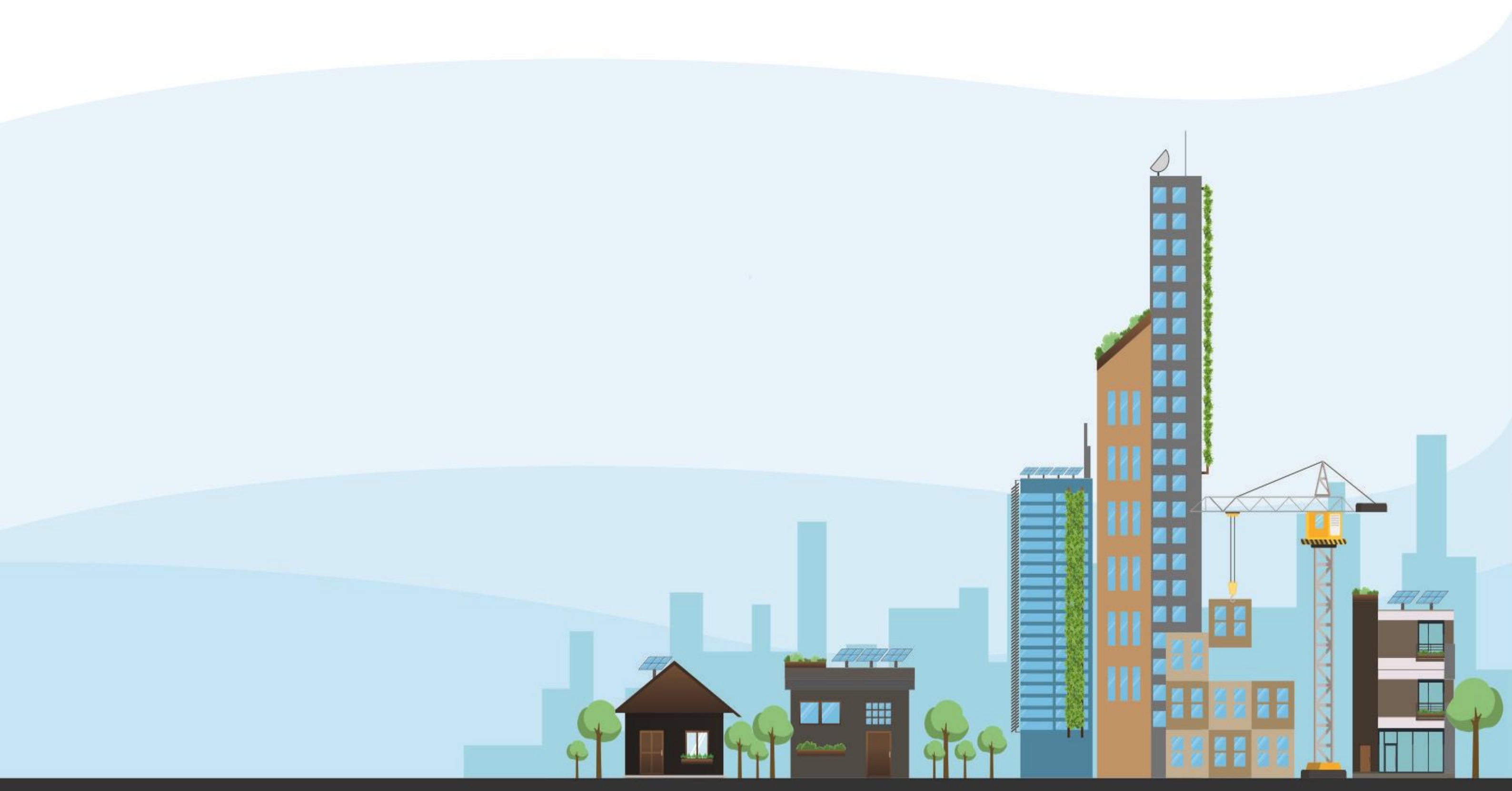
Ministry of Environment, Climate Change & Technology

Maldives Energy Efficiency Guideline for Buildings



Ministry of Environment, Climate Change & Technology

Strengthening Low Carbon Energy Island Strategies (LCEI) Project

This guideline was developed as part of the Strengthening Low Carbon Energy Island Strategies (LCEI) Project. The LCEI project was funded by the Global Environment Facility and executed by the Ministry of Environment, Climate Change and Technology, with implementation support from the United Nations Environment Programme.

This guideline is designed for key stakeholders in the Maldives' building sector, including policy makers, regulators, developers, architects, engineers, property managers, and academics. It focuses on the energy-efficient design, construction, and operation of buildings in the Maldives and aims to be instrumental in the development of energy-efficient buildings.

The guideline is based on findings from the "Assessment of Local Conditions and Building Systems Report," which can be accessed here.

