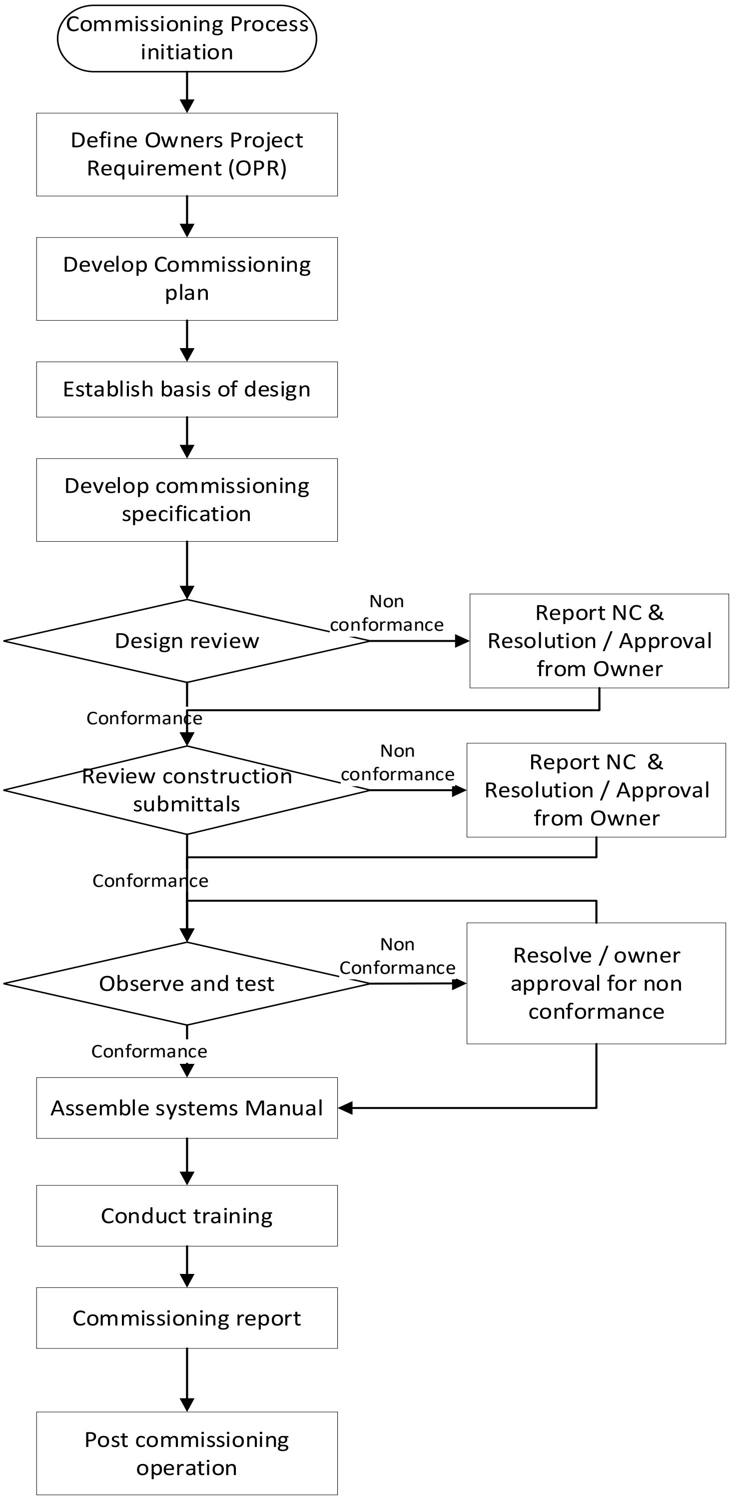


FIG. 18 COMMISSIONING FLOW CHART

17.8.1.4 Initiating the process. Owner shall designate commissioning authority (CxA) at the start of the process. CxA shall either be a member of the owner's project team or an independent agency appointed for this specific purpose. CxA shall have adequate knowledge and experience to guide the project through various stages of the process. Engagement of CxA shall be for a minimum period extending to one year from date the building/facility is put to use. It shall be the responsibility of CxA that all non-conformances, warranty issues, seasonal and occupancy related performance issues are fully resolved during her tenure with the project.

Owner shall be responsible for defining scope of the commissioning plan, incorporating CxA into the project team and establishing the commissioning budget.

Role of CxA and contractual requirements for commissioning shall be a part of all sub contracts including contracts with architects/consultants.

17.8.1.5 Owner's project requirements (OPR) shall include all functional requirements of the project and owner's expectation regarding its use and operation.

17.8.1.6 Commissioning plan shall be a written document scheduling the commissioning activities. This shall include scope, resources required at each stage, agreed timelines and roles and responsibilities of each member of the project team.

17.8.1.7 Basis of design document details design team's approach to meet OPR.

17.8.1.8 Commissioning specifications shall be established for all equipment and systems.

17.8.1.9 Commissioning design review shall involve verifying that all equipment and systems meet OPR. This shall not be a peer review of the design.

17.8.1.10 Testing shall involve preparation of check lists, test procedures and report forms which shall be agreed by all concerned. Person responsible for executing test protocols shall be identified.

17.8.1.11 Functional performance testing shall involve recording the operation, then initiating a change in one or more parameters and recording the changes in performance. This shall be done in auto mode with functional BMS and controls.

17.8.1.12 All information required to operate, maintain and if required, modify the system in future. Systems manual shall be approved by owner and kept updated.

17.8.1.13 Operation and maintenance training shall be documented. Evaluation and feedback are important.

17.8.1.14 Final commissioning report shall summarize the entire process and shall have owner's acceptance.

17.8.1.15 Post occupancy commissioning shall include all delayed and seasonal tests, warranty actions/records and resolution of all non-conformances with owner's specific approval.

17.8.2 For testing of equipment, receipt and inspection at site, safe storage and handling at site, please refer **17.2**. For each piece of equipment, sub system and system check lists shall be made use of for delivery, installation, start up and readiness of commissioning. Sample check lists available in special publication may be suitably adapted for use.

NOTE – Special publication maybe ISHRAE Standard 10003-2020.

17.8.3 Individual pieces of equipment, sub systems shall be considered ready for testing only when the complete installation is over, pressure testing/leak testing (as specified) are completed and required utility connections are made to the satisfaction of CxA. It shall be verified that all blank offs, shipping bolts etc have been removed. Where specified, manufacturer/supplier shall inspect and certify that the equipment/system is ready to start.

17.8.4 Testing of all equipment/ systems shall be in line with the documented protocol which is agreed between the manufacturer/vendor, CxA, design consultant, project management consultant and any other agency who may have jurisdiction over the project. Check lists, reporting formats and standards applicable shall all be agreed in writing beforehand.

17.8.5 Training and documentation for data collection leading to energy analysis shall form part of the process. It is recommended that all individual loads greater than 15 KW be monitored for energy management.

17.8.6 Static inspections that verify proper installation (for example, belt tensions, coupling alignments, oil levels, labelling, gauges and instrumentation in place, sensors calibrated etc) shall be submitted by the vendor to CxA with the request for startup.

17.8.7 Pre-commissioning cleaning of the installed ducting and leak testing of the ducts (where specified) shall be carried out prior to staring of AHU/Fans.

17.8.8 Activities where the equipment is initially energized, tested and operated shall be completed before functional performance testing (FPT) (**17.8.1.11**). FPT shall involve testing under dynamic situations such as low load, full load, varying ambient, power outage, distress and emergency conditions etc. FPT shall establish that the equipment/system performs as designed under all these conditions. Systems shall be operated integrally through all specified operation sequences. Each step of FTP shall be planned in advance, agreed between vendor and CxA, performed under supervision and results tabulated in a pre- agreed format. In case FPT shall not be performed due to any reason (such as ramp up period) before the equipment /plant is put to beneficial use, same shall be recorded and owner’s approval taken.

17.8.9 Operation of all controls and safety cut outs shall be demonstrated and recorded. All measuring instruments shall have valid calibration certificates which shall be part of the record.

17.8.10 Handover documentation shall include all information owner/ user will need to operate, maintain and if required, modify the system at a later date. Hand over documents shall include the following as a minimum requirement.

a) Updated and approved (by owner) systems manual.
b) Final commissioning report.
c) Set of as built drawings.
d) Full set of design calculations.

e) Spare parts lists/ordering procedure.
f) Warranty records, Escalation Matrix
g) List of Non-conformance with resolution records.
h) List of accessories/ tools/ spare parts supplied with system.
j) Operation and maintenance manuals provided by equipment supplier.
k) List of spares and escalation matrix.

17.9 Safety Points Specific to HVAC Systems

The following are safety guidelines specific to HVAC systems to ensure safe operation and maintenance:

17.9.1 Persons working on installation of HVAC Systems, large and small, are exposed to the same risks applicable to any construction activity such as bodily injuries, fall from height, electrical shocks etc. It is of prime importance to follow all safety requirements mandated by National as well as local codes, rules and regulations, including but not limited to, the safety provisions of Indian electricity act and rules framed thereunder and fire safety regulations prescribed by authority having jurisdiction (AHJ).

17.9.2 Following are the safety guidelines specific to HVAC Systems:

17.9.2.1 Nature and level of smoke hazard from the type of insulation material used in the system shall be carefully evaluated and proper ventilation and smoke management provisions shall be made dep, ending on the type and scalability of potential smoke generation.

