دائرة الطاقة
DEPARTMENT OF ENERGY

COOLING LOAD MANUAL FOR THE EMIRATE OF ABU DHABI

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Changes History Sheet

Version	PAGE NO.	SUMMARY OF CHANGE	NEW EFFECTIVE DATE
Original Version (DoE_PR_P04_001)	All	N/A	May 2026

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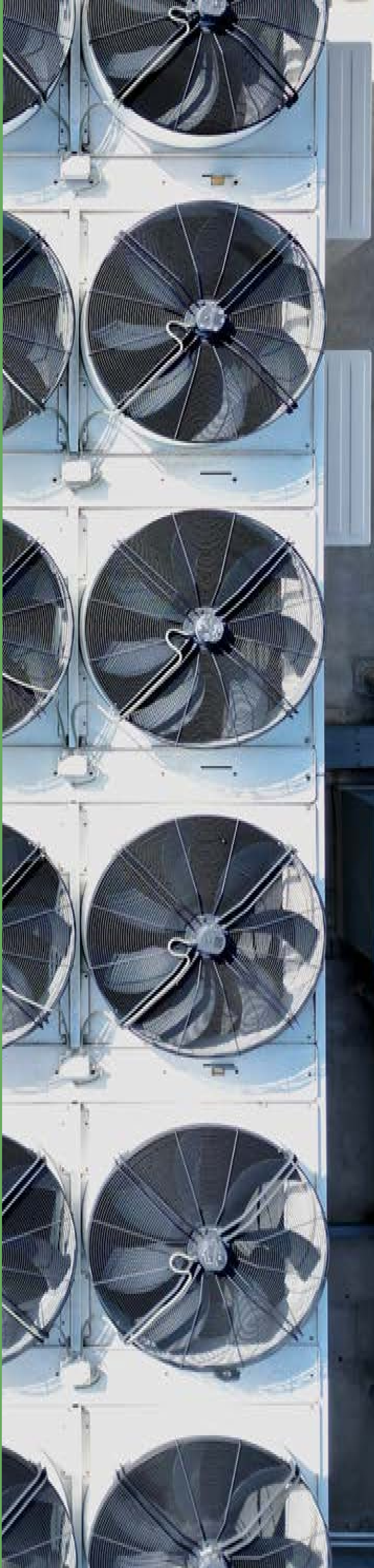
FOREWORD

The development of the Cooling Load Manual (CLM) for the Emirate of Abu Dhabi marks a significant milestone in the pursuit of energy efficiency and sustainability within the built environment of the emirate. As the global climate continues to change and energy demands rise, the need for accurate, data-driven cooling load calculations has never been more critical. Air conditioning (AC) systems are the largest energy consumers in Abu Dhabi buildings, so their proper sizing is essential to reduce capital costs of equipment and infrastructure, optimise energy use and operational costs, and enhance overall system performance.

The CLM has been carefully crafted in response to these challenges, drawing on best practices from international standards, while incorporating the unique conditions and requirements of the Emirate of Abu Dhabi. It offers developers, building owners and practitioners in the fields of engineering, architecture, and construction a set of recommendations to follow for accurately calculating cooling loads while ensuring their AC systems are sized correctly. The CLM also illustrates the consequences of using inaccurate assumptions and diversity factors during the AC design process and emphasizes the risks associated with inaccurate adjustments or the omission of critical inputs in load calculations.

In addition to the manual itself, a Cooling Load Verification Tool (CLVT) has been developed to enable users to benchmark their own cooling load calculations against calculations made following the CLM recommendations.

Nonetheless, the CLM, supported by the CLVT, does not introduce a new method for cooling load calculations, replace established techniques, or provide step-by-step instructions for conducting these calculations. Instead, it promotes best practices for rightsizing AC equipment that, when followed, will help to resolve the widespread issue of AC oversizing. The CLM also provides a comprehensive solution for practitioners and government officials to verify cooling loads for new and existing buildings against best practices, thus promoting consistency and reliability across projects.



ABBREVIATIONS AND ACRONYMS

AC	Air Conditioning
ACH	Air changes per hour measured in (m^3/h)
AD	Abu Dhabi
AGW	Above Grade Walls
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BR	Bedroom
CBE	Centre Built Environment of University of California Berkeley
CD	Concept Design
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
CLM	Cooling Load Manual
CLVT	Cooling Load Verification Tool
CO_2	Carbon dioxide
COANDA	Coandă Effect (tendency of a fluid jet to stay attached to a surface)
DBT	Dry Bulb Temperature (measured in °C)
DC	District Cooling
DCP	District Cooling Plant
DCV	Demand Controlled Ventilation
DD	Detailed Design
DISCOs	Distribution Companies (utility providers)
DMT	Department of Municipalities and Transport – Abu Dhabi
DoE	Department of Energy – Abu Dhabi
DSM	Demand Side Management
ERV	Energy Recovery Ventilator
FAHU	Fresh Air Handling Unit
FCU	Fan Coil Unit
GI	Galvanised Iron
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality

ABBREVIATIONS AND ACRONYMS

IESVE	Integrated Environmental Solutions Virtual Environment (a software used for cooling load calculations)
LPD	Lighting Power Density (measured in W/m^2)
MAHU	Make-up Air Handling Unit
MEP	Mechanical, Electrical, and Plumbing
R-value	Thermal Resistance measure of a material's resistance to heat flow ($m^2 \cdot K/W$)
SHGC	Solar Heat Gain Coefficient
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
U-Value	Thermal transmittance, indicating how well a building element conducts heat (measured in W/m^2K)
VOCs	Volatile Organic Compounds
WBT	Wet Bulb Temperature (measured in °C)
WWR	Window-to-wall ratio

UNITS

°C	Degree Celsius (unit of temperature)
ΔT	Delta T (Temperature Difference)
fpm	Feet per Minute (unit of air velocity)
K	Kelvin (unit of temperature)
kW	Kilowatt (unit of power)
L	Litre (unit of volume)
L/s	Litre per Second (unit of airflow rate)
$L/s.m^2$	Litre per Second per Square Meter (unit of air flow per area)
m/s	Meters per Second (unit of velocity)
m^3/h	Cubic Meters per Hour (unit of airflow rate)
$m^2 \cdot K/W$	Square Meter Kelvin per Watt (unit of thermal resistance)
NE	North-East (direction)
NW	North-West (direction)
Pa	Pascal (unit of pressure)
PM	Particulate Matter

UNITS

SE	South-East (direction)
SW	South-West (direction)
W/m²K	Watt per Square Meter Kelvin (unit of heat transfer coefficient)

LEGEND

In this manual, a combination of mandatory (standards) and recommended (guidelines) statements are used. They are intended to ensure minimum standards are maintained as well as to allow interpretation by HVAC system designers.

The statements are defined using the following language:

- SHALL and SHALL NOT are mandatory statements
- SHOULD and SHOULD NOT are recommended or expected statements
- CAN and CANNOT refer to physical or technical capability and do not imply obligation
- MAY and MAY NOT refer to a possibility or permitted statements

In addition, the following formatting conventions are used:

- **Text in green boxes are recommendations that designers should consider during the project. For example:**

RECOMMENDATION TO DESIGNERS

Ambient design conditions should not deviate from the prescribed values based on arbitrary personal judgment, preference, or client instruction or request.

- **Text in light blue boxes are highlighted extracts from selected guidelines and regulations. For example:**

> “The air conditioning and ventilation systems should be designed such that the building is maintained at a positive pressure.”
>
> CIBSE Design Guide for Abu Dhabi

- **Text in beige boxes are worked-out examples, e.g. calculations, for illustrative purposes. For example:**

EXAMPLE

In an office building with a total floor area for office spaces of 10,000 m^2, if the LPD is assumed to be 10 W/m^2 based on a general rule but the actual design constitutes only 6 W/m^2, the resulting overestimation significantly impacts the cooling load:

Assumed Lighting Heat Gain=(10,000×10)/1,000=100 kW

Actual Lighting Heat Gain=(10,000×6)/1,000=60 kW

Overestimated Cooling Load Due to Lighting=100–60=40 kW (i.e., 66% overdesign)

This unnecessary 40 kW increase in cooling load would lead to oversized HVAC equipment, higher capital costs, and inefficient energy performance. To prevent this, cooling load calculations should be based on actual lighting design, include all relevant fixtures, and avoid arbitrary LPD assumptions.

1. Introduction

In support of the Abu Dhabi Energy and Water Efficiency Strategy 2030 (DSM Strategy 2030), the Department of Energy (DoE) in collaboration with the Abu Dhabi Department of Municipalities and Transport (DMT) developed the Cooling Load Manual (CLM) for the Emirate of Abu Dhabi. The CLM aims to address the widespread issue of oversized heating, ventilation and air conditioning (HVAC) systems and its associated inefficiencies caused by the improper design of the cooling equipment.

The CLM provides practitioners with a cost-effective, practical and streamlined approach to accurately calculate cooling loads and rightsize cooling systems for new buildings, ultimately reducing capital and operational costs associated with HVAC systems. This is beneficial for developers, investors, building owners, operators and end users, as it allows design flexibility and optimised resource allocation that encourages market competitiveness, enables energy savings without reducing comfort as well as longer lifespans and reduced maintenance costs of the HVAC equipment. Finally, it is also beneficial for the government and the wider society, as it encourages resource conservation, and minimises infrastructure strain and environmental impact as shown in Figure 1.

Developers & Investors

Market Competitiveness

Adequately sized HVAC systems enable developers to strategically position their projects as both environmentally responsible and economically sustainable. This strategy can augment the development's marketability, attracting stakeholders who prioritise sustainability and cost-effectiveness in their investment considerations.

Design Flexibility

Adequately sized HVAC systems allow flexibility in architectural design and spatial utilisation. This enables more innovative architectural strategies and optimised use of available space.

Optimised Resource Allocation

The selection of appropriately dimensioned HVAC systems allows developers to allocate resources with greater efficiency across various project components. By avoiding the purchase of oversized equipment, developers can redirect investment to other crucial areas, such as enhanced construction materials, integration of advanced technologies, or supplementary amenities, which can collectively amplify the overall value and appeal of the development.

Building Owners, Operators & End-users

Energy Savings

Optimally dimensioned HVAC systems enhance operational efficiency, resulting in decreased energy expenditure and subsequent reductions in utility costs over the long term.

Enhanced Comfort

Installation of excessively large units may induce short-cycling, i.e. fast on and off switching, which in turn can cause inconsistent temperature distribution and humidity control discrepancies, thereby adversely impacting occupant comfort levels.

Longer Life span and Reduced Maintenance Costs

Systems with oversized capacity for the designated space suffer accelerated wear due to frequent on-off cycling, resulting in elevated maintenance and repair expenditures.

Government & Wider Society

Resource Conservation

Avoiding oversized equipment contributes to resource conservation through the reduction of demand for raw materials and energy expended in the manufacturing and operation of larger systems.

Infrastructure Strain

The utilisation of appropriately sized systems minimises the need for additional associated electricity infrastructure necessary for powering them and alleviates the strain on the existing electrical grid, thereby contributing to enhanced energy security and stability within the community.

Environmental Impact

Correctly-sized HVAC systems typically consume less energy than oversized units and therefore have lower carbon footprints.

Figure 1. CLM benefits for multiple stakeholders

The CLM is complemented by an excel based Cooling Load Verification Tool (CLVT) to help practitioners and officials to optimise and verify the building cooling loads for multiple building typologies.