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- State Electric Company Ltd
- Male' Water and Sewerage Company Ltd
- Dhiraagu
- Indhira Gandhi Memorial Hospital
- Maldives Monetary Authority
- Maldives National Association of Construction Industry
- State Trading Organization
- Utility Regulatory Authority

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1. Acknowledgement

Maldives has a high dependence on fossil fuels to meet all of its domestic energy demand and the use of fossil fuels have resulted in huge greenhouse gas (GHG) emissions and its associated climate change risks. Also, fossil fuels are imported, thereby making the Maldives vulnerable to global oil price shocks. Therefore, energy efficiency and conservation is very crucial for the Maldives to mitigate the climate change risk and achieve energy security. As the energy demand continues to grow at more than 8.5% per annum, Maldives' government initiated the "Strengthening Low Carbon Energy Island Strategies(LCEI)" project with support from the United Nation Environment Programme (UNEP) which encompasses several initiatives for mainstreaming energy efficiency in policies and building design practices to achieve substantial reduction of energy consumption from buildings. The Development of Energy Efficiency Guideline for Buildings is one such initiative under LCEI that targets to achieve energy efficiency in the design and operation of buildings in the Maldives.

2. About the Guideline

Buildings (including commercial and residential but not including those in resorts) in the Maldives consume approximately 30% of the total energy consumption in the region. Therefore, it becomes necessary to reduce the energy use in the buildings and related carbon emissions more so to achieve the country's commitment to reduce GHG emissions by 26% from the existing levels before 2030. The energy performance index (EPI)[1] of the existing building stock in Male and Hulhumale was found to be higher than that of the modern buildings which have adopted energy efficiency strategies in building design and operation. The Energy Efficiency Guideline for Buildings thereby specifies various energy efficiency strategies in the design and operation of buildings in the Maldives to reduce the energy use in buildings. Additionally, the guideline also provides strategies for reducing water consumption and the use of on-site renewable energy systems in the buildings so as to have a holistic approach towards designing green, sustainable and self-sufficient buildings in the Maldives.

The objective of the energy efficiency guideline is to facilitate building owners, builders/developers, energy consultants, engineers, and architects in designing and operation of resource (energy and water) efficient buildings of all sizes and types in the Maldives. This is achieved by providing minimum efficiency requirements for each of the following sections covered in chapter *6* to chapter *12* in this guideline:

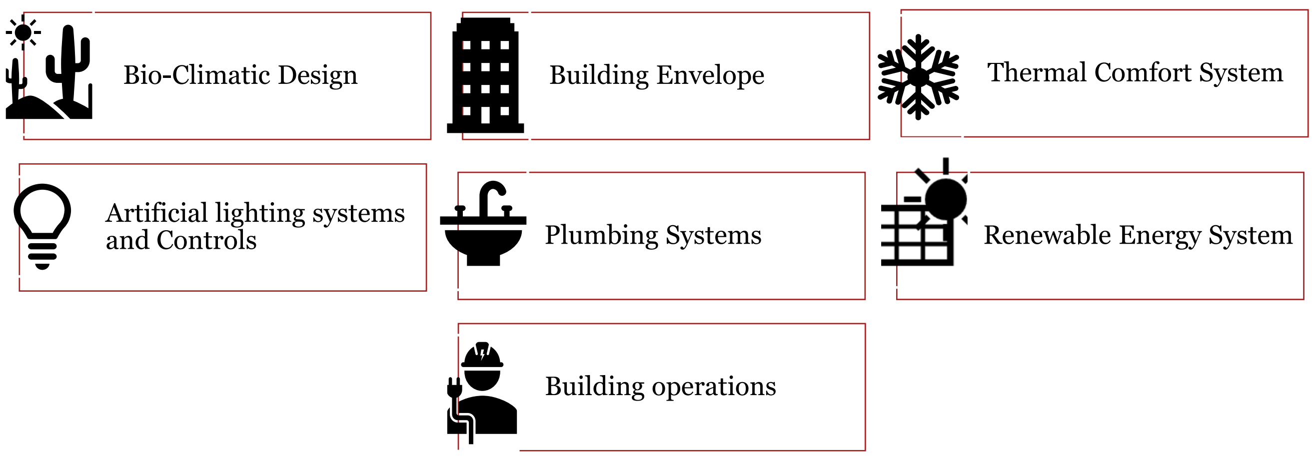

Figure 1: Aspects covered under building energy efficiency guidelines

The guideline also provides flexibility to the architects/engineers by providing an additional approach to achieve resource-efficient building design which involves undertaking computer-based whole building performance assessment, details of which are outlined in chapter *13*. The compliance to the guideline using either of the approaches is laid out in chapter *3* of this document. The guideline has been finalized after extensive consultation with all stakeholders by a committee of experts constituted by the Ministry of National Planning, Housing & Infrastructure, Ministry of Environment, Climate Change & Technology, and the local architects.