17.9.2.2 Refrigerant gas being heavier than air, shall cause suffocation in enclosed spaces. Personnel shall use prescribed (by the refrigerant supplier) safety equipment while handling refrigerants and the plant room shall be well ventilated. Refrigerant cylinders shall be stored in upright position. Appropriate safeguard shall be in place based on manufacturer supplied information with respect to physical and chemical health hazards as well as storage and handling information.

17.9.2.3 While pressure testing systems, the following precautions shall be taken.

a) Obtain necessary work permit.
b) Barricade the area.
c) Use calibrated instruments and gauges.
d) Store gas cylinders in covered area and in upright position. Use colour codes to identify the gas inside the cylinder. Avoid exposing cylinders to sunlight. Cylinder cap is shall during storage and transit.
e) Isolation/relief valves shall be provided appropriately.
f) Air shall be completely purged from water systems before pressure testing. Identify drain valves and drainage routes/ sumps.
g) Have documented SOP approved by Engineer-in-Charge before work is taken up. Maintain appropriate records.

18 POST OCCUPANCY OPERATION AND MAINTENANCE

Proper maintenance schedules, regular inspections, and timely repairs are critical to optimizing system functionality and extending equipment lifespan. These practices also contribute to energy efficiency and occupant comfort in the building.

18.1 Operation and Maintenance Procedures

The following guidelines for post occupancy operation and maintenance are essential to ensure long-term performance, safety, and efficiency of the HVAC systems after installation-

18.1.1 *Operating Plan*

The operating plan is given below:

a) Facility operating plan shall describe the intended use of this facility to ensure safety to the users, maintain thermal comfort, optimize resources efficiency, monitoring and data collection of the systems being operated in the facility.
b) Key focus of this plan to ensure safety, reliability, comfort and healthy environment for the users/occupants.
c) During the post occupancy phase of operations, the facility shall develop a systems operations manual.
d) This manual shall comprise the owner's project requirements (OPR) and also the current facility requirements (CFR).
e) These documents shall be maintained throughout the operations of the facilities and shall update the changes in the operational procedures and functions of the facility.
f) Maintaining the information is essential for the facility / building operators to understand, operate and maintain the building systems for entire life cycle of the facility as per design.
g) Operations and maintenance staffs shall effectively utilize the procedures for documenting and tracking of information on any updates, modifications to systems that occurred during occupancy and post occupancy of the facility.
h) The document shall include the modifications performed and the reasoning for the modification to the building operations.
j) As part of the operating plan the facility/operations team shall ensure all the safe operational practices recommended by the original equipment manufacturers (OEM).
k) The facility / operations team shall ensure that the design documents like basis of design (BOD), as built drawings / documents updated time to time, are kept intact to ensure the intended operations of the systems in the facility / building.

18.1.2 *Facility Layouts*

This includes simple line diagrams (schematics) capturing the facility site / building plan, floor layouts and locations of major equipment and systems, control centers (like, electrical power isolations points), utility shut off points (like, dampers, Isolation valves) to assist orientation/training of operators.

18.1.3 *Data Logging*

Maintain daily log of each system operations, record values as per OEM checklist for daily readings and record any abnormalities. (sound, vibration, leakages, etc.)

18.1.4 *Scheduling of Operation*

Operating hours for the facility to be described and listed and this should be the basis to perform more detailed scheduled and operational sequences.

18.1.5 *Roles and Responsibilities*

The building owner/operator shall describe their facility team/operating staff on the requirements of the building operations.

18.1.6 *Minimum Qualifications for the building HVAC Operators*

The Minimum Qualifications for the HVAC Operators should be:

a) The operator should be having a required education qualification of reading operating manuals, standard operating procedures in the language that written with.
b) *Engineering-in-Charge* – Degree or diploma in electrical / mechanical / HVAC with not less than 5 years of experience respectively in operating and maintaining the HVAC systems.
c) *Supervisor* – Diploma in electrical/ mechanical/ HVAC with 3 years of experience or ITI or equivalent in HVAC with 5 years of experience.
d) *Technician* – Diploma in electrical / mechanical / HVAC with minimum 1 year of experience or ITI or equivalent in HVAC with 3 years of experience.
e) *Operator* – Should have passed 10th Class / Intermediate from a state board of education [like CBSE or higher secondary education (HSC)]. Also, operator should have minimum technical qualification of certificate course or refrigeration and air-conditioning from an institute having reputation with state board of technical education (like ITI / NCVT/ AICTE).
f) *Trainee* – Anybody not meeting the above qualifications may be inducted as a Trainee attached to any of the above positions. He/she may not be allowed to operate systems without supervision or support during their training period of minimum one year

18.1.7 *Building and Equipment Operating Schedules, Set Points and Ranges*

The following guidelines for building and equipment operating schedules, set points, and ranges are designed to maintain optimal system performance and energy efficiency:

a) List and describe the planned / intended operating hours of the facility / building.
b) Building owner/ operator shall define the initial operating schedules, anticipated occupancy, desired temperatures in the occupied zones.

c) All the set points of equipment with their safe operational requirements/adjustments shall be listed and provided to the operations team to perform their tasks.
d) The list shall comprise safe operating set point values, acceptable ranges and limitations.
e) Any change to be implemented on the set points shall be recorded and implemented with reason for changing the set values to eliminate human errors.

18.1.8 *Sequence of Operations and Limitations*

The sequence of operations and limitations are listed as follows:

a) List out and provide operational sequences of all equipment to be operated in language and format that is understandable to the operating staffs.
b) The operators shall be briefed on the occupied and un occupied mode of operations of system and components.
c) The operators shall be briefed on the safe shutdown of plant and equipment.

18.1.9 *Start-Up and Shut Down Procedures / Actions*

Start-up procedures shall be adopted as stated in **18.1.10** to **18.1.12**. The maintenance procedure shall be as laid down in **18.1.13**.

18.1.10 Before starting the plant, the operator shall ensure that,

a) All the valves in the refrigeration system, condenser water lines and chilled water lines are kept open, except those of the standby items of equipment.
b) Adequate water in the cooling tower basin and the make-up water system is working satisfactorily.
c) The make-up water system to the expansion tank of the chilled water circuit is working and there is a regular water supply. Water is lost from the chilled water system through pump gland drips / leaky mechanical seal. If the level in the expansion tank is not maintained, air shall enter the chilled water system, affecting the system performance substantially. It shall even lead to system / plant breakdown.
d) All the air filters and water strainers are clean. Any dirty filter and/or the blocked strainer shall be cleaned periodically.
e) All doors and windows of the air conditioned/refrigerated area are closed.
f) The crankcase of the compressor is warm (to the physical touch). If it is not warm, defects in the crankcase heater and/or circuit should be checked fully. The compressor shall not be started until the defect is rectified and the crankcase warms up, else it will result to poor lubrication, thereby substantially reducing the life of the bearings of the compressor.
g) The supply voltage is within permissible limits. The windings of the motors shall get affected, if run on low voltage conditions.

18.1.11 The starting sequence shall be as follows:

a) Switch 'ON' the mains. Observe the voltage. If it is less than the permissible level, do not start any component of the system.

b) Start air handling unit motors (all dampers have to be checked based on their specific application).
c) Start condenser water pumps. Check that sufficient water pressure is obtained.
d) Start cooling tower fan.
e) Start chilled water pumps and check the pressure.
f) Switch 'ON' the compressor control switch.
g) Start the compressor motor.

18.1.12 Following aspects require special attention:

a) In the compressor with oil pump, the compressor oil pressure should build up as the compressor is started. Check that corrects net oil pressure is built up.
b) Check the oil level in the oil sight glass of the compressor. The oil level should be about 40 to 50 percent of the sight glass. In operation, certain amount of oil gets entrained in the refrigerant vapor in the compressor and is carried to the system along with the refrigerant.
c) After the plant operation has stabilized, check all the pressures and temperatures and ensure that the system is working satisfactorily.
d) Record periodically the readings of temperature, pressure, current and other required data in the log sheet.
e) Check for any unusual noise/vibration in the plant. If something unusual is noticed, trace out the reason for it and rectify the cause.
f) During the operation of the system, if any major component stops suddenly, trace out its reason, before starting the component/system again.

18.1.13 The stopping sequence of the system shall be as follows:

a) Switch off the compressor on the low-pressure switch, as the system gets pumped down.
b) Switch off the power supply to compressor.
c) Check that the crankcase electric heater comes on as soon as compressor stops and ensure that the heater is working.
d) Stop chilled water pumps.
e) Stop air handling units.
f) Stop condenser water pumps and cooling tower fans.

18.1.14 Following are standard operating instructions which the operator should follow:

a) In case stand-by chiller, pumps, etc, are provided, systematically change over the stand-by components, periodically. This will ensure uniform wear and tear of the system. Further, this also helps in ensuring that all equipment is in good shape and the stand-by is in working condition.
b) Do not switch off the main switch on the main electrical board or switch off any component of the system, when the plant is in operation.
c) All the water valves in the system shall be kept open and need not be closed, unless specifically instructed by designer. But it is essential to close and open each valve periodically to ensure that the valves work and are not stuck by scale formation or dirt accumulation.

d) Keep the plant room clean. Do not use the plant room, particularly the air handling unit rooms for storage.

NOTE – An automatic sequence of operation shall be covered under Chapter 15 - Building Management System.

18.1.15 *Maintenance Procedures, Check Points and Records*

Procedure for establishing and maintaining effective maintenance practices, ensuring comprehensive inspection points, and maintaining accurate records for facility management.