Designers shall size HVAC equipment by creating models in appropriate simulation software (as per Appendix 1: Simulation Software Requirements). During the design process, design teams are encouraged to apply the principles outlined in the CLM to help reduce the required HVAC capacity. The CLVT can be used to benchmark the proposed HVAC sizing. Designers should input key parameters into the CLVT, including building envelope areas and thermal characteristics, infiltration rates, internal loads from lighting, equipment, and occupancy, among others. Additionally, model outputs such as diversified peak loads, redundancy margins, safety factors, and total cooling plant capacity should also be entered. The CLVT will then generate a benchmark cooling load based on the inputs and highlight discrepancies, helping to identify potential overdesign issues. If the design value exceeds ±10% of the benchmark generated by the CLVT, the designer shall provide a clear justification, along with supporting documentation, if necessary, to explain the deviation.

1.1. Scope

The CLM is applicable to new developments within the Emirate of Abu Dhabi and outlines principles that can be adopted from the Concept Design (CD) stage through to 100% Detailed Design (DD). These principles support accurate thermal load estimation, effective control strategies, occupant comfort, and appropriate sizing of standalone HVAC systems.

The accompanying CLVT, however, is limited to the following specific building types that collectively account for the majority of the Emirate's cooling load:

- Offices
- Mosques
- Hotels
- Schools
- Retail
- Restaurants
- Multi-residential
- Villas

The main exclusions include buildings such as data centres, manufacturing facilities, theme parks, exhibition centres, hospitals and other similar facility types. These are not included because their cooling loads are highly variable and dependent on unique design requirements such as high ventilation rates, process-driven internal gains, or low indoor temperature setpoints that differ significantly from those of typical commercial or residential buildings. As a result, a standardized tool or methodology would not accurately reflect their performance, and they require bespoke modelling approaches tailored to their specific functions.

The CLVT is not intended for projects served by District Cooling Plant (DCP).

2. Environmental Design Conditions

The climate of Abu Dhabi, characterized by high temperatures and humidity, directly influences the performance and energy efficiency of HVAC systems. Understanding these regional temperatures is essential for designing systems that maintain comfort and indoor air quality (IAQ) while minimizing energy consumption. Figure 2 below presents a psychrometric chart overlaid with data points representing Abu Dhabi's ambient weather conditions, sourced from the latest typical meteorological year (TMY) file. The coloured bands indicate thermal comfort categories based on ASHRAE 55: green denotes the most preferred and optimal comfort conditions, blue represents acceptable comfort conditions, and grey reflects periods considered thermally uncomfortable.

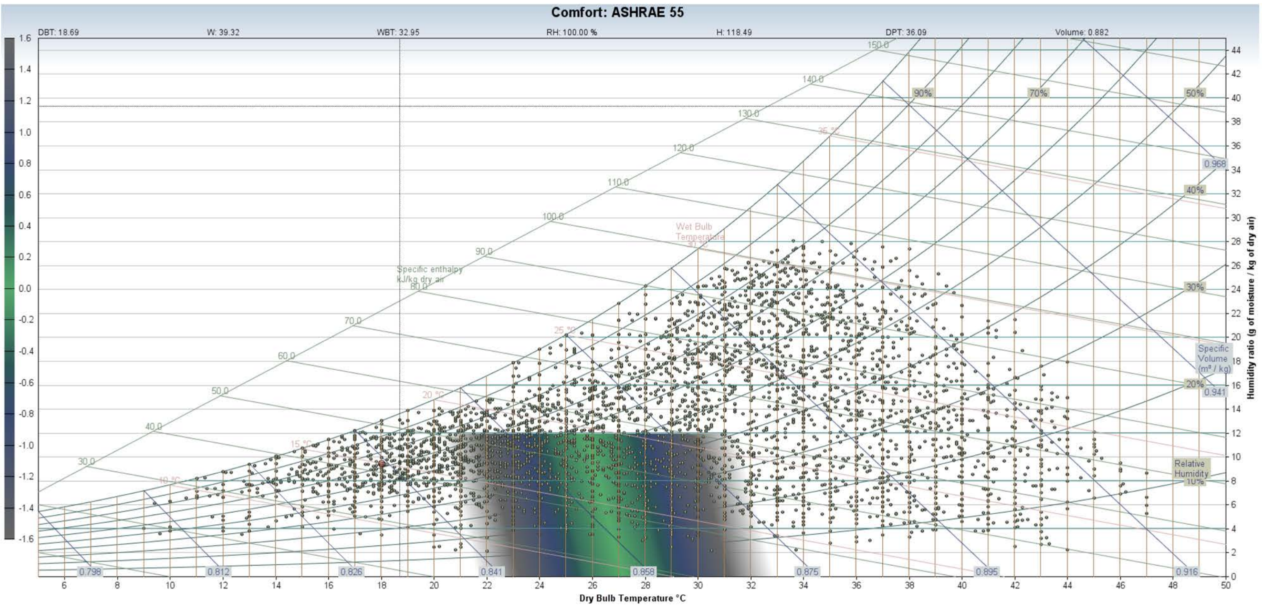


Figure 2. Regional Abu Dhabi City Temperature Comfort Zone Illustration

2.1. Cooling Load Ambient Design Conditions

When calculating the cooling load for a building, the largest contributor is typically the external gain, i.e. heat that enters the building through the envelope (such as walls, windows, and the roof) from the outside environment. This is primarily associated with the sensible heat load, which is directly influenced by the dry bulb temperature (DBT). Therefore, peak DBT conditions at the building location are used to determine the amount of sensible heat gain entering the building.

The outdoor design conditions for Abu Dhabi City or Al Ain City, as specified in Table 1, shall be used when calculating the heat gains through the building envelope of projects located there. These two locations can also be used by projects respectively in other coastal and inland areas of the emirate of Abu Dhabi considering the adjustments mentioned in Section 2.2 below. ASHRAE 169-2021 (Climatic Data for Building Design standard) determined Abu Dhabi's climate zone as 0B and the 2021 ASHRAE Handbook Fundamentals (Chapter 14 Climatic Design) determine the outdoor design condition of DBT corresponding to 0.4%, 1%, and 2% annual cumulative frequency of occurrence (warm conditions). In the Abu Dhabi International Energy Conservation Code (ADIECC) the Abu Dhabi climate zone is 1.

In alignment with both local and international best practices, it is recommended to adopt the 0.4% design condition to ensure that the building's thermal performance is assessed against more extreme, but credible, peak load conditions. Considering the global trend of rising temperatures, using the 0.4% design condition provides an additional safety margin, mitigating to a certain extent the risk of system underperformance or discomfort in the future due to increased ambient temperatures.

This approach enhances the precision of equipment sizing and bolsters the building's adaptability to projected climate change scenarios. In this regard, the example in Section 7.4 illustrates the impact of using higher than standard outdoor design temperatures on cooling system sizing that result in oversized equipment.

Table 1. Ambient Design Conditions for Heat Gain Calculations – Abu Dhabi

Parameter	**Abu Dhabi City** (Representative of Coastal area)	**Al Ain City** (Representative of Inland area)	**Reference**
Climate Zone	0B / 1	0B / 1	ASHRAE 169-2021 / ADIECC
Dry Bulb Temperature	46.1°C	48.8°C	ADIECC
Wet Bulb Temperature	29.4°C	28.3°C	ADIECC
Latitude	24.433°N	24.262°N	2021 ASHRAE Handbook – Fundamentals
Longitude	54.651°E	54.609°E	2021 ASHRAE Handbook – Fundamentals
Elevation	27 m	265 m	2021 ASHRAE Handbook – Fundamentals

RECOMMENDATION TO DESIGNERS

Ambient design conditions should not deviate from the prescribed values based on arbitrary personal judgment, preference, or client instruction or request.

2.2. Ventilation Load Ambient Design Conditions

For ventilation load calculations, which involve determining the amount of outdoor air required to maintain good IAQ, the focus shifts towards controlling both temperature and humidity. A significant portion of the cooling load is often dedicated to removing moisture from the outdoor air, particularly in humid areas. This refers to the energy required to remove moisture from the air to control humidity levels inside the building which is typically treated using Fresh Air Handling Units (FAHUs), Make-up Air Handling Units (MAHUs), and Energy Recovery Ventilators (ERVs). Since humidity is closely tied to wet bulb temperature (WBT), it is the peak WBT that dictates the potential latent heat load of the outdoor air, not the DBT. The outdoor design conditions for Abu Dhabi city and Al Ain city as provided in Table 2 shall be considered for calculating the ventilation load.

Table 2. Ambient Air Design Conditions for Ventilation Systems Calculations – Abu Dhabi

Parameter	**Abu Dhabi City** (Representative of Coastal areas)	**Al Ain City** (Representative of Inland areas)	**Reference**
Dry Bulb Temperature	35.3°C	35.8°C	2021 ASHRAE Handbook – Fundamentals
Wet Bulb Temperature	30.6°C	28.8°C	2021 ASHRAE Handbook – Fundamentals

Regional climatic variations, i.e. different DBT and WBT, exist within other areas of the Abu Dhabi emirate, e.g. Liwa, Madinat Zayed, etc., however, the CLVT ambient design conditions are calibrated for Abu Dhabi and Al Ain City only and will not be as accurate elsewhere. For those other locations, designers can still follow the principles mentioned in this CLM and shall adjust their models to their specific location and consider the guidance of the following three points in this section. This can be done within the CLVT by adding an extra load in the "Other Loads" worksheet.

If untreated fresh air is supplied to a space or multiple spaces, the system load shall be calculated for both design conditions (peak ambient sensible and peak ambient latent). The higher of the two results shall be used for HVAC system design at the space level, while diversified load shall be applied for building-level system design.

1. Adjustment Requirement

Projects located outside the Abu Dhabi and Al Ain cities shall adjust their design cooling conditions (DBT and WBT) appropriately to reflect local microclimates. These adjusted values shall be used consistently across:

- Envelope heat gain calculations
- Ventilation (latent/sensible) loads
- HVAC system and coil sizing
- Simulation weather file selection

2. Approved Data Sources

Designers shall base their regional adjustments on one of the following:

- ASHRAE Handbook—Fundamentals, Chapter 14: Climatic Design Conditions (latest edition)
- UAE National Meteorological Data, when publicly available or officially issued

3. Design Documentation

Designers shall retain documentation of their adjustments, e.g. design ambient DBT and WBT conditions used, and supporting data, e.g. weather file source, percentile used, etc. for future reference.

3. Indoor Design Conditions

Indoor design conditions such as temperature, relative humidity, and air speed are fundamentally linked to the thermal comfort of buildings occupants that is also influenced by clothing, activity levels, age, and gender. Consequently, indoor design parameters are established to ensure acceptable thermal comfort for 80% of the occupants within a given space, following the ASHRAE 55-2023, Thermal Environmental Conditions for Human Occupancy, recommendation. Variations of these indoor design conditions, but also poor system zoning and controls may result in oversized HVAC equipment and increased energy consumption.

RECOMMENDATION TO DESIGNERS

Designers should use advanced thermal comfort analysis tools, for example CBE Thermal Comfort Tool, which is also endorsed by several green building certification systems, to justify that indoor spaces are neither undercooled nor overcooled. These tools account for key influencing factors such as clothing insulation, occupant activity, space function, and design conditions, and help ensure conditions fall within the acceptable comfort range defined by ASHRAE 55-2023.

3.1. Thermal Comfort

Maintaining thermal comfort within air-conditioned spaces requires control of DBT, humidity, radiant temperature and air velocity. The ADIECC and ASHRAE Standard 55-2023 establish specific combinations of DBT and relative humidity, inclusive of defined air movement parameters, that are designed to provide acceptable thermal comfort for 80% of occupants within a given space.