2.1. Purpose of the Guideline

The purpose of the Energy Efficiency Building Guideline is to provide minimum requirements for the energy and water-efficient design and operation of new and existing buildings in the Maldives. The guideline also provides additional sets of incremental requirements for buildings to achieve enhanced levels of resource (energy and water) efficiency that go beyond the minimum requirements.

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[1] Energy Performance Index of a building is ratio between its total annual energy consumption in kilowatt-hours (kWh) and built-up area in square meter.

2.2. Scope of the Guideline

The guideline is applicable to the following typologies **of new and existing buildings in Male and Hulhumale**:

1. Government Buildings
2. Commercial Buildings
3. Residential Buildings
4. Hotels and Guesthouses

The detailed applicability under each building typologies along with exemptions, precedence, and reference standards are given below.

2.2.1. Applicability

Categories of buildings that come under the scope of this guideline are:

1. **Government Buildings**: Buildings that are owned or operated or occupied by government officials for delivering public services. These are of two types:

   a) **Non- Communal:** Applies to a building or use in which any natural resources, goods, services or money are either developed, sold, exchanged or stored. Examples: an amusement park, auction room, bank, car-park, catering facility, computer center, fire station, funeral, library, office, police station, post office, public laundry, radio station, showroom, storage facility, television station or transport terminal.

   b) **Communal Non-Residential:** Applies to a building or use being a meeting place for people where care and service is provided by people other than the principal users. There are two types:

      i. Assembly Service: Applies to a building or use where limited care and service is provided. Examples: a mosque, cinema, clubroom, hall, museum, public swimming pool, stadium or theatre.

      ii. Assembly Care: Applies to a building or use where a large degree of care and service is provided. Examples: an early childhood centre, college, day care institution, centre for handicapped persons, kindergarten, school or university.

2. **Commercial Buildings**: Buildings that are owned or operated or occupied by private entities or individual for providing services such as:

   c) **Non- Communal:** Applies to a building or use in which any natural resources, goods, services or money are either developed, sold, exchanged or stored. Examples: an amusement park, auction room, bank, car-park, catering facility, café computer center, fire station, funeral parlour, salon, library, office, laundry, radio station, restaurant, service station, shop, showroom, storage facility, television station or transport terminal.

   d) **Communal Non-Residential:** Applies to a building or use being a meeting place for people where care and service is provided by people other than the principal users. There are two types:

      iii. Assembly Service: Applies to a building or use where limited care and service is provided. Examples: a mosque, cinema, clubroom, hall, museum, public swimming pool, stadium or theatre.

      iv. Assembly Care: Applies to a building or use where a large degree of care and service is provided. Examples: an early childhood centre, college, day care institution, clinic, centre for handicapped persons, kindergarten, school or university.

3. **Residential Buildings**

a) **Housing:** Applies to buildings or use where there is self-care and service (internal management). There are three types:

i. Detached Dwellings: Applies to a building or use where a group of people live as a single household or family. Examples: a holiday cottage, boarding house accommodating fewer than 6 people, dwelling or hut.

ii. Multi-unit Dwelling: Applies to a building or use which contains more than one separate household or family. Examples: an attached dwelling, flat or multi-unit apartment.

iii. Group Dwelling: Applies to a building or use where groups of people live as one large extended family. Examples: within communal housing centers.

b) **Communal Residential:** Applies to buildings or use where assistance or care is extended to the principal users. There are two types:

i. Community Service: Applies to a residential building or use where limited assistance or care is extended to the principal users. Examples: a boarding house, hall of residence, holiday cabin, hostel, nurse's home.

ii. Community Care: Applies to a residential building or use where a large degree of assistance or care is extended to the principal users. There are two types:

- Unrestrained: where the principal users are free to come and go. Examples: a hospital, an old people's home or a health camp.
- Restrained: where the principal users are legally or physically constrained in their movements. Examples: a borstal or drug rehabilitation centre, an old people's home where substantial care is extended, a prison or hospital.

c) Mixed-use Residential: Applies to buildings where the upper floors are Multi-unit dwellings and the lower floors are non-communal use in which any natural resources, goods, services or money are either developed, sold, exchanged or stored.

4. **Hotels and Guesthouses:** Any building in which sleeping accommodation is provided for commercial purposes, except any building classified under healthcare such as hospitals. Buildings and structures under Hotels and Guesthouses shall include No-star Hotels like Lodging-houses, dormitories, no-star hotels/motels, Resort, Star Hotels.

In case, any of the building(s) do not fall under any of the building categories defined above, then such building(s) shall be classified in a category mentioned above that best describes the function of the building(s).

2.2.2. Exemption

The guidelines do not cover hotels and resorts in tourism islands.