18.1.15.1 *Preventive maintenance*

The preventive maintenance is:

a) The goal of preventive maintenance is to prevent equipment failure caused normal wear and necessary action by replacing worn out components prior to actual failure of an equipment.
b) Maintenance activities shall include partial or complete overhauls at specified periods and shall include oil changes, lubrication of components, minor adjustments and so on.
c) Operators shall record equipment deterioration by inspection to facilitate the replacement or repair of worn-out parts prior to any system failures.
d) Implement preventive maintenance of installations and equipment to maintain efficient working of building HVAC system and its components.
e) Implement periodic inspection schedule, testing and maintenance throughout their life cycle.
f) Conduct periodic maintenance and testing, servicing, checking, calibration, overhauls and certification, annual inspection, testing, witness regular test and certification.
g) Perform overhauling or replacement at a certain usage (as recommended by OEM) or due to specific causes. This shall be outlined specifically in a preventive maintenance program.
h) Implement preventive maintenance program (PMP) and shall include the methodology and record for all action that are necessary to maintain the efficient working order of the HVAC system.
j) The maintenance procedures shall be unique to each property and the installations and equipment within these facilities.
k) Conduct preventive maintenance in accordance with statutory requirements. (pressurization system, smoke control system, fire alarm interlock with air handling units are few example).
m) Conduct preventive maintenance and overhauls with clear maintenance schedule, instruction and procedures.
n) Ensure O&M personnel induction training on safety, statutory requirements and performance target and work manner.
p) Adopt condition based / reliability-based maintenance where appropriate
q) Conduct a regular review of all procedures / standards.

r) Conduct a regular update of relevant procedures/ standards against the latest statutory requirements, good industrial practices, maintenance records and fault history by a working / facility team comprising competent personnel.
s) Adopt a web based / mobile application-based performance monitoring system for maintenance that is contracted out.

18.1.15.2 *Maintenance schedule*

18.1.15.2.1 *Day-to-day maintenance schedule*

a) *Clean the air filters* – Dirty filters cause poor air flow through air handlers and results in thermal discomfort. Unattended filters could result in damage to the filtering media and the unfiltered air shall pass through them and settle on the cooling coils. This results in poor heat transfer and impacts the efficiency of the air handler system and total efficiency of the HVAC system as a cascading effect.
b) *Leak testing for refrigerant leaks* – Check physically for oil traces, which is indicates source of refrigerant leaks. Perform leak testing using soap bubble or electronic leak detectors. Refrigerant leaks impact the system operation and leads to breakdown of system. Refrigerant leaks impact our environment due to global warming potential of the refrigerants being used in the HVAC system.
c) *Water pump (packed) glands* – Certain amount of water should drip through the gland which is necessary to keep the gland cool. However, if the drip develops into a flow of water, then, it is an indication of leak gland. This should be attended by tightening the gland nuts to reduce the water leaks or gland packing to be replace to prevent loss of water from the distribution system. Unattended gland water leaks shall result in loss of water and facilitates air entry into to the system which could result in abnormality in the chilled water distribution system.
d) Check and monitor any abnormal noise or vibration.

18.1.15.2.2 *Weekly maintenance schedule*

a) *Belt Tension of belt drives* – Check the belt tensions and tighten whenever necessary if found loose. A loose belt reduces the transmission efficiency, reduced air volume of the air handlers and thus affects the thermal comfort. Loose belts cause noisy air handlers and results disturbance to the building occupants.
b) *Check the cooling coil drain tray* – Check and ensure the drain tray is clean from dirt and debris to prevent mold growth or water leakage due to drain block.
c) *Check the lubrication* – Check the lubrication of bearings to ensure smooth operation and prevent breakdowns due to worn out bearings.
d) *Check the Cooling tower* – Check the cooling tower sumps to keep them clean from debris (tree leaves if the towers are located at ground level). The towers are kept open to ambient and dust from the air shall settle on the fills, sumps and requires cleaning to ensure proper operation of the cooling towers which are very critical for a water-cooled system efficiency and performance.
e) Conduct water quality test for cooling towers periodically

18.1.15.2.3 *Monthly Maintenance Schedule*

a) Replace the air handling unit filters with a set of replacement filters kept under stock.
b) Check the Starters and check loose connections of cables and ensure tightness.
c) Check the operation of automatic blow down system for cooling towers.
d) Check and clean the Y-strainers and Pot Strainers.
e) Check the preventive maintenance schedule of components and equipment and conduct maintenance activities.
f) Check and tighten all base bolts to prevent breakdown due to vibration.

18.1.15.2.4 *Quarterly maintenance schedule*

a) Perform pre scheduled preventive maintenance activities equipment and components.
b) Check the log book and conduct thorough study of equipment to ensure healthiness of its operation.
c) Check and lubricate all the moving parts.
d) Check and clean the cooling tower sumps.
e) Check and clean all the strainers and pot strainers.
f) Check and replace belts if necessary.
g) Check the safety interlock of all air handling units.
h) Check and replace defective instruments like pressure gauges, thermometers etc.
j) Check and rectify any refrigerant leaks.
k) Check and replace any defective / malfunctioning components of the system.

18.1.15.2.5 *Half year maintenance schedule*

a) Perform all the activities listed under quarterly maintenance schedule.
b) Check the conditions of the cooling tower fills and clean them.
c) Check and clean the air handling unit blowers from dust/ dirt accumulation.
d) Check the operation of cooling tower blow down system (automatic) and chemical dosing system.

18.1.15.2.6 *Yearly Maintenance Schedule*

a) Perform all the activities listed under half yearly maintenance schedule.
b) Collect oil sample from the chiller system and send them for laboratory test to analyze presence of metal particles, viscosity etc.
c) Post lab results replace the oil to ensure safe operation of the compressors to enhance the life cycle.
d) Check and clean the condenser tubes of the water-cooled system to improve heat transfer. If, required only, conduct de-scaling of the tubes. Frequent de-scaling is not recommended and cause potential damage to the copper tubes.
e) Check the operation of auto tube cleaning system if it is in place and ensure its components are intact or replace if required.
f) Conduct vibration test of all major equipment and record the test readings for further comparisons till life cycle of the equipment.

g) Witness maintenance of all the electrical starter panels, switch gears, earthing conductors and perform interlock testing for safe operations of the total system.
h) Conduct indoor air quality test and if required perform duct cleaning procedures to ensure good indoor air quality.

18.1.15.2.7 *Check points*

a) Compare the previous maintenance log and record any abnormalities.
b) Conduct necessary actions to rectify or replace component / equipment as noticed on abnormalities.
c) Ensure O&M personnel induction training on safety, statutory requirements and performance targets.
d) Conduct and analyze on operating costs due to lack of maintenance and ensure corrective actions.

18.1.15.2.8 *Records*

a) Good maintenance records are essential for ensuring that a piece of equipment is performing in line with OEM recommendations, warranties and thus help to determine an equipment preventive maintenance schedule.
b) Maintenance records to be maintained to assist the service matter experts, (SME's) service technicians for diagnosing any repeat problems with or within the plant or its equipment.
c) Maintain paper records of all maintenance related activities including testing and commissioning certificates, test records, as-built documents, statutory approved submission documents, water quality test reports, oil quality test report, indoor air quality reports, calibration certificates of instruments.
d) Maintain emergency call / fault attendance reports, fault history etc.
e) Maintain records of usage of refrigerants.
f) Maintain soft copies of all the documents listed under paper records.
g) Assign designated persons/s responsible to review and update routine maintenance inspection schedule, emergency call / fault attendance reports etc., on a monthly basis and the findings shall be documented for future reference.
h) Set up record system able to automatically provide alerts for outstanding shutdown notices and annual maintenance renewal etc.
i) Digitize all documents and records with a standardized file naming system in a reliable database server for easy retrieval. (Facility management system / manager shall perform this activity).

18.1.15.2.9 *Training*

a) Provide training to equip staff with knowledge to work safely and without risk to health.
b) To Ensure maintenance plans are followed correctly, facility managers and building owners should provide sufficient periodical training to all maintenance technicians. Good sources of trainings are,
    1) An experienced technician or facility staff member
    2) OEM's Training
    3) Technical and community colleges

   4) Videos, seminars and short-term courses by professional associations like ISHRAE.

c) The minimum training content delivered should generally include below:
   1) Basis of design or design brief.
   2) Documentation requirements.
   3) Operating procedures such as startup and shutdown procedures.
   4) Basic diagnostic instructions.
   5) Fire, life safety and emergency procedures.

18.1.15.10 *Spare parts inventory management*

a) Managing spare parts in an optimal way is an inherent and substantial part of O&M aimed at ensuring that spare parts are available in a timely manner for corrective maintenance in order to minimize the downtime of a system or equipment.
b) Maintain a spare parts list for plant and equipment.
c) Maintain an updated contact list of suppliers with lead time details of each spare.
d) Review constantly the quality and quantity of spare parts in stock and restock when necessary.
e) Maintain the log of spares utilized.
f) Assign designated person/s responsible for regular updates of any changes in spare parts inventory.
g) Monitor the condition of spare parts to ensure their quality is maintained.
h) Identify long lead items/ components for early procurement.
i) Identify discontinued items (obsolete) for sourcing an alternative parts or upgrade of system.

18.2 Predictive maintenance

a) Predictive maintenance is a planned maintenance basis diagnosis of equipment condition.
b) Measurements that detect the onset of a degradation mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state.
c) Predictive maintenance techniques may include vibration analysis, thermography, oil analysis, motor current analysis, Eddy current testing and pressure measurement etc.
d) Performance trending.

18.2.1 *Emergency operating procedures*

a) Emergency event requires planning, preparation and practice.
b) Regardless of type of risk, every facility shall have a risk event plan or emergency management in place to minimize the damage and danger to following:
   1) Building occupants
   2) Documents and assets within facility
   3) Building, IAQ and surrounding community, air and water.