Having uniform temperature, humidity, and air velocity for all occupants within a building is not practically feasible. Furthermore, human thermoregulation involves heat dissipation, with the proportion of sensible and latent heat varying according to activity level and ambient conditions. For instance, based on the 2021 ASHRAE Handbook—Fundamentals, during a state of rest, the human body dissipates approximately 130 W, predominantly as sensible heat. Conversely, during exercise, this energy dissipation increases up to 580 W, with a higher fraction of latent heat, particularly through perspiration when the surrounding temperature surpasses that of the skin.

Therefore, designers are advised to design HVAC systems capable of providing thermal comfort to building occupants by carefully considering the intended space usage as well as occupants' activities and clothing levels.

3.2. Zoning

Integrating internal and external spaces under a single cooling system will result in temperature variations throughout the day, even within a unified open area. The discrepancy arises from differing load profiles. Internal spaces are predominantly affected by internal heat gains, while external spaces experience the influence of both solar and internal heat gains, as illustrated in Figure 3 and Figure 4.

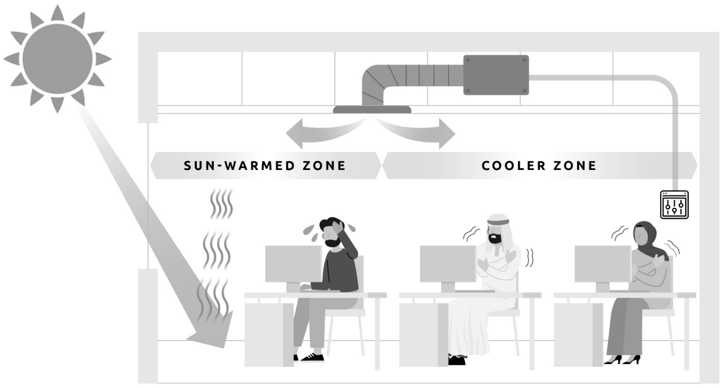


Figure 3. Incorrect Zoning Can cause Discomfort, Overcooling, and Energy Waste

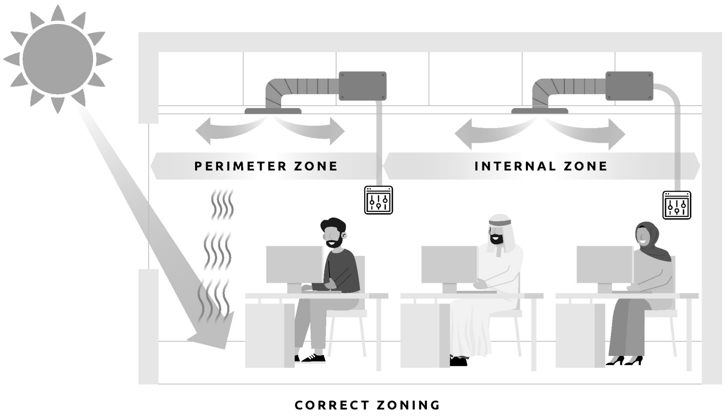


Figure 4. Correct Zoning Can Make Comfortable Conditions and Fewer Complaints

Table 3. Comparison of Incorrect (Figure 3) and Correct (Figure 4) Zoning Strategies

Figure 3: Incorrect Zoning	Figure 4: Correct Zoning
A single supply duct and thermostat are located in a central, typically cooler interior zone.	Two separate HVAC zones are provided: one for the sun-exposed perimeter and one for the interior core.
Thermostats controls the temperature based on core zone condition, resulting in poor representation of perimeter loads.	Each zone is equipped with its own thermostat or local controller, e.g. variable air volume box or fan coil unit (FCU), responding accurately to the respective loads.
Overheating occurs in sun-exposed zones, while overcooling occurs in the core. Thermal comfort is compromised for many occupants.	Improved comfort across all zones, with temperature regulated according to each area's exposure and occupancy.
A single temperature sensor located in a central area at the back wall, not reflective of varied conditions across the space.	Separate temperature readings are visible in the perimeter zone and in the core zone, allowing for accurate and responsive control in each zone.
Higher incidence of thermal complaints from occupants in different parts of the space.	Fewer comfort complaints due to balanced temperature distribution and localized control.

To ensure thermal comfort, designers can implement the following measures:

- Install discrete temperature control systems in each room and ensure the temperature sensors are correctly located.
- Stipulate multi-zone controls for open spaces that exceed 40 m^2, particularly those with varied façade orientations.
- Deploy independent temperature control systems within the perimeter zones of open spaces or expansive rooms, surpassing a depth of 5 m (see Figure 4).
- Subdivide double-height spaces featuring extensive façades, such as entrances, into zones to ensure dedicated temperature control for the area adjacent to the large glazing.

3.2.1. Temperature Control

The utilisation of ON-OFF control for HVAC equipment is prevalent within the region, primarily attributable to its economic efficiency and simplified maintenance requirements. Nevertheless, this control method incorporates a differential, commonly referred to as a dead band, to regulate equipment operation. This differential results in a deviation of the room temperature, oscillating above or below the established setpoint, defined as the user's desired temperature, by approximately 0.5–1.0°C. Consequently, such temperature variations may lead occupants to lower the thermostat setpoint to pre-emptively ensure the actual temperature does not surpass their desired limit, resulting in energy wastage.

A modulating control system will regulate the supply air temperature to correspond with the room load and maintain the room temperature proximate to the set point. Given that most end users will select a set point closely aligned with the design temperature, enhanced occupant comfort and energy conservation will be achieved as illustrated in Figure 5.

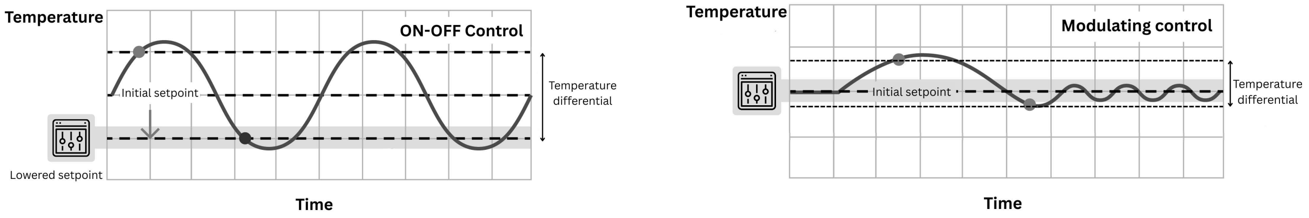


Figure 5. ON-OFF vs Modulating Control

RECOMMENDATION TO DESIGNERS

All new and retrofitted HVAC systems should be equipped with modulating controls and ON-OFF control mechanisms should be avoided except in applications where continuous modulation is not technically or economically feasible.

3.2.2. Air Movement

Proper air distribution is crucial for thermal comfort. Ineffective systems cause drafts and stagnant zones, requiring varied temperatures for occupant comfort. A uniform air velocity within the range of 0.1 to 0.25 m/s within the occupied zone is considered optimal. Velocities below 0.05 m/s may result in air stagnation, whereas velocities exceeding 0.25 m/s may lead to drafts.

Consequently, the selection of air outlets should prioritize the distribution of air throughout the entire room, but ensuring a terminal velocity of 0.25 m/s only occurs above the occupied zone, as illustrated in Figure 6.

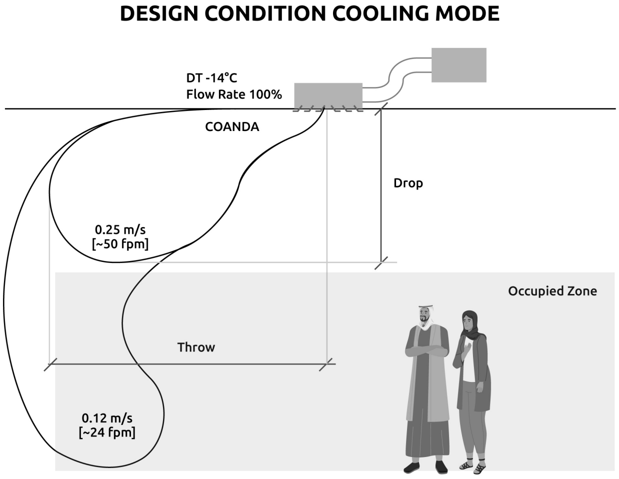
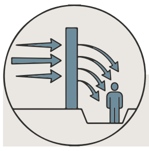


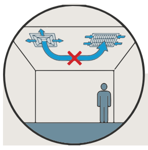
Figure 6. Air Distribution in Occupied Zone

The placement and configuration of air outlets are sometimes subject to constraints imposed by aesthetic considerations or other limitations. Designers should adhere to the aforementioned principles and maintain close collaboration to eliminate the occurrence of the following deficiencies:



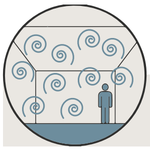
Overthrow

The impingement of airstreams upon opposing walls or ceiling obstructions within their designated projection distance, resulting in the deflection of air downwards into the occupied zone.



Short-circuiting

The direct projection of supply air outlets toward return air outlets, thereby prematurely redirecting airflow and negating its intended function.



Areas of stagnation

Occupied spaces characterised by inadequate air movement resulting on stagnation.

4. Building Geometry

This section outlines the importance of building orientation and geometry in energy modelling and explains the approaches to thermal load calculation, starting from a "Block Load" approach to a more detailed "Thermal Zoning". The CLVT can be used to analyse the impact of different building geometries, by inputting the relevant data in the "building envelope" and "other load" worksheets.

4.1. Orientation

Orientation plays a critical role in determining the amount and timing of solar radiation received on different façades, which directly influences solar heat gains and, consequently, the overall cooling load.

Designers should consider building orientation during the design stage and accurately represent it. Incorrect orientation inputs can lead to inaccurate results, potentially under sizing or oversizing HVAC systems. Careful alignment with the actual site layout ensures reliable and realistic load estimations.

4.2. Approaches to Load Representation

Thermal zoning is the process of dividing a building into multiple thermal zones, each with distinct characteristics and load profiles. Zoning is essential to accurately represent internal and external loads, occupancy patterns, system distribution, and solar exposures. Proper thermal zoning enables more realistic simulations and ensures that HVAC systems are appropriately sized for both diversity and simultaneous demand.

Zones are typically defined based on the following criteria:

- Space function and occupancy, e.g., offices, corridors, server rooms.
- Orientation and solar exposure.
- Internal heat gains from equipment and lighting.
- Operating hours and HVAC control schedules.
- HVAC system layout and ductwork routing.