4) Establish and implement environmental management systems and safety management systems. For additional information special publications may be referred.

NOTE – Special publication maybe ISO 14001 for Environmental Management Systems and OHSAS 18001 or ISO45001 for Safety Management Systems.

18.2.2 *Performance based operation and maintenance contracts*

a) Performance based or output based operation and maintenance contracts gaining traction.
b) The advantages of performance-based O&M contracts are,
c) Payment for actual performance or usage.
d) Contractor responsibility for full package.
e) Continuous improvement / Innovation
f) Reduced risks due to lower capital costs.

18.2.3 User feedback mechanisms for optimizing maintenance schedules or identifying:

a) Metering and sub-metering of energy and resource use is a critical component of a comprehensive O&M program.
b) Metering provides the information that when analyzed allows the building operations staff to make informed decisions on how to best operate mechanical/electrical systems and equipment.
    1) Metering approaches
    2) One time / spot measurement
    3) Run time measurement
    4) Short term monitoring
    5) Long term monitoring
    6) Measure, verify, and optimize equipment performance
    7) Identify improvement opportunities on environmental (especially energy, water efficiency) and safety aspects.

18.3 Computerized Maintenance Management System (CMMS)

CMMS is a computerized maintenance management system, which is a software application that helps controlling, monitoring and analysing operation of HVAC system. The centralized CMMS would help in optimization of cost, resources, and information at one place.

Benefits that the CMMS shall provide to the facility during operation and maintenance shall include

a) *Electronic records* – Use of electronic records reduces the amount of time spent by office personnel entering data, which improves the efficiency of the maintenance department.
b) *Reduced repair costs* – A CMMS shall store and provide easy access to equipment records. When historical records are easily accessible, they shall

be used to determine the most economical decision for a piece of equipment: repair or replace

c) *Personnel management* – Records for each employee shall be stored and easily accessed and updated. Electronic personnel records shall include, but are not limited to, training and certifications earned by each employee, pay scales, and hire dates.
d) *Asset management* – A CMMS shall be used to store electronic records for any type of asset, including equipment and supplies.
e) *Process automation* – When a CMMS is set up correctly, preventive and predictive maintenance work orders, parts and supply reordering, and other notifications shall be automated, saving time and increasing the efficiency of the maintenance team
f) *Improved work control* – CMMSs provide increased ability to manage work orders and prioritize and schedule work
g) *Increased budget accountability* – Accurate records of labour hours and inventory items increase the accuracy of expenses and budgets.
h) *Increased ability to measure performance and service* – When data are available, performance shall be determined for a period of time, such as that required to complete a specific type of maintenance activity or respond to a service call.

CCMS Modules shall be considered for facility operations are as below:

1) *Asset management* – Its asset operations, monitoring and control, repair and PM history.
2) *Work order management* – Helpdesk ticket end-to-end user complaint to closure of calls
3) *Procurement* – Inventory management, parts ordering.
4) *Dashboard reporting* – This module allows you to generate reports on a variety of maintenance metrics, such as downtime, costs, and asset health.

18.3.1 Broad CMMS selection process that shall be considered as follows:

a) *Team involvement* – To include the facility managers, clients, property management team, consultants and technicians shall be involved during the planning phase to select the suitable CMMS software, scope of working of CMMS and integration requirement with other third-party systems (BMS, EMS and AI).

b) When selecting the software, the following shall be part of the process:
   1) Continued focus and understanding of the true need for the CMMS.
   2) Clear understanding of how the CMMS implementation will support maintenance best practices desired by the organization.

18.3.1.1 Process of selection given below shall be followed:

a) For Planning:
   1) Establish a CMMS selection task force.
   2) Perform interviews with all members of the facilities team who will use the CMMS.

3) Determine the needs, wants, reporting features, and goals for the CMMS.
4) Determine what CMMS outputs are needed to meet the goals.
5) Determine input data that shall be collected.
6) Evaluate the value of data versus the cost of collecting, inputting, and maintaining the data within the CMMS
7) Integration of third-party software data to CMMS.
8) Determine available budget.
9) Determine CMMS modules needed.
10) Write CMMS specification.
11) Prepare for CMMS vendor meetings.
12) Meet with vendors and participate in vendor demonstrations.
13) Prepare bid package.
14) Develop a continual implementation plan.
15) Determine if a phased implementation plan is needed.
16) Develop a phased implementation plan (if needed).

b) CMMS software/ CMMS module selection shall fulfil the operational needs of facility and shall address the following:
1) Areas for improvement in current maintenance practices (for example, reduced downtime, improved preventive maintenance).
2) Advanced features and functionalities (for example, mobile access, work order management, reporting).
3) Strong asset management, work order creation and tracking, preventive maintenance scheduling, and inventory control.
4) Consider advance features like AI-based functionalities for predictive maintenance, asset analysis from R and M, PM perspective, dash-board reporting, mobile capabilities for Equipment operative team.
5) Integration with any existing software you use.
6) Options for future scalability
7) Requirements towards company where CMMS to be installed IT / data security and compliance with relevant regulations.
8) Implementation costs, licensing fees (one time and recurring), availability of software key, and ongoing software support.
9) Strong after sale service and customer support.

18.3.2 *Implement a CMMS, Going-Live Phase*

a) Select a CMMS.
b) Collect input data.
c) Input data into CMMS.
d) Determine how users will be trained.
e) Implement training.
f) Go live and cut over.
   i) Going live is the transition between setting up a system and using the CMMS for daily maintenance activities. This project phase reveals how successful the planning and implementation processes were. Before going live, the CMMS shall be tested and checked to ensure correct system configuration
g) Implement continual implementation plan
h) Create standard operating procedures (SOPs) for using the CMMS.

18.3.3 *Integration of CMMS with Building Automation Systems (BAS) for Data Collection and Analysis*

a) Integrating of CMMS with a building automation system (BAS) will be an intense tool for property and facility management engineering team. The BAS regularly monitors and collects data on several characteristics of a building's management systems.
b) Integration complexity shall be looked during planning phase for example, specific software and desired functionality, shall ensure that both the systems communicate with each other properly.
c) To protect sensitive building information, a common IT security protocol, proper data security protocol shall be ensured.
d) It shall be ensured that periodic data export from the BAS and import into the CMMS be established or worked during RFP phase. Make certain consistent data formats and naming principles between the CMMS and BAS for seamless integration.
e) Protocol for two-way communication between both the systems, allowing for real-time data exchange shall be established.

18.3.4 *Automation and Integration of Chiller plant and Pumps*

Following systems shall be considered for automation and integration in the BMS and CMMS. Refer to Part 12 'Asset and Facility Management' of this code for further details:

a) Building automation system (BAS)
b) Chiller plant manager
c) Sensors, VFD, communication system / PLCs

18.4 Controls to measure and monitor building energy performance.

18.4.1 *System for data collection and analysis*

Building controls such as CMMS and BMS systems shall consists of following metering systems, controls and monitoring systems for data collection and analysis:

a) Main meters for sources of energy used by facility
b) Submetering for applications that represent 10 percent or more of the total building consumption such as chillers, pumps, cooling towers, AHU's, ventilation systems, hotel rooms (cumulative), lighting and UPS systems
c) Data collection systems: collecting data from energy meters, sub-meters on pumps, cooling towers, AHU feeders
d) Building Automation System (BAS)
e) Chiller plant manager
f) Sensors, VFD, communication system / PLCs

NOTE – Refer to Part 12 'Asset and Facility Management' of this code for further details

18.4.2 *Maintenance Strategy and Controls Including Integration of CMMS with Building Automation Systems (BAS)*

a) *Predictive maintenance* – Using CMMS / CPM/ BMS, BAS data for example, equipment performance metrics and sensor readings, helps to predict potential breakdowns and shall schedule maintenance before failures occur. CMMS shall be used to analyze this data and initiate work orders.
b) *Condition* – Based Maintenance: BAS/ CMMS shall use this data to prioritize maintenance tasks based on actual equipment condition, optimizing resource allocation.
c) *Preventive maintenance* – CMMS should be used to schedule PM tasks based on OEM recommendations, historical data, and BAS/CMMS/ BAS alerts.
d) A 52 Week PPM planner shall be used aligned with checks prescribed in OEM manuals.

18.4.2.1 Critical systems identification and analysis of efficiency and healthiness checks:

a) AHUs
b) Compressors
c) Chiller
d) Condenser
e) Cooling towers
f) CMMS, PLC and controls
g) Electrical, power distribution network
h) Water cycle – open and closed circuits
j) Boilers
k) PAHUs / PACs, domestic air conditioners
m) STPs in case STP water is used in cooling towers.

18.4.2.2 Analysis of efficiency and healthiness checks:

a) ikW and COP test shall be performed with the help of OEM and maintenance agency the analysis report should contain performance designed vs actual.
b) Check for the AHU performance
c) A regular health check-up should be conducted by a professional HVAC engineer, preferably on annual basis, the test should be considered during Peak load for example, summer,

Further an equipment wise check shall be conducted using calibrated equipment’s.

18.4.2.3 *Selection of maintenance class and transitioning from reactive to proactive maintenance*

To transition from one particular maintenance approach to another, a detailed analysis shall be made to determine what will be the most effective. Table 41 below indicates the type of maintenance to be considered for the systems / facility.