Thermal zoning enhances load calculation accuracy, improves system design decisions, and supports better load balancing across the HVAC network. An example of thermal zoning showing comparison between block load and thermal zoning is shown in Figure 7 below:

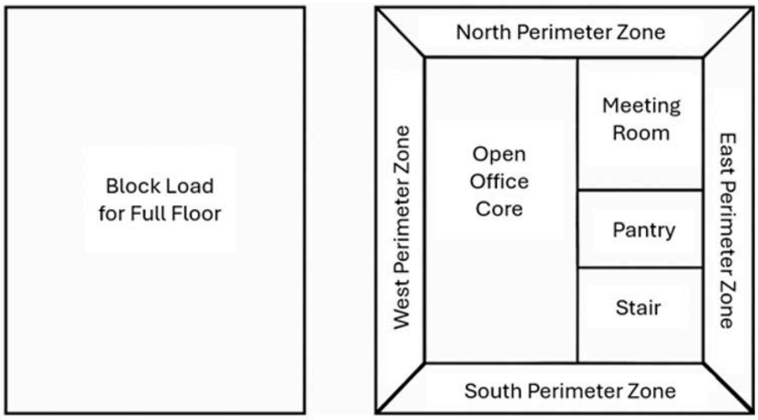


Figure 7. Different Zoning Methodologies – Block Load (Left) and Individual Thermal Blocks (Right)

4.2.1. Block Load Approach

The Block Load method considers the entire building, or large sections of it, as a single thermal entity to calculate the peak cooling load. This method is typically used in the early design stages (e.g. CD) when limited information is available or for quick, high-level system sizing. It aggregates all internal and external loads without accounting for zoning diversity and has the following key features:

- Assumes peak load conditions occur simultaneously across the entire building.
- Aggregates all internal and external heat gains.
- Provides a conservative, i.e. usually higher, load estimate, useful for preliminary sizing.
- Simplifies early-stage HVAC equipment selection.

This method does not reflect internal load variation across different spaces and is unsuitable for final equipment selection or zoning layout development.

4.2.2. Individual Thermal Zoning Approach

After the initial high-level estimate, a detailed design requires a thermal zoning strategy. Thermal zoning divides a building into multiple zones, each with unique load characteristics to better reflect real operating conditions.

To accurately calculate the cooling load, it is recommended to treat each HVAC zone as a separate thermal block. Nonetheless, different HVAC zones may be combined to create a single thermal block or identical thermal blocks to which multipliers are applied, if all of the following conditions are met:

- The space use classification is the same throughout the thermal block.
- All HVAC zones in the thermal block that are adjacent to glazed exterior walls and glazed semi exterior walls face the same orientation or their orientations vary by less than 45 degrees.
- All of the zones are served by the same HVAC system.
- All of the zones have similar operating schedules.
- Perimeter zones are those located within 4 m to 6 m of an exterior wall.

4.3. Building Shades

Building shading devices affect external heat gains, however, not all software platforms support detailed geometric input for complex shading structures. In such cases, it is recommended to choose a software (see Appendix 1: Simulation Software Requirements) that can simulate the effects of shading with a reasonable degree of accuracy. In the CLVT, shading can be considered by entering a negative load in the “Other Loads” worksheet.

RECOMMENDATION TO DESIGNERS

To reduce the cooling load effectively, provide optimise shading: use horizontal shading devices for windows on the south-facing façade, a mix of vertical and horizontal shading for east and west-facing façades, and horizontal shading for skylights.

4.4. Adjacent Buildings

Software models used to calculate the cooling load should include massing models of surrounding buildings or structures to evaluate their impact on the load. In the CLVT, this shading effect can be considered by entering a negative load in the “Other Loads” worksheet.

Additionally, it is important to verify whether the surrounding structures are permanent or temporary. If any adjacent buildings are slated for demolition or future redevelopment, their current shading effect should not be relied upon in long-term load calculations. Overlooking this consideration can lead to underestimated solar gains and undersized cooling systems, potentially impacting thermal comfort and HVAC systems performance in the future.

5. External Heat Gains

External heat gains are the thermal loads that originate from outside the conditioned space and contribute to the overall cooling demand of a building. These gains primarily occur through the building envelope due to solar radiation, conduction through materials, ventilation, and air leakage. Accurately assessing external heat gains is essential for accurate cooling load calculations and optimum HVAC system sizing.

External heat gains can be categorized into the following main sources:

- Solar radiation transmitted through glazing (windows and skylights).
- Heat conduction through opaque building elements (walls, roofs, and floors).
- Ventilation outdoor air treatment.
- Air infiltration through unintentional gaps and openings in the envelope.
- Solar absorption and re-radiation by building surfaces.

Each of these components must be properly evaluated based on the building's design, orientation, materials, and local climatic conditions. The CLVT can be used for this evaluation by inputting the relevant data in the "Building Envelop", "Infiltration", "Ventilation", and "Other load" worksheets and assessing the variation on the heat gains in the "Tool Output" worksheet.

5.1. Building Envelope

The building envelope acts as the primary barrier between the indoor and outdoor environments. Its thermal performance directly influences the magnitude of external heat gains and, consequently, the cooling load. To accurately determine peak cooling demand, calculation tools must account for the properties of construction layers and thermal mass, as these elements affect how heat is absorbed, stored, and released over time.

Key elements of the building envelope that should be included in the cooling load calculations are as follows:

5.1.1. Walls

Heat transfer through external walls occurs mainly by conduction, influenced by wall material properties (thermal conductivity, thickness, density) and exposure to direct solar radiation. To ensure precise heat gain calculations from walls, the following aspects must be considered:

- Thermal mass and insulation type to be considered as per design as they play a major role on peak load calculations.
- Wall colour and material reflectivity (albedo) because they affect solar heat absorption.
- Thermal bridging due to its impact on the overall U-Value of the wall.

RECOMMENDATION TO DESIGNERS

Insulated walls with high exposed thermal mass will prevent and delay heat transfer into the building's interior, reducing and potentially shifting peak cooling loads to later in the day. Light-coloured and reflective finishes will reduce heat gains. Thermal bridges will reduce the insulation effect of the walls.

5.1.2. Roofs

Roofs are often subjected to the highest solar exposure. Being mostly horizontal in nature, they often receive the most intense solar radiation. The following factors should be taken into account to ensure accurate cooling load calculations:

- Thermal mass and insulation type to be considered as per design as it plays a major role on the peak load calculations.
- Roof colour and materials reflectivity (albedo) because they affect solar heat absorption.

RECOMMENDATION TO DESIGNERS

Insulated roofs with high thermal mass will prevent and delay heat transfer into the building's interior, reducing and potentially shifting peak cooling loads to later in the day. Light-coloured, reflective finishes and high-performance insulation will reduce heat gains. Cool roofs, e.g. those with high reflectivity and high emissivity, can minimise heat transfer and green roofs, e.g. those with vegetation, if feasible, are also effective at reducing heat gains.

5.1.3. Glazing (Windows and Skylights)

Glazed surfaces are often the most variable and complex components of the building envelope in terms of heat gain. They permit direct solar radiation inside the building and a larger amount of conductive heat transfer than walls from the outside into the building, making their accurate representation in load calculations critical. The following factors should be taken into account while performing heat gain calculations from windows and skylights:

- Solar Heat Gain Coefficient (SHGC), which is critical for determining the amount of solar radiation admitted through the glass.
- Glazing type, e.g. double glazing, low-e coating, that should be considered accurately.
- Overall U-Value of glazing elements, i.e. frames should be considered while calculating the U-Values for glazing and skylight assemblies rather than using centre of glass U-Values, which are the typical U-Values available on data sheets from the manufacturer.
- Accurate frame-to-glass area ratios based on window specifications to model thermal performance precisely.

RECOMMENDATION TO DESIGNERS

Choose double/triple glazing and low-e coatings and select glazing with low U-Value and SHGC to minimise heat gains through glazing.

5.1.4. Floors

When a conditioned space is situated above unconditioned zones, e.g. car parks, utility spaces, or basements, or the floor is exposed to outdoor air, e.g. cantilevered sections, overhangs, or soffits, or the floor is in direct contact with the ground, the thermal transfer through the floor assembly may become a significant source of heat gain.

To ensure accurate cooling load estimates, the conductive heat gain through the floor should be explicitly included in calculations. This requires evaluating the construction buildup, insulation levels, and thermal exposure of the underside. Omitting this can result in underestimated cooling demands, particularly in hot climates or during peak load periods.

5.1.5. Internal Walls Adjacent to Unconditioned Spaces

Temperature differences across walls separating conditioned zones from unconditioned spaces, e.g. service rooms, parking areas, storage rooms, etc., can lead to significant heat transfer. The thermal mass and insulation type of these internal walls should be considered as per design as it plays a major role on calculating the peak load.

RECOMMENDATION TO DESIGNERS

Incorporate insulation or thermal breaks in order to reduce heat transfer from warmer unconditioned spaces.

5.1.6. Assessing Passive Design Strategies for Cooling Load Reduction

To support effective cooling load management, the design team should be required to systematically assess and integrate passive design measures from the early stages of the project, specifically during the Concept Design (CD) stage, prior to relying on active mechanical systems.

Passive strategies help reduce heat gains, which in turn lowers the demand on mechanical cooling systems. To assess the impact of passive design strategies for cooling load reduction, during the CD stage, design teams can compare the impact of at least two options on the building's cooling load for each of the following strategies, during the early stages of the project:

Building orientation	Shading strategies	Window-to-wall ratio (WWR)	Glazing thermal performance	Thermal insulation for opaque elements
Optimise building layout and orientation to minimise exposure to solar gains, favouring window placement on façades with the least solar intensity.	Assess impact of fixed or operable external shading devices, overhangs, fins, or screens to block direct solar radiation, especially on glazed surfaces.	Maintain a balanced WWR that considers both daylight access and solar heat gain. Where high WWRs are proposed, they must be justified through simulation and higher cooling loads to be mitigated with appropriate shading and glazing measures.	Assess a range of glazing types with varying Solar Heat Gain Coefficients (SHGC) and U-Values to identify options that reduce both solar and conductive heat transfer and achieve sufficient daylight.	Evaluate various U-Value options for roofs, walls, and floors to minimise external heat ingress through the building fabric.

RECOMMENDATION TO DESIGNERS

Designers should effectively assess the influence of passive design strategies on reducing peak cooling loads during the early stages of the project, and document the analysis in a report summarizing the measures considered, adopted, or excluded with a justification for each decision based on site context, feasibility, and performance impact.

5.2. Ventilation

Ventilation systems typically managed CO$_2$, odours, and oxygen levels. Today, they must address these and other diverse pollutants to ensure correct IAQ, a key design factor for occupant well-being and productivity. While ASHRAE 62.1 and 62.2 standards guide ventilation, additional design considerations are needed for achieving a satisfactory IAQ.

Maintaining good IAQ while minimising cooling energy is not easy. Although vital for healthy environments, effective ventilation increases cooling loads and energy costs, especially in hot, humid climates.

The subsequent sections explain the recommended methodologies for achieving equilibrium between good IAQ and energy-efficient design.

RECOMMENDATION TO DESIGNERS

Including demand-controlled ventilation, high-efficiency air filtration, high-efficiency energy recovery, and limiting infiltration will contribute to good IAQ with an energy-efficient design.

5.2.1. Heat Recovery

Current ASHRAE standards mandate a heat recovery system in ventilation designs due to its benefits in lowering cooling demands and conserving energy. There are several types, including thermal wheels, counterflow heat plate heat exchangers, heat pipes, and run-around systems. It is recommended for designers to follow the Abu Dhabi International Energy Conservation Code (ADIECC), the Abu Dhabi International Mechanical Code (ADIMC), ASHRAE standards, and consult the relevant ASHRAE handbooks to identify the pros and cons of each heat recovery type and to select the most efficient solution for their project.

RECOMMENDATION TO DESIGNERS

Prioritize highly effective heat recovery equipment for FAHUs and MAHUs when feasible, referencing ASHRAE standards and handbooks (Systems and Equipment, and Fundamentals) for selection guidance. System selection should:

- Comply with ADIECC, ADIMC, ASHRAE 90 and 62 standards
- Demonstrate compatibility with Abu Dhabi areas hot-humid climate and maintenance regimes

5.2.2. Indoor Air Quality

One aspect of IAQ that is often underserved by standard design approaches is the control of other air contamination, predominantly air particulate matter (PM) and volatile organic compounds (VOCs), which are major air pollutants with significant health implications. PM2.5, in particular, is linked to millions of premature deaths globally.

While parameters such as temperature and humidity are frequently considered when evaluating a healthy indoor environment, the determination of PM levels within a space during the design phase is complex. This complexity arises from the significant influence of construction quality, facilities management operations, and the local micro-climate. Indoor air pollution originates from two primary sources: pollutants generated internally, and pollutants transported from outdoor environments. These sources can be mitigated through several strategies:

- Implementation of air infiltration control, specifically through enhanced airtightness, which is a critical measure to reduce the direct ingress of outdoor pollutants. It is strongly recommended to design new buildings with a high degree of airtightness to improve occupant well-being and enhance energy efficiency.
- Maintenance of positive pressurisation within the building via the mechanical ventilation system. For further details, refer to Section 5.2.3.
- Utilisation of appropriate air filtration for ventilation and AC equipment - FAHUs, AHUs, and MAHUs. This will improve IAQ by reducing outdoor-to-indoor contamination and removing internally generated or transferred particulates.
- Careful design of spaces with particulate-generating processes, such as printing, spray painting, or other similar operations. It is recommended to employ measures such as well-ventilated, negatively pressurized, and sealed sub-spaces.
- Utilisation of zero VOC products and materials for construction and furniture.
- Thorough ventilation of new buildings and the performance of IAQ testing prior to occupancy.

RECOMMENDATION TO DESIGNERS

Achieving a high degree of airtightness in a building necessitates the sealing of all potential air infiltration points. Particular attention should be directed to wall junctures, fenestration interfaces, and service penetrations.

5.2.3. Building Pressurisation

> "The air conditioning and ventilation systems should be designed such that the building will be maintained at a positive pressure."
>
> CIBSE Design Guide for Abu Dhabi

Mechanical pressurisation is identified as the sole mechanism by which infiltration of ambient air, and consequently ambient particulates, is regulated by the HVAC system designs and specifications. This process involves the deliberate introduction of a greater volume of outside air into the building's air handling system compared to the volume of exhausted and relieved air. This differential is orchestrated to establish a positive internal pressure relative to the external environment. This can be achieved through manual balancing by providing approximately 10% excess fresh air, or automatically via differential pressure sensors and demand-controlled ventilation systems.

RECOMMENDATION TO DESIGNERS

Calculate the air leakage rates of doors and windows and verify that the provision of surplus fresh air equals or surpasses infiltration rates under all operating conditions.

5.2.4. Demand Control Ventilation

Ventilation calculations use full occupancy for conservative design, though actual occupancy will vary. Demand Controlled Ventilation (DCV) systems are required for energy conservation in large or high-density spaces to comply with standards and regulations.

The function of a DCV system, which is engineered to maintain CO_2 concentration within the parameters defined by the system's sensor(s) to ensure good IAQ, should be understood, because its operation may cause a low or negative building pressure, subsequently leading to undesirable air infiltration and IAQ issues.

RECOMMENDATION TO DESIGNERS

When using DCV systems, designers should ensure the provision of adequate fresh air and a predetermined differential airflow between the supply and return air streams.

5.3. Infiltration

External air infiltrates into the occupied spaces of a building through both designed apertures, such as windows and doors, and adventitious openings, such as cracks. This ingress can result in problems related to humidity and mold growth. Moreover, the sensible and latent heat gains brought by the infiltrated air need to be considered into the cooling load calculations.

While air infiltration is often calculated using a static rate based on air changes per hour (ACH), this uniform approach fails to account for variations across different building zones. Areas like entrances with high traffic exhibit greater infiltration, while interior spaces have negligible infiltration. Consequently, it is recommended to determine the infiltration load for each zone individually, considering specific parameters such as the dimensions and style of doors and operable windows. For instance, a space equipped with a sliding balcony door will exhibit a greater degree of infiltration compared to a similar space featuring a smaller, hinged window.

The data from whole-building air infiltration tests should not be directly used for cooling load calculations, as the tests are conducted at elevated pressure levels (typically 50 Pa or 75 Pa), whereas the building operates under much lower pressure differentials. Therefore, the test results must be appropriately converted to reflect actual operating conditions before being used in the calculations.

EXAMPLE

Conversion of air infiltration test data for application in cooling load analysis as per ASHRAE 90.1:

The air leakage rate of the building envelope (I_{75Pa}) at a pressure differential of 75 Pa can be converted to appropriate units to be used with the cooling load calculations software.

The air leakage (I_{AGW}) as a function of the area of above-grade walls (A_{AGW}) that separate conditioned spaces from the exterior shall be calculated using the following formula:

$I_{AGW} = 0.112 \times I_{75Pa} \times S/A_{AGW}$

When using the measured air leakage rate of the building envelope at a pressure differential of 75 Pa for the proposed design, the air leakage rate shall be calculated as follows:

$I_{75Pa} = Q/S$

where,

I_{75Pa} = air leakage rate of the building envelope (L/s·m^2) at a fixed building pressure differential of 75 Pa

Q = volume of air in L/s flowing through the building envelope when subjected to a pressure differential of 75 Pa, in accordance with ASTM E 779

S = total area of the building envelope (m^2), including the lowest floor, any below-grade walls or above-grade walls, and roof (including vertical fenestration and skylights)

I_{AGW} = adjusted air leakage rate of the building envelope (L/s·m^2) at a reference wind speed of 4.47 m/s and relative to the area of the above-grade walls of the building envelope

A_{AGW} = total area of above-grade walls of the building envelope (m^2)

RECOMMENDATION TO DESIGNERS

The implementation of enhanced building airtightness contributes to improved IAQ, occupant well-being, and energy conservation. A whole building airtightness test should be performed in accordance with American Society for Testing and Materials (ASTM) E779 or similar standard and infiltration rates. If the air tightness test is not carried out, the air leakage rate at a fixed building pressure differential of 75 Pa shall be considered as 2.03 L/s.m^2.

6. Internal Heat Gains

This section describes the internal heat loads of a building that are a consequence of the heat produced within the conditioned space from lighting, computers, business machines, occupants, and mechanical and electrical equipment like fans, pumps, compressors, and transformers. These internal heat gains need to be compensated by the cooling system to maintain a comfort environment for the building users.

The internal heat gains calculations usually consider the worst-case scenario to size the cooling systems that is the correct approach at the room/zone level to ensure the cooling systems will be capable of maintaining comfort during the peak load. However, summing the peaks of each zone results in an oversized HVAC system therefore it is recommended to consider a diversity factor as elaborated in Section 7.2 to calculate the overall internal heat gains for the whole building/project.

Not following this recommendation or using very high unjustifiable assumptions for the internal heat gains will incorrectly increase the cooling load. Conversely, in some cases wrong assumptions result in under sizing of cooling systems. The CLVT considers these gains in its "Internal gains" worksheet, where the relevant values should be input on a per space basis.

6.1. Lighting

Lighting contributes to internal heat gains through both radiant and convective heat transfer, which must be accurately accounted for in cooling load calculations. The lighting power density (LPD) factor expressed in W/m^2 is typically used for these calculations; however, incorrect LPD estimation based on rule-of-thumb values or default limits from ASHRAE 90.1 rather than actual project-specific lighting design often leads to unnecessary upsizing of cooling equipment and the overdesigning of the cooling system, increasing both initial costs and energy consumption.

EXAMPLE

In an office building with a total floor area for office spaces of 10,000 m^2, if the LPD is assumed to be 10 W/m^2 based on a general rule but the actual design constitutes only 6 W/m^2, the resulting overestimation significantly impacts the cooling load:

Assumed Lighting Heat Gain=(10,000×10)/1,000=100 kW

Actual Lighting Heat Gain=(10,000×6)/1,000=60 kW

Overestimated Cooling Load Due to Lighting=100–60=40 kW (i.e., 66% overdesign)

This unnecessary 40 kW increase in cooling load would lead to oversized HVAC equipment, higher capital costs, and inefficient energy performance. To prevent this, cooling load calculations should be based on actual lighting design, include all relevant fixtures, and avoid arbitrary LPD assumptions.

6.2. Occupancy

Occupant density should be determined based on the actual furniture layout rather than relying solely on standard values. In cases where furniture layouts are unavailable, relevant industry standards, such as ASHRAE 62.1, may be used. However, designers must ensure that these values are neither underestimated nor overestimated, which can be verified by comparing them against a typical layout for that space type.

ASHRAE 62.1 recommends an occupant density of 20 m^2/person for open office spaces, but in practice, based on actual furniture layouts the occupancy ratio may be higher, i.e. less m^2 per person. If the default standard value is used, it may result in undersized cooling and ventilation systems, leading to insufficient airflow and discomfort.

EXAMPLE

Based on the open plan office layout shown in Figure 8, the occupant density is calculated as 6 m²/person (i.e., 236.5 m² divided by 39 occupants). Collaboration seats have been excluded to avoid double counting, as these are typically used by the same individuals.

Figure 8. Sample Office Layout

Figure 9. Sample Restaurant Layout

EXAMPLE

For instance, the restaurant shown in Figure 9 has an area of 160 m² and an occupancy of 50 people (43 visitors and 7 staff), resulting in an occupant density of approximately 3.2 m² per person.

Restaurant dining areas such as those shown in Figure 9, ASHRAE 62.1 suggests 1.43 m^2/person, but actual layouts, which include food counters, circulation spaces, and waiting areas, typically result in lower occupancy levels, i.e. more m^2 per person. Relying on the default standard in such cases can lead to oversized cooling and ventilation systems, increasing both capital costs and energy consumption.

All sensible and latent heat loads should be referenced from ASHRAE Handbook - Fundamentals (2021) to maintain accuracy in cooling system design. By incorporating these best practices, HVAC systems can be designed to optimise performance, comfort, and energy efficiency while avoiding unnecessary over or under sizing.

In summary, to ensure accurate cooling load calculations, designers should:

- Use furniture layout-based occupant densities whenever available.
- Validate the expected operational maximum occupancy with the client and wider project design team.
- Utilise default occupancies only where it can be demonstrated that no other information is available.
- Apply appropriate sensible and latent heat gains based on activity levels.

RECOMMENDATION TO DESIGNERS

Occupant density should be checked against real-world space planning, but for spaces where furniture layout is unavailable, occupancy assumptions can then be based on Abu Dhabi International Mechanical Code, Table 403.3 or latest ASHRAE Standards 62.1 and 62.2.

6.3. Equipment

Equipment heat gains should be calculated based on actual heat dissipation rates of project-specific equipment rather than relying on generic assumptions. To ensure accurate cooling load calculations, diversity factors should be applied based on realistic operational assumptions and detailed calculations. Proper consideration of equipment usage patterns can prevent overdesigning and optimise system performance. For example:

Offices	Bedrooms	Kitchens	Laundry Rooms
Office equipment heat gain is typically estimated as 15 W/m^2 (as per CIBSE TM37). Nevertheless, the actual load, based on actual equipment, should be used for the cooling load calculations.	While some devices, such as hairdryers and irons, have high power ratings, they operate for short durations and do not contribute significantly to the overall cooling load. Therefore, considering such load in the continuous cooling load calculations is an incorrect practice.	A significant portion of the heat generated by cooking appliances is captured and exhausted by kitchen hoods, leaving only a small fraction of heat gain affecting the conditioned space. The cooling load should account only for the residual heat gain that remains in the space after ventilation.	The water heater in a laundry system primarily heats water, which is then drained away, meaning it does not significantly contribute to space heat gain. However, motor-driven components (such as washing machine and dryer motors) dissipate heat into the room and should be accounted for in load calculations.