Table 41 Type of Maintenance to be Considered for the Systems / Facility
(*Clause* 18.4.2.3)

Sl No.	Maintenance Class	Effect of Failure	Desired Result	Analysis Used to Determine Most Effective Maintenance Technique	Implementation of Maintenance Practices
(1)	(2)	(3)	(4)	(5)	(6)
i)	**A:** Mission Critical	Significant financial, safety and/or operational impact	Risk mitigation and maximize equipment and system availability	Reliability centered maintenance and risk assessment	Preventive and predictive approaches
ii)	**B:** Optimize Life-Cycle Costs	Minor impact on core business activities	Minimize equipment LCC over time	Reliability centered maintenance and risk assessment	Preventive, predictive and reactive approaches
iii)	**C:** Minimize Short-Term Costs	No impact on core business activities	Minimize short-term costs	Risk assessment	Risk mitigation measures, visual inspection, and preventive maintenance
iv)	**D:** Industry Standard Maintenance	No impact on core business activities	Minimize short-term costs	Risk assessment	RS Means or original equipment manufacturer job plans, preventive maintenance
v)	**E:** Out-of-Service	No impact on core business	Ability to operate	Risk assessment	Minimum maintenance

To select the appropriate maintenance class, The facility mangers to develop an effective maintenance program and shall consider the following:

a) Focus on maintenance that results in the best return on investment (ROI).
b) Make sure results shall be measured.
c) Avoid intrusive maintenance.
d) Employ an effective management system, such as a computerized maintenance management system (CMMS).

18.4.2.3.1 The Systems to consider for proactive maintenance shall include:

a) AHUs
b) Compressors

c) Chiller
d) Condenser
e) Cooling towers
f) CMMS, PLC and controls
g) Electrical, power distribution network
h) Water cycle – open and closed circuits
j) Boilers
k) PAHUs / PACs, domestic air conditioners
m) STPs in case STP water is used in cooling towers.

18.4.2.3.2 Transition from reactive to proactive maintenance shall benefits the facility operation and maintenance and that shall include:

a) Fixing things only when they break is a reactive maintenance, which leads to a sudden failure to equipment, causing down-time, production loss, Impact equipment life span / age and requires more budget / cost to manage.
b) Making a switch towards proactive maintenance for example, prevention over repairs requires time and efforts but helpful enhance equipment life, up-time, reliability, maintenance cost, safety and increased efficiency.
c) A proactive maintenance should have deep understanding of your assets, thorough study of OEM manuals, drawings, design brief / project reports, regular inspection, analysis of failure history / equipment down-time/break-down historical data, condition monitoring, a regular training to operators understanding various failures code as described in OEM manuals.

18.5 Benchmarking of building performance with KPI index

18.5.1 *Strategies for implementing the Measurement and Verification (M and V)*

M and V strategies/ techniques shall be used by facility owners or energy efficiency project investors for the following purposes:

a) Increase energy savings
b) Enhance financing for efficiency projects
c) Improve engineering design and facility operations and maintenance
d) Manage energy budgets

M and V plan produce verifiable savings reports. An M and V Plan shall be developed for each facility by qualified professional. M and V applies to a wide variety of facilities including existing and new buildings and industrial processes. M and V strategies consist of some or all of the following:

1) Meter installation calibration and maintenance.
2) Submetering for applications such as HVAC (Chillers, Pumps, CT), AHU's, ventilation fans, internal lighting, external lighting and UPS.
3) Data gathering and screening,
4) Development of a computation method and acceptable estimates,
5) Computations with measured data, and
6) Reporting, quality assurance and third-party verification of reports.

M and V options to be followed shall include as below:

i) Option-1 – Retrofit Isolation: key parameter measurement
ii) Option-2 – Whole facility

18.5.1.1 *Option-1 – Retrofit isolation: key parameter measurement*

Retrofit isolation techniques are best applied where:

a) Only the performance of the systems affected by the ECM is of concern, either due to the responsibilities assigned to the parties in an energy performance contract, or due to the savings of the ECM being too small to be detected.
b) Interactive effects of the ECM on the energy use of other facility equipment shall be reasonably estimated or assumed to be insignificant.
c) Sub-meters already exist to isolate energy use of systems
d) Meters added at the measurement boundary shall be used for other purposes such as operational feedback or tenant billing.
e) Long term testing is not warranted.

18.5.1.2 *Option-2 – Monitoring performance of whole facility*

Monitoring of whole facility Involves use of utility meters, whole-facility meters, or sub-meters to assess the energy performance of a total facility. The measurement boundary encompasses either the whole facility or a major section. This option determines the collective savings of all ECMs applied to the part of the facility monitored by the energy meter.

Facility team shall select the M and V options based on the energy metering infrastructure availability and energy conservation measures (ECM) implementation and monitoring of ECM.

a) *Overall HVAC System efficiency for benchmarking*

   The overall HVAC systems efficiency shall be measured with the help of submetering as suggested in the M and V section and overall HVAC systems efficiency shall be calculated as overall HVAC energy consumption in kWh and divided by conditioned area of the facility.

   $$\text{Overall HVAC systems efficiency} = \frac{\text{overall HVAC consumption (kWh)}}{\text{Conditioned area-sqm}}$$

b) Scheduled intervals, equipment performance to be measured and monitored and compared with bench marking of efficiency till the end-of-life cycle of the equipment. The equipment performance to be measured on monthly basis in kWh and performance to be tabulated for comparing with benchmarking.

c) Corrective action to ensure performance of the system.

   The corrective actions to ensure performance of systems shall be as per table 43.

Table 43 Potential corrective measures list
(*Clause* 18.5.1.2)

Sl. No.	**Possible cause**	**Recommended Corrective Action**
(1)	(2)	(3)
1)	**General**	
	Human error in data collection and analysis	Train staff in data collection and analysis
	Instrumentation error	Check error and calibrate to attain manufacturer recommended level
	Equipment operating schedules	Change equipment operating schedules to more closely follow actual building activities.
	Equipment load	Identify correct plug load and ensure their proper use
2)	**Lighting**	a) Fine tune on hours more closely to reflect actual. b) Measure actual lux level and take corrective action to ensure task-based lux level c) Check voltage level to ensure there is no over voltage to avoid over consumption d) Ensure fixture and accessories cleaning to increase lighting efficiency
3)	**HVAC- Chilled Water System**	a) Ensure preventive maintenance as per schedule. b) Check DPT function. c) Check pump operates at its best efficiency point. d) Check COP at full load condition.
4)	**Water**	a) Check for leak in pipes, fittings. b) Ensure periodical cleaning of the filters provided at the roof for rainwater harvesting. c) Rainwater collection sumps to be have a maintenance plan in place.

d) Measure the indoor air quality, thermal comfort, water performance and energy performance as part of KPI.

Metrics and trends are important parts of maintenance organization. Metrics, also known as key performance indicators (KPIs), shall be used to drive improvement, minimize problems, help set priorities and goals, and help determine milestones and evaluate success.

To effectively use metrics and trends, reports shall be set up and generated using the CMMS. There are two basic types of reports

1) *KPIs and measures reports* – Reports that contain key performance indicators, trends, and measurements that identify systems and equipment, processes, other maintenance management topics that need the most attention

2) *Functional reports* – Reports used Measure the indoor air quality, thermal comfort, water performance and energy performance.

18.6 HVAC System Life Expectancy Comparison

a) Comparison of HVAC systems to check the end of life / replacement of systems.

   1) The typical lifespan of an HVAC system is known. Nevertheless, after years of regular use, the efficiency and performance of an HVAC system naturally decreases overtime.
   2) There are few signs that signal this decrease are
      i) Increase in breakdown frequency.
      ii) Increased energy use.
      iii) Performance degradation
      iv) Unusual noise
   3) Risk based approach to plan and schedule replacement works in accordance with spare parts availability as well as any specific law and safety requirements, etc.

b) Performance based approach to analyse the HVAC systems life served including the factor affecting the HVAC systems lifespans.

   1) Output based approach to understand the life of HVAC system
   2) Factors that affect the HVAC systems lifespan are
      i) Quality of installation
      ii) Utilization time of equipment
      iii) Location
      iv) Operation and maintenance

19 SMOKE MITIGATION – FIRE AND LIFE SAFETY

This chapter on smoke mitigation towards fire and life safety is towards providing human life safety with tenability to enable the occupants ideally to exit from event (fire incident) zone or in some occupancies to have occupants towards defend in place.

Compartmentation is essential to ensure space by space integrity to prevent the spread of fire. Such spaces enable occupants to proceed to exits and to be provided with aspects of smoke mitigation though ideally pressurization or in some cases with smoke ventilation.

Smoke ventilation is also essential predominately post fire incident to enable reducing smoke concentration levels for firefighters and emergency responders shall more effectively check reoccurrence of fires and rescue occupants from the defend in place safe zone to exits. This also helps in reducing property damage by purge of smoke post fire incident in the fire incident area/ spaces.

The various strategies and spaces shall be identified in this chapter to enable designers to adopt the required strategy of smoke mitigation and also have specific design, systems provided and its functions on respective occupancy of the project.

The chapter shall provide all the technical, design, performance aspects with essential integration to fire alarm system and also importantly evacuation strategy.

Aspects of pressurization (Pascals) for defend in place [One door open], phased evacuation [Three door open], assisted firefighting shaft [Three door open] shall be detailed in the smoke mitigation aspects towards life safety.

Smoke venting and ACPH aspects on smoke purging for post incident, cold smoke extract for space review, ascertain safe conditions shall be included in the chapter.

The power supplies, fire rating, interlocking of the smoke mitigation system on mechanical systems, equipment, elevators, lobby compartmentation, damper control shall be included for successful implementation of the smoke mitigation system.