By applying these best practices, HVAC systems can be right-sized, leading to improved energy efficiency, cost savings, and better indoor comfort.

RECOMMENDATION TO DESIGNERS

To improve accuracy, cooling load estimations should be based on actual equipment specifications and heat dissipation rates.

6.4. Heat Gain from Motors

The heat generated by fan and pump motors serving cooling systems should be accounted for in the overall system cooling load. These components generate heat during operation, and depending on their location, a portion, or in some cases the entirety, of that heat is transferred to the conditioned air or water stream.

For example, in AHUs with draw-through fan arrangements, the fan motor heat is added to the air stream after it is cooled by the coil, thereby increasing the supply air temperature and the load on the cooling coil. Similarly, pumps circulating chilled or condenser water can contribute heat to the fluid they move, which increases the cooling demand on the chillers.

RECOMMENDATION TO DESIGNERS

Accurately accounting for internal energy gains ensures realistic system sizing and avoids underestimating the actual cooling requirement.

7. System Design

Considering all previously described factors such as outdoor environmental design conditions, indoor comfort levels, building geometry, and internal and external heat gains, the resultant cooling load may be computed, and the corresponding system designed. The CLVT is intended to support designers in translating calculated cooling loads into accurate and efficient system designs. By providing a structured platform to input climatic, building, and operational parameters, the CLVT enables verification of cooling load calculations while ensuring consistency with local codes and guidelines. Its purpose within system design is to help designers avoid unnecessary oversizing.

7.1. Safety Margin

Applying multiple safety factors at different stages, load calculations, equipment selection, and plant design, can result in overly conservative and oversized systems. Designers are therefore advised to clearly define and justify all safety factors based on project-specific requirements and to avoid sequential or progressive application, particularly between space loads and final plant selection.

> “Cooling Load Calculations in Practice
>
> Load calculations should accurately describe the building. All load calculation inputs should be as accurate as reasonable, without using safety factors. Introducing compounding safety factors at multiple levels in the load calculation results in an unrealistic and oversized load.”
>
> ASHRAE handbook – Fundamentals

Historically, safety factors of between 10 and 20% were included in cooling load calculations to account for potential discrepancies between actual and certified U-Values, manual calculation errors, building infiltration, inadequate insulation, lack of skilled labour/tools, complex site conditions, etc. These safety factors resulted in oversized equipment and increased costs. However, due to improvements in construction practices, technology, and expertise, the issues highlighted are now less common. Therefore, incorporating a default safety factor as a standard risk management approach is discouraged without careful consideration and thorough justification.

RECOMMENDATION TO DESIGNERS

The practice of concealing design or implementation deficiencies by oversizing equipment and thereby inflating project costs is unacceptable and unjust to the project owner/investor. All applied margins must be substantiated through reasoned engineering judgment.

Certain design parameters such as supply and return duct heat gain, duct leakage, and non-ducted or return air plenum gains present challenges for precise calculation. Consequently, it might be argued that designers should incorporate a safety factor to account for these elements. However, prior to implementing a safety factor, a comprehensive system review is imperative to ascertain if the system possesses sufficient spare capacity to offset minor losses or partially accommodate these gains. For instance, FCUs are typically selected based on mid-speed airflow for cooling loads and often have a 3-7% capacity surplus compared to the design load. High-speed operation can further increase capacities during periods of peak demand, which should be enough to handle these types of heat gains.

Nonetheless, the CIBSE Design Guide for Abu Dhabi: Minimum design standards for mechanical services”, that is based on good engineering practices, allows for a tolerance of up to 10% for sensible loads and 5% for latent loads in calculating space by space heat load and sizing air conditioning.

Should a higher safety factor be deemed necessary, it is recommended to provide detailed evidence, rigorous risk assessment, and a comprehensive evaluation of system capacity and performance.

7.2. Diversified Cooling Load

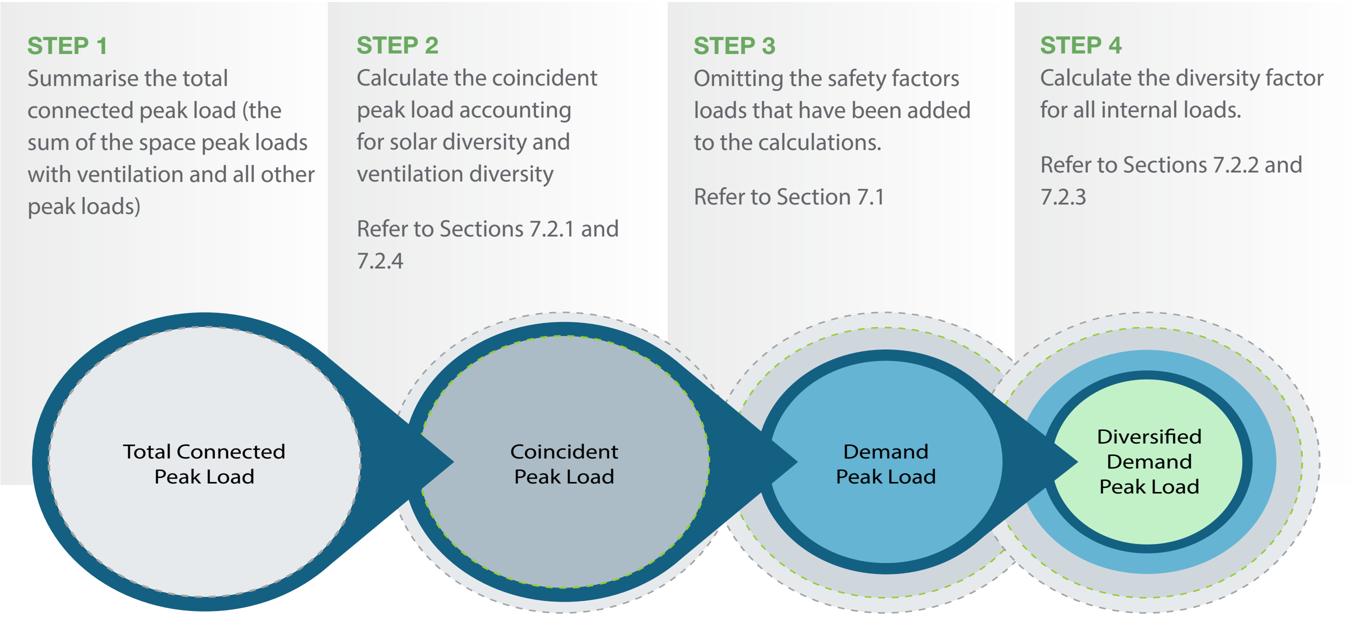
All international standards and guidelines, such as the CIBSE Design Guide and the ASHRAE Handbook- Fundamentals, highlight how designers should consider load diversity at the plant level.

> "The design should account for diversity profiles for people, lighting, equipment, etc., and these should be considered in the air conditioning plant calculations."
>
> CIBSE Design Guide for Abu Dhabi

> "With large buildings that involve more than a single HVAC system, simultaneous loads and any additional diversity also must be considered when designing the central equipment that serves the systems."
>
> ASHRAE Handbook – Fundamentals

The total load for a building is not as straightforward as simply adding up the individual loads of each space within it because these spaces do not all reach their peak load demand simultaneously. In fact, different spaces experience their highest load at different times of the day or even across different seasons.

Therefore, to accurately calculate the total building load and adequately size the building plant and equipment, diversity factors need to be taken into account as demonstrated in Figure 10 and Table 4. The proposed approach will avoid equipment oversizing of plant equipment, reduce unnecessary capital expenditure and inefficient energy utilisation.



STEP 1
Summarise the total connected peak load (the sum of the space peak loads with ventilation and all other peak loads)

STEP 2
Calculate the coincident peak load accounting for solar diversity and ventilation diversity

Refer to Sections 7.2.1 and 7.2.4

STEP 3
Omitting the safety factors loads that have been added to the calculations.

Refer to Section 7.1

STEP 4
Calculate the diversity factor for all internal loads.

Refer to Sections 7.2.2 and 7.2.3

Figure 10. Diversified Demand Peak Load Flow Chart

Table 4. Diversity Factor Calculation

Load Calculations Assumptions	**Safety Factor (%)**	**Note**
Safety Factors Sensible	SF_{S}	Assuming 10% has been used by the designer
Safety Factors Latent	SF_{L}	Assuming 5% has been used by the designer
Load Calculations Parameters	**Load (kW)**	**Note**
Total Sensible Load for all Spaces	L_{TS}	The summation of rooms' sensible loads
Total Latent Load for all Spaces	L_{TL}	The summation of rooms' latent loads
Coincident Peak Sensible Load	L_{CPS}	Refer to Section 7.2.1
Lighting Deviation Load	L_{LD}	L_{LD}= Lighting total load from cooling load calculation - The actual lighting load Refer to Sections 6.1 and 7.2.2
People Deviation Sensible Load	L_{PDS}	L_{PDS}= People total sensible load from cooling load calculation X {Actual number of people / number of people from cooling load calculation} Refer to Sections 6.2 and 7.2.2
People Deviation Latent Load	L_{PDL}	L_{PDL}= People total latent load from cooling load calculation X {Actual number of people / number of people from cooling load calculation} Refer to Sections 6.2 and 7.2.2
Equipment Deviation Sensible Load	L_{EDS}	L_{EDS}= Equipment total sensible load from cooling load calculation - The actual equipment load Refer to Sections 6.3, 6.4 and 7.2.2
Equipment Deviation Latent Load	L_{EDL}	L_{EDL}= Equipment total latent load from cooling load calculation - The actual equipment load Refer to Sections 6.3 and 7.2.2
Infiltration Deviation Sensible Load	L_{IDS}	L_{IDS}= Infiltration total sensible load from cooling load calculation X Infiltration diversity factor Refer to Sections 5.3 and 7.2.3
Infiltration Deviation Latent Load	L_{IDL}	L_{IDL}= Infiltration total latent load form cooling load calculation X Infiltration diversity factor Refer to Sections 5.3 and 7.2.3
Ventilation Actual Load (FAHUs and MAHUs)	L_{VA}	L_{VA}= Ventilation load at the outdoor temperature and not at the peak dehumidification peak Refer to Sections 2.1, 2.2, 5.2 and 7.2.4
Other Diversified Cooling Loads	L_{OT}	Such as swimming pool(s) cooling load
Diversified Cooling Demand Load	L_{CD}	$L_{CD}= L_{CPS}-\{L_{LD}+L_{PDS}+L_{EDS}+L_{IDS})x(1-SF_{S})\}+L_{TL}-\{L_{PDL}+L_{EDL}+L_{IDL})x(1-SF_{L})\}+L_{VA}+L_{OT}$
Load Calculations Results	**Result (%)**	**Note**
Overall Diversity Factor	DF	$DF=L_{CD} / (L_{TL}+L_{TS})$

7.2.1. Solar Load Diversity

Buildings experience variable solar gain peaks throughout the day, correlating with the sun's trajectory. Specifically, eastern façades achieve maximum solar gain during the morning, whereas western façades experience peak gain in the evening.

The building's coincident solar peak is primarily determined by the extent of glazed area, given the negligible solar diversity on well-insulated walls, as well as the building's form and orientation. Consequently, a rectangular building with substantial East and West-facing glazed areas will exhibit a higher solar diversity factor than an identical building with glazed areas facing North and South.

The peak coincident load of a building, considering solar load diversity, can be determined by building simulation software which can calculate the hourly loads of each space. Also, the CLVT can be used to estimate the Solar Peak diversity factor as it utilises hourly data, calculating solar loads in 1-hour time steps. It identifies the peak solar gain for each orientation individually, then sums these peaks as if they all occurred at the same moment - representing a theoretical "worst-case" scenario without considering timing diversity. The tool then determines the building's actual overall peak solar load based on the hourly data. Since peak gains occur at different times, this coincident peak is typically lower than the sum of the individual orientation peaks.

For example, Figure 11 illustrates the difference between diversified and undiversified cooling loads:

- Each zone (dashed lines) has a unique cooling load profile based on its orientation and peak time.
- The solid green line represents the undiversified sum of peak loads (i.e., if each zone was sized and summed independently, assuming simultaneous peak).
- The solid blue line shows the diversified total load, which is the hour-by-hour sum of all zones — capturing actual total coincident demands.

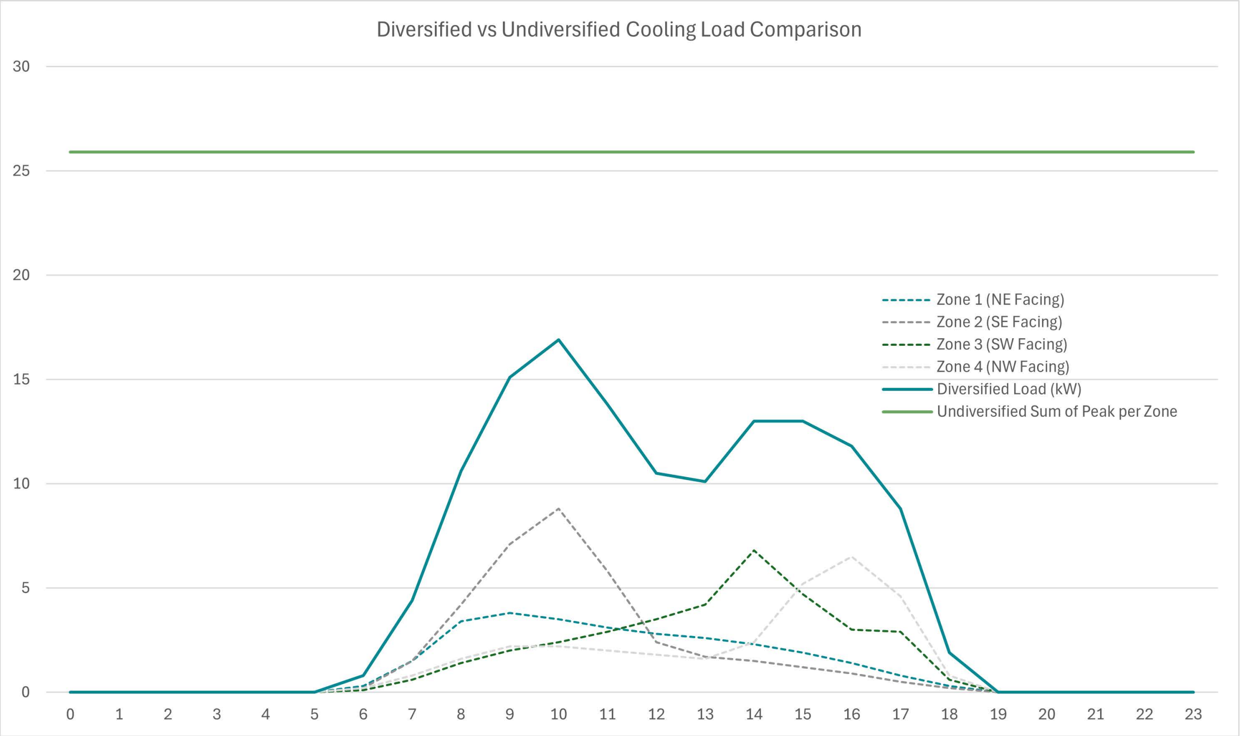


Figure 11. Diversified Vs Undiversified Cooling Load Profile for 4 Zones

Table 5. Hourly Cooling Load Comparison for 4 Zones

Hour	Zone 1 (NE Facing)	Zone 2 (SE Facing)	Zone 3 (SW Facing)	Zone 4 (NW Facing)	Diversified Load (kW)
0	0	0	0	0	0
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0.3	0.2	0.1	0.2	0.8
7	1.5	1.5	0.6	0.8	4.4
8	3.4	4.2	1.4	1.6	10.7
9	**3.8**	7.1	2.0	2.2	15.1
10	3.5	**8.8**	2.4	2.2	**16.9**
11	3.1	5.8	2.9	2.0	13.9
12	2.8	2.4	3.5	1.8	10.6
13	2.6	1.7	4.2	1.6	10.0
14	2.3	1.5	**6.8**	2.4	13.0
15	1.9	1.2	4.7	5.2	13.0
16	1.4	0.9	3.0	**6.5**	11.9
17	0.8	0.5	2.9	4.6	8.9
18	0.3	0.2	0.6	0.8	1.8
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
Undiversified Peak per Zone (kW)	**3.8**	**8.8**	**6.8**	**6.5**	**16.9**
Undiversified Sum of Peak per Zone (kW)	**25.9**				

EXAMPLE

Based on the Table 5 above, the diversified load (16.9 kW) peaks at a much lower total than the undiversified sum (25.9 kW). Therefore, using the former, allows for more accurate and efficient sizing of the cooling plant.

7.2.2. Internal Heat Gains Diversity

> “Central equipment size is based on the block load of the entire building at the time of the building peak load, not on the sum of individual in-room terminal unit peak loads. Cooling load should include appropriate diversity factors for lighting and occupant loads.”
>
> ASHRAE Handbook – System and Equipment

While the peak load for individual zones reflects a worst-case scenario, this approach may lead to an inaccurate assessment of the overall building load. It is advisable to account for the low probability of all spaces within a building being occupied at peak capacity simultaneously.

For instance, occupants of a residential dwelling will move between various rooms but cannot occupy all rooms at the same time. Likewise, in office environments, the individuals occupying workstations are likely the same individuals who will utilise meeting rooms.

As demonstrated in Table 6, the application of a diversity factor of 27% to the occupant heat gain is appropriate for a representative two-bedroom apartment accommodating a family of four.

Table 6. Occupancy Diversity Example

2BR Apartment Individual zones	Number of people	Equipment serving the zone
Living room	8	AC unit number 1
Kitchen	2	AC unit number 1
Internal lobby	1	AC unit number 1
Bedroom 1	2	AC unit number 2
Bedroom 2	2	AC unit number 3
Total	15 people	3x AC units
Actual	4 people	At central plant
Diversity Factor	4/15 = 27%	At central Plant

The designer is required to calculate internal gains load, utilizing appropriate load diversity factors to prevent oversizing of the central plant. The ASHRAE Handbook – Fundamentals, specifically Chapters 17 and 18, offers comprehensive guidance on diversifying internal gains, which designers should utilise to calculate the accurate building-level load. Furthermore, the CLVT may be used to determine the diversification of the internal thermal loads.

7.2.3. Infiltration Diversity

Air infiltration calculations for individual spaces or zones are based on a worst-case scenario, utilizing the maximum wind speed. Conversely, at the building level, the designated infiltration rate will be applicable only to the windward side, with minimal infiltration or exfiltration occurring on other façades. Furthermore, the occurrence of the peak summer condition with the maximum wind speed simultaneously is very unlikely.

For buildings where infiltration constitutes a significant portion of the external thermal gains (typically 15% or more), it is essential to conduct more detailed analyses to accurately assess its impact. In such cases, advanced techniques like

Computational Fluid Dynamics (CFD) studies are recommended to evaluate how infiltration varies across different orientations and façade exposures. These studies help in understanding wind pressure distribution, stack effect, and localized leakage paths, which influence how air infiltrates into the building.

By capturing these variations, the results can be used to apply diversity across different zones or façades, instead of uniformly applying worst-case infiltration rates across the entire building. This refined approach leads to more realistic and optimised peak load estimates, avoiding unnecessary overdesign of HVAC systems.

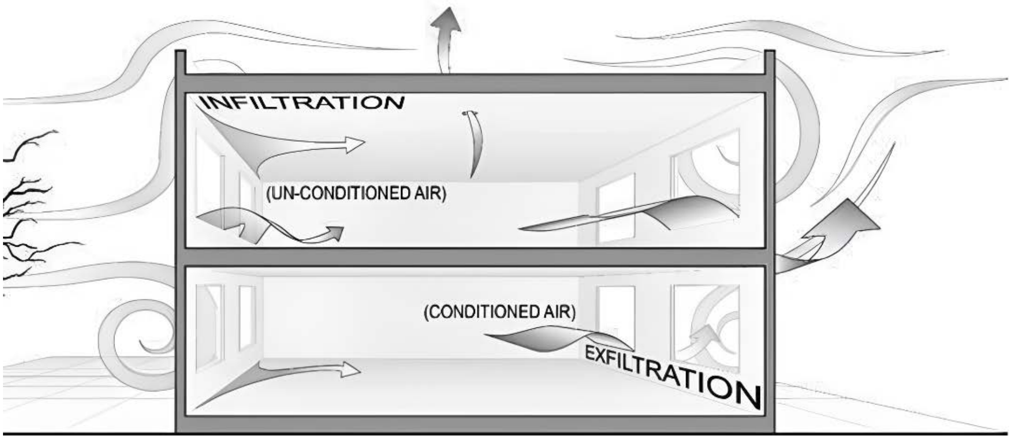


Figure 12. Infiltration and Exfiltration Due to Wind

7.2.4. Ventilation Diversity

In areas with high humidity, such as Abu Dhabi city and other coastal areas of the Emirate, fresh air load calculations based on dehumidification conditions require greater cooling capacity than those based on peak DBT conditions, which are typically used for cooling plant sizing. Consequently, the ventilation load should be determined using the cooling plant's peak condition to accurately reflect the diversified ventilation load on the cooling plant.

RECOMMENDATION TO DESIGNERS

Accurately determine total building cooling loads, do not just sum individual space loads. Use diversity factors for solar, internal gains, infiltration, and ventilation to prevent oversizing and energy waste.

7.3 Systems' Losses

The generated cooling capacity at the central plant is not entirely transferred to the building zones due to losses in the distribution system, primarily within the chilled water network, refrigerant piping network, and ducting systems. Utilizing high-performance thermal insulation and low-leakage ducts are effective strategies for minimizing these losses.

7.3.1. Thermal Insulation

Thermal insulation for pipes and ducts is a mandatory requirement Abu Dhabi International Energy Conservation Code (ADIECC) standard in Abu Dhabi projects. While insulation performance is quantified by its thermal resistance (R-value) determined during manufacturing, this value can decrease over time. This degradation leads to increased energy loss, potential HVAC system failure, and ultimately, energy waste. The degradation of R-value necessitates the specification of high-quality insulation materials that comply with relevant standards.

7.3.2. Duct Leakage

Duct air leakage is a source of energy waste in HVAC systems. According to the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) HVAC Systems Duct Design Manual, the duct leakage can be well above 30% of the total system airflow of conditioned air. This inefficiency may lead to the installation of oversized cooling systems to compensate for the lost cooling air and resulting increased energy consumption.