19.1 Smoke Mitigation – Sub Structure

19.1.1 *Car Parking in Sub Structure*

19.1.1.1 *Basement car parking non-mechanical*

In case of smoke exhaust and pressurization of areas below ground, each basement shall be separately ventilated. Vents with cross-sectional area (aggregate) not less than 2.5 percent of the floor area spread evenly round the perimeter of the basement shall be provided in the form of grills, or breakable stall board lights or pavement lights or by way of shafts.

19.1.1.2 *Basement Car Parking Stack/ Mechanical*

In case of smoke exhaust and pressurization of areas below ground, mechanical ventilation system be provided with following requirements:

a) Mechanical ventilation system shall be designed to permit 12 ACPH in case of fire or distress call. However, for normal operation, air changes schedule shall be as given in **3**.
b) In multi-level basements, independent air intake and smoke exhaust shafts (masonry or reinforced concrete) for respective basement levels and compartments therein shall be planned with its make-up air and exhaust air

fans located on the respective level and in the respective compartment. Alternatively, in multi-level basements, common intake masonry (or reinforced cement concrete) shaft may serve respective compartments aligned at all basement levels. Similarly, common smoke exhaust/outlet masonry (or reinforced cement concrete) shafts may also be planned to serve such compartments at all basement levels. All supply air and exhaust air fans on respective levels shall be installed in fire resisting room of 120 min. Exhaust fans at the respective levels shall be provided with back draft damper connection to the common smoke exhaust shaft ensuring complete isolation and compartmentation of floor isolation to eliminate spread of fire and smoke to the other compartments/floors.

c) Due consideration shall be taken for ensuring proper drainage of such shafts to avoid insanitation condition. Inlets and extracts may be terminated at ground level with stall board or pavement lights as before. Stall board and pavement lights should be in positions easily accessible to the fire brigade and clearly marked ‘AIR INLET’ or ‘SMOKE OUTLET’ with an indication of area served at or near the opening.

d) Smoke from any fire in the basement shall not obstruct any exit serving the ground and upper floors of the building.

e) The smoke exhaust fans in the mechanical ventilation system shall be fire rated, that is, 250°C for 120 min.

f) The smoke ventilation of the basement car parking areas shall be through provision of supply and exhaust air ducts duly installed with its supports and connected to supply air and exhaust fans. Alternatively, a system of impulse fans (jet fans) may be used for meeting the requirement of smoke ventilation complying with the following:

   1) Structural aspects of beams and other down stands/services shall be taken care of in the planning and provision of the jet fans.
   2) Fans shall be fire rated, that is, 250°C for 120 min.
   3) Fans shall be adequately supported to enable operations for the duration as above.
   4) Power supply panels for the fans shall be located in fire safe zone to ensure continuity of power supply.
   5) Power supply cabling shall meet circuit integrity requirement in accordance with accepted standard [8-3(46)].

The smoke extraction system shall operate on actuation of flow switch actuation of sprinkler system. In addition, a local and/or remote ‘manual start-stop control/switch’ shall be provided for operations by the fire fighters. Visual indication of the operation status of the fans shall also be provided with the remote control. Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas supply air shall not be less than 5 m from any exhaust discharge openings.

19.1.1.3 *EV Car Parking*

The aspect of smoke ventilation for EV car parking shall be as above in **19.1.12**.

19.1.2 *Habitat Spaces in Substructure*

Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas.

19.1.3 *Services Spaces in Substructure*

Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas.

19.2 Smoke Mitigation – Super Structure/ Above Ground

19.2.1 *Group A (Residential Buildings) to Group G (Industrial Buildings)*

For the residential buildings (Group A), all kitchen exhaust fans, where provided shall be fixed to an outside wall or to a duct of non-combustible material, which leads directly to the outside. The ducts shall not pass through areas having combustible materials. However, in case of centralized ducting, the duct shall be provided with adequate protection to limit the spread of fire.

For the industrial buildings (Group G), occupancy requiring undivided floor areas so large that the distances from points within the area to the nearest outside walls where exit doors are 45 m and more, requirements for distance to exits should provide stairs leading to exit tunnels or to overhead passageways. In cases where such arrangements are not practicable, the authority may, by special ruling, permit other exit arrangements for single storeyed buildings with distances higher than distances specified in **4**, if completely automatic sprinkler protection is provided and if the heights of ceiling curtain boards and roof ventilation are such as to minimise the possibility that employees will be overtaken by the spread of fire or smoke within 1.8 m of the floor level before they have time to reach exits, provided, however, that in no case may the distance of travel to reach the nearest exit exceed 65 m where smoke venting is required as a condition for permitting distances of travel to exits in excess of the maximum otherwise allowed.

Additional precautions for smoke mitigation are as follows:

a) In any room in which volatile flammable substances are used or stored, no device generating a glow or flame capable of igniting flammable vapour shall be installed or used, such a room shall be provided with a suitably designed exhaust ventilation system.
b) Storage buildings, such as for warehouses, natural draft smoke venting shall utilize roof vents or vents in walls at or near the ceiling level; such vents shall be normally open, or, if closed, shall be designed for automatic opening in case of fire, by release of smoke sensitive devices.

19.3 Smoke Mitigation of Exits - Natural/ Mechanical

19.3.1 *Staircases and Exits Passageways*

19.3.1.1 Smoke control of exits

a) In building design, compartmentation plays a vital part in limiting the spread of fire and smoke. The design should ensure avoidance of spread of smoke to adjacent spaces through the various leakage openings in the compartment enclosure, such as cracks, openings around pipes ducts, airflow grills and doors.

b) The pressurization of staircases and lift lobbies shall be adopted.
   1) The pressure difference for staircases shall be minimum 50 Pa.
   2) Pressure differences for lobbies (or corridors) shall be between 25 Pa and 30 Pa. Further, the pressure differential for enclosed staircase adjacent to such lobby (or corridors) shall be 50 Pa. For enclosed staircases adjacent to non-pressurized lobby (or corridors), the pressure differential shall be 50 Pa.

c) Equipment and ductwork for staircase pressurization shall be in accordance with one of the following:
   1) Directly connected to the stairway by ductwork enclosed in non-combustible construction.
   2) If ducts used to pressurize the system are passed through shafts and grills are provided at each level, it shall be ensured that hot gases and smoke from the building shall not ingress into the staircases under any circumstances.

d) The normal air conditioning system and the pressurization system shall be designed and interfaced to meet the requirements of emergency services. When the emergency pressurization is brought into action, the following changes in the normal air conditioning system shall be affected:
   1) Any re-circulation of air shall be stopped and all exhaust air vented to atmosphere.
   2) Any air supply to the spaces/areas other than exits shall be stopped.
   3) The exhaust system may be continued, provided:
      i) The positions of the extraction grills permit a general air flow away from the means of egress;
      ii) The construction of the ductwork and fans is such that, it will not be rendered inoperable by hot gases and smoke; and
      iii) There is no danger of spread of smoke to other floors by the path of the extraction system which shall be ensured by keeping the extraction fans running.

e) For pressurized stair enclosure systems, the activation of the systems shall be initiated by signalling from fire alarm panel.

f) Pressurization system shall be integrated and supervised with the automatic/manual fire alarm system for actuation.

g) Wherever pressurized staircase is to be connected to unpressurized area, the two areas shall be segregated by 120 minutes fire resistant wall.

h) Fresh air intake for pressurization shall be away (at least 4 m) from any of the exhaust outlets/grille.

19.3.1.2 In case of smoke exhaust and pressurization of areas above ground, corridors in exit access (exit access corridor) are created for meeting the requirement of use, privacy and layout in various occupancies. These are most often noted in hospitality, health care occupancies and sleeping accommodations. Exit access corridors of guest rooms and indoor patient department/areas having patients lacking self-preservation and for sleeping accommodations such as apartments, custodial, penal and mental institutions, etc, shall be provided with 60 minutes fire resistant wall and 20 minutes self-closing fire doors along with all fire stop sealing of penetrations. The fire doors shall be as per the accepted standard [8-3(39)].

Smoke exhaust system having make-up air and exhaust air system or alternatively pressurization system with supply air system for these exit access corridors shall be required. Smoke exhaust system having make-up air and exhaust air system shall also be required for theatres/auditoria. Such smoke exhaust system shall also be required for large lobbies and which have exit through staircase leading to exit discharge. This would enable eased exit of people through smoke-controlled area to exit discharge. All exit passageway (from exit-to-exit discharge) shall be pressurized or naturally ventilated. The mechanical pressurization system shall be automatic in action with manual controls in addition. All such exit passageway shall be maintained with integrity for safe means of egress and evacuation. Doors provided in such exit passageway shall be fire rated doors of 120 min rating.

Smoke exhaust system where provided, for above areas and occupancies shall have a minimum of 12 air changes per hour smoke exhaust mechanism. Pressurization system where provided shall have a minimum pressure differential of 25 Pa to 30 Pa in relationship to other areas. The smoke exhaust fans in the mechanical ventilation system shall be fire rated, that is, 250°C for 120 minutes. For naturally cross-ventilated corridors or corridors with operable windows, such smoke exhaust system or pressurization system will not be required.

19.3.2 *Lift Lobby*

Smoke control of exits – pressure differences for lobbies (or corridors) shall be between 25 Pa and 30 Pa.

Firefighting shaft (fire tower) is an enclosed shaft having protected area of 120 minutes fire resistance rating comprising protected lobby, staircase and fireman's lift, connected directly to exit discharge or through exit passageway with 120 minutes fire resistant wall at the level of exit discharge to exit discharge.