Leakages have varying consequences depending on the specific ductwork system:

- In supply and fresh air ductwork systems, air leakages result in a reduction of airflow volume delivered to conditioned spaces. Failure to mitigate this issue during the design phase requires to increase the airflow during commissioning to achieve the specified flow rate, thereby increasing fan power consumption and the cooling load.
- Air leakage in the extract air ductwork requires increased airflow and fan power consumption to reach the designed airflow targets. Consequently, this increased airflow results in a higher extract air temperature, thereby reducing heat recovery efficiency and increasing the cooling load.
- Air infiltration into return ducts introduces unconditioned air into the system, thereby increasing the cooling load. Furthermore, it can lead to air contamination if return air crosses the plenum of a moisture-prone area, typically characterized by a non-airtight suspended ceiling, or potentially result in issues with humidity, mold, and fungal growth should the return air duct be routed through exterior spaces.

RECOMMENDATION TO DESIGNERS

Designers should carefully select and specify ductwork with attention to leakage performance and its impact on system design, operation, and energy use. This should include compliance with recognised standards (such as SMACNA HVAC Duct Leakage Test Manual or DW 144) and evaluation of opportunities to use pre-insulated round or oval ducts in suitable locations, as they have less air leakage, and hence energy losses, than rectangular ducts of the same seal class.

Designers should prioritise leak testing on main ducts within plant rooms and risers, where it is likely to deliver the greatest impact, rather than focusing on smaller terminal branches.

7.4 Overdesign from Non-standard Ambient Design Conditions

When cooling plant sizing is based on ambient design conditions higher than those prescribed by local codes or international standards such as ASHRAE, the result is often unnecessary overdesign of the cooling plant and associated HVAC systems for the building owner, and increased electricity distribution infrastructure costs.

EXAMPLE

A sample office building designed using ASHRAE's standard design conditions of 45.1°C DBT and 23.0°C WBT resulted in a peak cooling plant load of 822 kW. When the same building was analysed at 52°C DBT and 23.0°C WBT, the calculated cooling load increased to 873 kW. This corresponds to an approximate 6% increase in system size for the analysed building, driven solely by the adoption of non-standard ambient conditions.

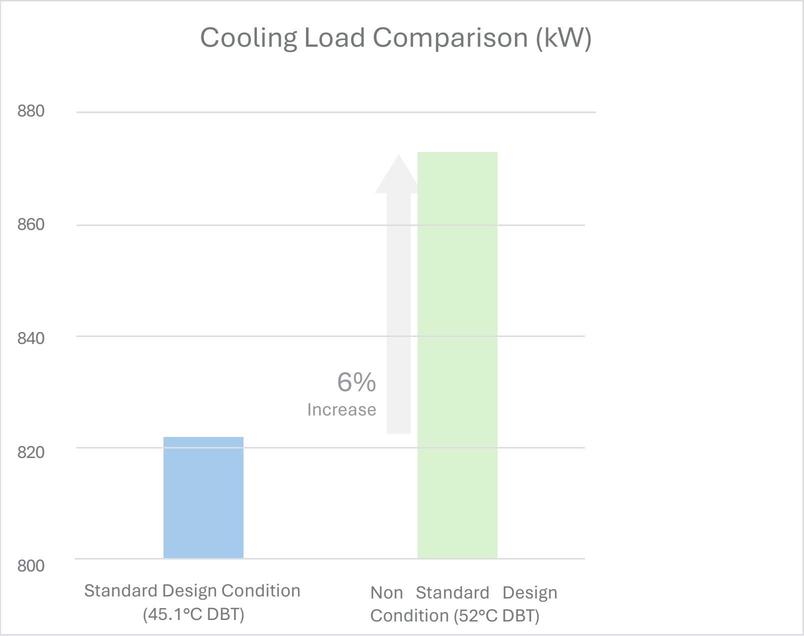


Figure 13. Cooling Load Comparison for Different Ambient Design Conditions

RECOMMENDATION TO DESIGNERS

Designers should adhere to the recommended ambient design conditions provided in Section 2 of this manual. The logic of any deviation should be justified and the impact documented.

8. Cooling Plant

Excessive capacity in cooling plants results in unnecessary expenditure and infrastructure requirements. Following system design finalization, engineers are to prioritize the optimisation of installed capacity to match the calculated cooling loads.

A comprehensive life cycle cost analysis is recommended to select the cooling plant technology with the lowest energy consumption and operational costs. This should include initial capital, ongoing expenses, advanced energy efficiency technologies (e.g. thermal energy storage or heat recovery), and innovative procurement strategies like Cooling as a Service (CaaS). Ecological impacts of refrigerants and future district cooling interoperability should also be considered.

Specifically, the following considerations should be made during cooling plant selection.

8.1. Installed Capacity (Duty and Standby)

Oversized chiller plants, often with up to double the required cooling capacity, lead to unnecessary costs and infrastructure requirements. There is a tendency to meet the calculated maximum chiller load by specifying multiples of a standard size of chiller (for example, the calculated load to be met by three chillers each capable of 33% and an extra chiller of the same size to achieve the N+1 resilience requirement). This approach is no longer the most efficient or cost-effective solution mainly due to:

- **Repairs and parts availability**
  Online ordering and expedited shipping have significantly reduced the time required for repairs and spare parts procurement.
- **Predictive maintenance**
  Remote monitoring enables manufacturers to identify and address potential issues before they result in system downtime, minimising the need for backup chillers.
- **Short-term chiller rentals**
  Temporary chiller rentals are readily available to maintain cooling capacity during unexpected repairs or maintenance, eliminating the need for a permanent backup chiller. However, a provision for the connection of these chillers should be made during initial design and implemented during construction.

RECOMMENDATION TO DESIGNERS

Design the size of the cooling plant equipment, e.g. chillers, considering their efficiency at the individual load factor that will be required for the whole plant to meet the cooling demand during the different periods of the year, e.g. summer and winter. To add resiliency whilst minimising the number of equipment, consider possible faults in individual equipment under different periods of the year to ensure that the remaining plant equipment is capable of meeting the total demand. Summarise these design considerations in a comprehensive risk assessment to substantiate for the client the necessity, or not, of investing in standby chillers.

The risk assessment should encompass all capital and hardware considerations, including, but not limited to, the estimated increase of cooling load capacity and its means of provision, the additional spatial requirements for chiller plant equipment connections and ancillary devices, the necessity of an expanded transformer, and an enlarged substation area. With respect to the provision of supplementary capacity, the risk assessment should evaluate various modalities, such as onsite deployment or rental alternatives, as well as the optimal combinations of cooling capacity to ensure effective delivery.

Furthermore, operational factors must be integral to the risk assessment, including warranties, manufacturer service level agreements and logistical arrangements, the proposed operational strategies aimed at efficiency maximization and degradation minimisation, and a meticulously defined approach to preventive and reactive maintenance.

9. Design Checks and Verification

Errors in design and calculations are possible due to human factors. Therefore, stringent verification of the design by a senior professional at every stage is essential to ensure compliance with established industry best practices and standards.

The design reviewer should have relevant expertise and a judicious level of confidence that will enable to optimise designs, spot errors and follow best practices and standards. The designer should verify all aspects of the design process, including conceptualisation, space planning, calculations, specifications, and equipment selection and sizing.

The CLVT, along with its associated checklist, may be utilised as a supporting tool to streamline and enhance the design review and validation process.

RECOMMENDATION TO DESIGNERS

A senior team member with the relevant skills and experience should review and verify each design and calculation stage to ensure that the design is accurate, error-free and complies with best practices and standards.

10. References

1. Abu Dhabi International Building Code (ADIBC)
2. Abu Dhabi International Energy Conservation Code (ADIECC)
3. Abu Dhabi International Mechanical Code (ADIMC)
4. ANSI/ASHRAE/ACCA Standard 183-2007 (RA 2014) - Peak Cooling and Heating Load Calculations in Buildings Except Low-Rise Residential Buildings
5. ANSI/ASHRAE/IES Standard 90.1-2022 - Energy Standard for Buildings Except Low-Rise Residential Buildings
6. ASHRAE 55 - Thermal Environmental Conditions for Human Occupancy
7. ASHRAE 62 - Ventilation and Acceptable Indoor Air Quality
8. ASHRAE 169 – Climatic Data for Building Design standard
9. ASHRAE Handbook – Fundamentals
10. ASHRAE Handbook – HVAC Systems and Equipment
11. ASHRAE Load Calculation Applications Manual (SI), Second Edition
12. ASTM E779 - Standard Test Method for Determining Air Leakage Rate by Fan Pressurization
13. Centre for Built Environment (CBE) Thermal Comfort online tool for thermal comfort calculations and visualizations
14. CIBSE Design Guide for Abu Dhabi
15. CIBSE TM37 - Design for improved solar shading control
16. DW 144 - Building and Engineering Services Association - specification for sheet metal ductwork
17. SMACNA - HVAC Systems Duct Design Manual
18. Strategy Guideline: Accurate Heating and Cooling Load Calculations – U.S. Department of Energy

Appendix 1: Simulation Software Requirements

It is the designer's responsibility to ensure that all inputs and assumptions conform to the CLM and relevant ASHRAE guidance (particularly Handbook Fundamentals and ASHRAE 90.1)

However, to ensure reliable and verifiable cooling load calculations, any simulation software used under the CLM shall meet the following requirements, adapted from ASHRAE 90.1-2007 (Appendix G PRM):

1. Comply with the Performance Rating Method (PRM) as specified in Appendix G of ASHRAE Standard 90.1 and must be validated in accordance with ASHRAE Standard 140. Documentation of ASHRAE 140 validation and Appendix G modelling capability shall be made available upon request.
2. Support full hourly simulation (8,760 hours/year) using hourly climatic data (including solar radiation, dry/wet bulb temperatures, humidity, and wind) representative of the project location.
3. Model both block and zonal loads, supporting a minimum of 10 thermal zones.
4. Accurately simulate:
    - Internal and external heat gains (people, lighting, equipment, envelope)
    - Thermal mass effects
    - HVAC system part-load and correction curves
    - Design ventilation and infiltration strategies
    - Hourly variation in occupancy and control schedules
5. Allow calculation of diversified cooling loads at plant level.
6. Include or accept exceptional calculation methods for elements not modelled directly, provided full documentation is submitted.
7. Utilise consistent design weather data between baseline and proposed case.

While the DoE does not certify or endorse any specific simulation software, the following tools (latest versions) are generally recognized as compliant with the above requirements, provided they are used appropriately and in accordance with best practices:

1. IES VE
2. HAP (Hourly Analysis Program)
3. EnergyPlus
4. TRACE
5. TAS

Overview of Cooling Load Calculation Methods

Understanding the methodology behind various cooling load calculation approaches is essential to selecting the appropriate tool. The Table 7 below provides a summary of commonly used methods, along with their applicability and limitations in cooling load analysis. This serves as a reference for designers, highlighting that CLVT specifically employs Heat Balance (HB) method, which is recognized as the most rigorous and accurate approach endorsed by ASHRAE for dynamic cooling load calculations.

Table 7. Summary of Cooling Load Calculation Methods

Cooling Load Method	Description	Limitations
CLTD/CLF (Cooling Load Temperature Difference / Cooling Load Factor)	Simplified tabular method using temperature differences and load factors	Does not fully account for dynamic thermal mass or complex glazing; limited for large or complex buildings
Heat Balance (HB) Method	Full surface and space heat balance solution; ASHRAE's most rigorous method	Requires software; higher effort; complex setup
TETD/TA (Total Equivalent Temperature Difference / Time Averaging)	Older simplified method using equivalent temperature differences over time	Superseded by RTS; less accurate for modern assemblies
TFM (Transfer Function Method)	Dynamic heat flow model using transfer functions	Largely superseded; complex for manual calculation
RTS (Radiant Time Series)	ASHRAE-recommended manual dynamic method balancing accuracy and practicality	More complex than CLTD/CLF; it requires careful setup