19.3.3 *Hoist Way*

If the lift lobby is not be provided at any of the levels in air-conditioned buildings or in internal spaces where funnel/flue effect may be created, lift hoist way shall be pressurized at 50 Pa.

19.3.4 *Fire Tower/ Fire Fighting Shaft*

Firefighting Shaft (Fire Tower) is an enclosed shaft having protected area of 120 min fire resistance rating comprising protected lobby, staircase and fireman's lift, connected directly to exit discharge or through exit passageway with 120 minutes fire resistant wall at the level of exit discharge to exit discharge.

If lift lobby shall not be provided at any of the levels in air-conditioned buildings or in internal spaces where funnel/flue effect may be created, lift hoist way shall be pressurized at 50 Pa.

19.3.5 *Egress and Evacuation Strategy*

Staircase and fire lift lobby of a firefighting shaft shall be smoke controlled. It is recommended that the pressurization requirement for staircase in firefighting shaft and for other fire exit staircases in buildings greater than 60 m in height be evaluated to limit the force required to operate the door assembly (in the direction of door opening) to not more than 133 N to set the door leaf in motion. The aspect of pressurization, door area/width and door closure shall be planned in consideration to the above.

19.4 Smoke Mitigation – Special Occupancy and Spaces

19.4.1 *Atrium*

Given below are the requirements for atrium concerning with the smoke prevention and management for occupancy and spaces:

a) Atrium in business occupancy shall be planned with 6 ACPH while atrium in hotels and assembly occupancy shall be planned with 8 ACPH smoke extraction system. Such air changes shall be planned in atrium for a height of 15 m from the top.
b) Smoke exhaust fans shall be capable of operating effectively at 250°C for 120 minutes.
c) Makeup air supply points shall be located beneath the smoke layer and on the lower levels connected by the atrium. Makeup air shall be provided by fans, openings to outside to allow infiltration, or the combination thereof.
d) It is recommended that makeup air be designed at 85 percent to 95 percent of the exhaust flow rate, not including the leakage through these small paths. The makeup air shall not cause door-opening force to exceed allowable limits. The makeup air velocity shall not exceed 1.02 m/s where the makeup air could come in contact with the plume unless a higher makeup air velocity is supported by engineering analysis.

e) Atrium smoke management system fans shall be provided with emergency power. If so, required by the authority, an engineering analysis should be performed which demonstrates that the smoke system for the atrium is designed to keep the smoke layer interface 1 800 mm above the highest occupied floor level of exit access, open to the atrium, for a period equal to 1.5 times the calculated egress time or 20 min, whichever is greater.

19.4.2 *Commercial Kitchens*

Given below are the requirements for fire separation for commercial kitchens:

a) Where the flue or exhaust duct passes through the compartment wall or floor, the flue or duct shall be encased by non-combustible construction and no damper shall be permitted to be installed in such flue or duct. Also, such flue or ductwork shall be clear from combustible materials.

b) It is advisable to locate the kitchen/cooking operations on the external periphery of the building so that in the event of mechanical ventilation failure, it shall be naturally ventilated.

19.4.2.1 *Exhaust ventilation system*

Following guidelines shall be ensured for proper functioning of exhaust ventilation system for cooking equipment:

a) Provision of cleaning of the kitchen exhaust every six months to ensure that the carbon soot accumulated in the exhaust duct is cleaned to avoid the chances of outbreak of fire shall be made.

b) Independent exhaust ducts shall be provided for equipment using dry fuel like wood/ charcoal which produce spark and are likely to ignite the grease which might have accumulated in the common duct.

c) Alternatively, approved spark arrestors may be provided before the duct from equipment using dry fuel meets the main duct. These spark arrestors shall be so provided that these are easily accessible and removable for cleaning.

19.4.2.2 *Cooking equipment*

Following procedures shall be adopted for handling of cooking equipment:

a) Any penetrations to the outside of a hood, be either welded or fit with a sealing device in accordance to the relevant Indian standard for not allowing cooking grease, oil to migrate to the outer portion of the hood. The fitment arrangements shall be of approved type. Gaskets for the panels shall be certified to withstand a temperature of 815.6°C.

b) Grease strip shall be readily available for efficient and regular cleaning of concrete or paved floors of kitchen and restaurant and also the drainage areas.

c) The hood or that portion of a primary collection means designed for collecting cooking vapours and residues shall be constructed of and be supported by steel not less than 1.09 mm (No. 18 MSG) in thickness or stainless steel not less than 0.94 mm (No. 20 MSG) in thickness or other approved material of equivalent strength and fire and corrosion resistance.

d) All seams, joint, and penetrations of the hood enclosure that direct and capture grease-laden vapours and exhaust gases shall have a liquid tight continuous external weld to the hood's lower outermost perimeter.

e) Grease filters shall be of steel rigid construction that will not distort or crush under normal operation handling and cleaning conditions. They shall be so arranged that all exhaust air passes through the grease filters. Filters shall be easily accessible and removable for periodic cleaning.

f) Grease filters shall be installed at an angle not less than 45° from the horizontal.

g) Grease filters shall be equipped with a grease drip tray beneath their lower edges and shall have a suitable minimum depth needed to collect grease. The grease drip trays shall be pitched to drain into an enclosed metal container having a capacity not exceeding 3.8 litre.

h) The exhaust ducts shall be constructed of and supported by carbon steel not less than 1.37 mm (No. 16 MSG) in thickness or stainless steel not less than 1.09 mm (No. 18 MSG) in thickness.

19.4.2.3 *Rooftop terminations — exhaust systems*

The exhaust system shall terminate either outside the building with a fan or duct or through the roof or to the roof from outside with minimum 3 m of horizontal clearance from the outlet to the adjacent buildings, property lines and air intakes. There shall be a minimum of 1.5 m of horizontal clearance from the outlet (fan housing) to any combustible structure. There shall be a vertical separation of 1.0 m below any exhaust outlets for air intakes within 3.0 m of the exhaust outlet.

19.4.3 *Auditoriums and Cinemas*

Smoke exhaust and pressurization of areas above ground – smoke exhaust system having make-up air and exhaust air system shall also be required for theatres/auditorium.

19.4.4 *Multilevel Car Parking (MLCP) Non-Mechanical*

Open parking structures (including multi-level parking and stilt parking) specifies the degree to which the structure's exterior walls shall have openings. Parking structures that meet the definition of the term open parking structure provide sufficient area in exterior walls to vent the products of combustion to a greater degree than an enclosed parking structure.

A parking structure having each parking level wall openings open to the atmosphere, for an area of not less than 0.4 m^2 for each linear metre of its exterior perimeter shall be construed as open parking structure. Such openings shall be distributed over 40 percent of the building perimeter or uniformly over two opposing sides. Interior wall lines shall be at least 20 percent open, with openings distributed to provide ventilation, else, the structure shall be deemed as enclosed parking structures.

NOTE – A car park located at the stilt level of a building (not open to sky) shall be considered an open or an unenclosed car park if any part of the car park is within 30 m of a permanent natural ventilation opening and any one of the following is complied with towards the permanent natural ventilation requirement: i) 50 percent of the car park perimeter shall be open to permanent natural ventilation. ii) At least 75 percent of the car park perimeter is having the 50 percent natural ventilation opening.

19.4.5 *Multilevel Car Parking Stack/ Mechanical*

For enclosed multilevel car parking structures utilizing stack or mechanical systems, provisions for smoke ventilation should be considered to enhance safety during fire incidents. Smoke ventilation systems may include natural or mechanical ventilation strategies to ensure the rapid removal of smoke and hot gases. Such systems shall comply with the applicable fire safety standards and guidelines, as detailed in Part 4 ‘Fire and Life Safety’ of the Code.

For smoke ventilation requirement of car parking, *refer* **19.1.1.2**

19.5 Aspects of Pressurization (Pascals) Smoke Mitigation

Smoke ventilation systems should be designed in line with the principles of pressurization to manage smoke spread effectively. These include:

a) *Defend in Place (One Door Open)* – Maintaining a pressure differential to protect occupants who remain within the structure.
b) *Phased Evacuation (Three Doors Open)* – Ensuring controlled evacuation by balancing pressurization for multiple door openings.
c) *Firefighting Shaft (Three Doors Open)* – Providing safe access for firefighters with maintained pressure differentials.
d) *Pressure Differential Measurement* – Ensuring pressure is appropriately maintained in staircases, lift lobbies, and lifts.
e) *Door Opening Force Measurement* – Verifying door operation under pressurized conditions to allow safe egress.

19.6 Aspects of Ventilation (ACPH) Smoke Mitigation

Ventilation systems play a crucial role in maintaining occupant safety during fire emergencies by controlling smoke spread and ensuring adequate air changes per hour (ACPH). Proper compartmentalization, isolation of air handling units, and adherence to fire resistance standards for ducts and dampers are essential to prevent smoke infiltration and maintain safe evacuation routes. These units ensure effective fire containment and support emergency response operations.

19.6.1 *Air Handling Unit*

From fire safety point of view, separate air handling units (AHU) for each floor shall be provided so as to avoid the hazards arising from spread of fire and smoke through the air conditioning ducts. The air ducts shall be separate from each AHU to its floor and in no way shall interconnect with the duct of any other floor. Within a floor it would be desirable to have separate air handling unit provided for each compartment. Air handling unit shall be provided with effective means for preventing circulation of smoke through the system in the case of a fire in air filters or from other sources drawn into the system and shall have smoke sensitive devices for actuation in accordance with best practices.

Shafts or ducts, if penetrating multiple floors, shall be of masonry construction with fire damper in connecting ductwork or shall have fire rated ductwork with fire dampers at floor crossing. Alternatively, the duct and equipment should be installed in room having walls, doors and fire damper in duct exiting/entering the room of 120 minutes fire resistance rating. Such shafts and ducts shall have all passive fire control meeting 120 minutes fire resistance rating requirement to meet the objective of isolation of the floor from spread of fire to upper and lower floors through shaft/duct work.

NOTES

1 Zoned and compartmented HVAC systems are encouraged with an approach to avoid common exhaust shafts and fresh air intake shafts which will limit the requirement of such passive measure and fire rated duct work and dampers.

2 The air filters of the air handling units shall be made of non-combustible materials.

3 The air handling unit room shall not be used for storage of any combustible materials.

19.6.2 *Duct Work*

Air ducts serving main floor areas, corridors, etc, shall not pass through the exits/exit passageway/ exit enclosure. Exits and lift lobbies, etc, shall not be used as return air passage.

As far as possible, metallic ducts shall be used even for the return air instead of space above the false ceiling.

Wherever the ducts pass through fire walls or floors, the opening around the ducts shall be sealed with materials having fire resistance rating of the compartment. Such duct shall also be provided with fire dampers at all fire walls and floors unless such ducts are required to perform for fire safety operation; and in such case fire damper may be avoided at fire wall and floor while integrity of the duct shall be maintained with 120 minutes fire resistance rating to allow the emergency operations for fire safety requirements.

The ducting within compartment would require minimum fire resistance rating of 30 minutes. If such duct crosses adjacent compartment/floor and not having fire dampers in such compartment/floor, it shall require fire resistance duct work rating of 120 minutes. The requirements of support of the duct shall meet its functional time requirement as above.

The materials used for insulating the duct system (inside or outside) shall be of non-combustible type. Any such insulating material shall not be wrapped or secured by any material of combustible nature.

Inspection panels shall be provided in the ductwork to facilitate the cleaning accumulated dust in ducts and to obtain access for maintenance of fire dampers.

19.6.3 *Fire or Fire/Smoke Dampers*

These dampers shall be evaluated to be located in supply air ducts, fresh air and return air ducts/ passages at the following points:

a) At the fire separation wall,
b) Where ducts/passages enter the vertical shaft,
c) Where the ducts pass through floors, and
d) At the inlet of supply air duct and the return air duct of each compartment on every floor.

Damper shall be so installed to provide complete integrity of the compartment with all passive fire protection sealing. Damper should be accessible to maintain, test and also replace, if so required. Damper shall be integrated with fire alarm panel and shall be sequenced to operate as per requirement and have interlocking arrangement for fire safety of the building. Manual operation facilities for damper operation shall also be provided.

19.6.4 *Glass Facade*

Openable panels shall be provided on each floor and shall be spaced not more than 10 m apart measured along the external wall from centre-to-centre of the access openings. Such openings shall be operable at a height between 1.2 m and 1.5 m from the floor and shall be in the form of openable panels (fire access panels) of size not less than 1 000 mm × 1 000 mm opening outwards. The wordings, 'FIRE OPENABLE PANEL — OPEN IN CASE OF FIRE, DO NOT OBSTRUCT' of minimum 25 mm letter height shall be marked on the internal side. Such panels shall be suitably distributed on each floor based on occupant concentration. These shall not be limited to cubicle areas and shall be also located in common areas/corridors to facilitate access by the building occupants and fire personnel for smoke exhaust in times of distress.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfillment of the requirements of the Code. The latest version of a standard shall be adopted at the time of enforcement of the Code. The standards listed may be used by the Authority as a guide in conformance with the requirements of the referred clauses in the Code.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section of the Code.

	IS No.	*Title*
(1)	3615 : 2024	Glossary of terms used in refrigeration and air conditioning (*third revision*)
(2)	655:2006	Air ducts — Specification (*second revision*)
(3)	737:2008	Wrought aluminium and aluminium alloy sheet and strip for general engineering purposes - Specification (*fourth revision*)
(4)	1391 (Part 1) : 2023	Room Air Conditioners Specification Part 1 Unitary Air Conditioners (*fourth revision*)
(5)	1391 (Part 2) : 2023	Room Air Conditioners Specification Part 2 Split Air Conditioners (*fourth revision)*
(6)	8148 : 2018	Specification for packaged air conditioners (*second revision*)
(7)	3315 : 2024	Direct Evaporative Air Cooler - Specification (*fourth revision*)
(8)	661:2019	Thermal insulation of cold storage - Code of practice (*fourth revision*)
(9)	16656 : 2017 ISO 817 : 2014	Refrigerants - Designation and safety classification
(10)	60335-2-40 : 2018 IEC 60335-2-40	Household and similar electrical appliances – safety Part 2-40 Particular requirements for electrical heat pumps air-conditioners and dehumidifiers
(11)	60335-2-89 : 2010 IEC 60335-2-89 : 2010	Household and similar electrical appliances - Safety Part 2 - 89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor

(12)	16678 (Part 1) : 2018 ISO 5149-1 : 2014	Refrigerating Systems and Heat Pumps Safety and Environmental Requirements Part 1 Definitions, Classification and Selection Criteria
(13)	16678 (Part 2) : 2018 ISO 5149-2 : 2014	Refrigerating systems and heat pumps - Safety and environmental requirements: Part 2 design, construction, testing, marking and documentation
(14)	16678 (Part 3) : 2018 ISO 5149-3 : 2014	Refrigerating systems and heat pumps - Safety and environmental requirements: Part 3 installation site
(15)	16678 (Part 4) : 2024 ISO 5149-4 : 2022	Refrigerating Systems and Heat Pumps - Safety and Environmental Requirements Part 4 Operation, Maintenance, Repair and Recovery (*first revision*)
(16)	17570 (Part 1) : 2021 ISO 16890-1:2016	Air Filters for general ventilation Part 1 Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)
(17)	17570 (Part 2) : 2021	Air Filters for general ventilation Part 2 Measurement of fractional efficiency and air flow resistance (ISO 16890-2 : 2016, MOD)
(18)	17570 (Part 3) : 2021 ISO 16890-3:2016	Air Filters for general ventilation Part 3 Determination of the gravimetric efficiency and the air flow resistance versus the mass of test dust captured
(19)	17570 (Part 4) : 2021 ISO 16890-4:2016	Air Filters for general ventilation Part 4 Conditioning method to determine the minimum fractional test efficiency
(20)	16753 (Part 1) : 2022 ISO 29463-1 : 2017	High Efficiency Filters and Filter Media for removing Particles from Air Part 1 Classification, Performance, Testing and Marking (*first revision*)
(21)	16753 (Part 2) : 2018 ISO 29463-2 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 2 aerosol production, measuring equipment and particle - Counting statistics
(22)	16753 (Part 3) : 2018 ISO 29463-3 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 3 testing flat sheet filter media
(23)	16753 (Part 4) : 2018 ISO 29463-4 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 4 testing method for determining leakage of filter elements - Scan method
(24)	16753 (Part 5) : 2024 /ISO 29463-5	High-Efficiency Filters and Filter Media for Removing Particles in Air Part 5 Test Method for Filter Elements (*first revision*)

(25)	18794 : 2024	Air Handling Units - Specification
(26)	12615 : 2018	Line Operated Three Phase a.c. Motors (IE CODE) "Efficiency Classes and Performance Specification" (*third revision*)
(27)	13204 : 2024	Rigid Phenolic Foam for Thermal Insulation – Specification (*first revision*)
(28)	16590 : 2023	Liquid Chilling Package Units - Specification (*first revision*)
(29)	18728 : 2024	Multiple split-system air conditioners and air-to-air heat pumps (VRF air conditioners) – Specification
(30)	1893 (Part 1) : 2016	Criteria for Earthquake Resistant Design of Structures - Part 1 : General Provisions and Buildings (*sixth revision*)
(31)	3043 : 2018	Code of practice for earthing (*second revision*)
(32)	732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(33)	1255 : 1983	Code of practice for installation and maintenance of power cables up to and including 33 kV rating (*second revision*)
(34)	13301 : 1992	Vibration isolation for machine foundations – Guidelines
(35)	4759 : 1996	Hot - Dip zinc coatings on structural steel and other allied products - Specification (*third revision*)
(36)	10234 : 1982	Recommendations for general pipeline welding
(37)	2075 : 2017	Ready mixed paint, stoving, red oxide zinc chrome, priming - Specification (*third revision*)
(38)	15652 : 2006 IEC 61111	Insulating mats for electrical purposes – Specification
(39)	3614 : 2021	Fire Doors and Doorsets - Specification (*first revision*)
(40)	61439-1 : 2020 IEC 61439-1:2020	Low-voltage switchgear and controlgear assemblies Part 1: General rules (*first revision*)
(41)	3601 : 2006	Steel tubes for mechanical and general engineering purposes - Specification (*second revision*)
(42)	17025 : 2017 ISO/IEC 17025:2017	General requirements for the competence of testing and calibration laboratories (*second revision*)

(43)	IS/IEC 60529 : 2001	Degrees of protection provided by enclosures (IP Code)
(44)	8188 : 1999	Treatment of Water for Cooling Towers - Code of Practice (*first revision*)
(45)	IS/IEC 62305-4 : 2010	Protection against lightning – Part 4 Electrical and electronic systems within structures
(46)	SP 30 : 2023	National Electrical Code of India 2023 (*second revision*)
(47)	5610 : 2025	Refrigerants — Specification (*third revision*)

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