2.2.3. Precedence

1. Any code(s) or bye-laws.
2. Any rules on safety, security, health or environment by Government.

2.2.4. Reference Standards and green building rating programmes

1. Maldives National Building Code
2. Planning Regulation of Male and Hulhumale
3. Maldives Standards & Labeling standards for air conditioners
4. Energy Conservation Building Code 2017 – India
5. National Building Code-Australia
6. CARICOM Regional Energy Efficiency Building Code- Caribbean Island
7. European Standard for lighting - EN 12464-1:2019
8. BREEAM Certification
9. Singapore BCA Green Mark Scheme
10. Indian Green Building Council’s manual for New Buildings, Green Homes, Green Schools, etc.
11. ASHRAE standards for thermal comfort
12. ANSI/AHRI Standard 1230
13. ANSI/ AHRI 550/ 590 conditions

3. Compliance Approach and Requirements to the Guideline

This chapter outlines the approach and requirements to demonstrate compliance with the guideline.

3.1. Compliance Approach

Since every building project is unique, for example, the aesthetic appeal of a building design is dependent on the user preference. Therefore, the architects and engineers would need more flexibility while designing the building to accommodate diverse user requirements and compliance with the guideline. The guideline addresses such challenges by providing multiple approaches to comply with the guideline.

To comply with the guideline, a building shall adopt either of the two approaches listed below:

1. meet all the mandatory requirements specified in chapter *6* to chapter *12*. This is known as the "Perspective Method.

   or,

2. having an Energy Performance Index Ratio (EPI Ratio) (defined in section *3.1.1)* that is less than or equal to 1. This is achieved by meeting the "Whole Building Performance" method.

The Perspective Method offers distinct and discrete actions. The Prescriptive method contains a menu of options describing ***mandatory requirements*** for different design and construction elements. Common prescriptive measures include

- Minimum U-values for insulation or wall assemblies,
- Efficiency requirements for mechanical systems

Additionally, the guideline provides certain **non-mandatory recommendations** in the Prescriptive Method approach to accommodate topographical limitations in building design and construction practices of the region which the developer/architect/engineer can adopt on a voluntary basis. The Prescriptive Method also encourages developer/architect/engineer to design for higher efficiency levels by specifying enhanced efficiency levels that go beyond the minimum mandatory requirements.

In the Whole Building Performance Method, energy simulations are carried out using computer-based analytical tools to evaluate the energy performance of the building and make it more energy efficient by undertaking necessary modifications in the building design before its construction. The "Whole building Performance" approach with approved computer software tools is given in chapter *13* of this report.

3.1.1. Energy Performance Index

The Energy Performance Index (EPI)[2] of a building is a ratio between its total annual energy consumption in kilowatt-hours (kWh) and the built-up area in square-meters. But while calculating the EPI of the building, the area of unconditioned basements is not included. The EPI of a building is determined by:

$$\text{EPI} = \frac{\text{Total Annual Energy Consumption of the building in kWh}}{\text{Total built-up area in square meters (excluding unconditioned basement)}}$$

[2] Energy Conservation Building Code 2017 – India

3.1.2. Determining of Energy Performance Index Ratio

The EPI ratio of a building is the ratio of the EPI of the proposed building to the EPI of the Standard Building:

$$\text{EPI Ratio} = \frac{\text{EPI of Proposed Building}}{\text{EPI of Standard Building}}$$

Where,

A standard building is a standardized building that has the same design configuration such as building floor area, gross wall area, and gross roof area as the proposed building that complies with the minimum requirements specified in chapter *6* to chapter *12* of this guideline.

3.2. Compliance Requirements

The provisions in the guideline are applicable to all the existing and new buildings in Male and Hulhumale in the Maldives. The buildings shall comply with requirements of the guideline during the **design, construction, and operation stage** by:

3.2.1. New Buildings

New Buildings shall **comply** either by meeting all the requirements mentioned in chapter *6* to chapter *12* of this guideline or by the Whole Building Performance approach provided in chapter *13* of this report during the **design and construction stage of the building**.

3.2.2. Existing Building

The provisions of the guideline are applicable to the existing building whenever retrofitting work is carried out in its design and systems. Retrofitting can either be any new additions to the existing building or any alterations to the existing building. For both cases, the compliance requirements are provided in the below sections.

Note- Systems here include thermal comfort, lighting, plumbing, and renewable energy systems.

3.2.2.1. New Additions to Existing Buildings

Any new structural additions to the existing building design and its systems shall demonstrate compliance to the guideline by meeting all the **applicable requirements** specified in chapter *6* to chapter *11* of this guideline.

For example:

1) If new air conditioner systems are installed in an existing building, then the new air conditioner systems shall comply with requirements mentioned in chapter *8* of this guideline

2) If a new block/building is constructed in the premises of an existing building, then the design and systems employed in the new block/building shall comply with requirements mentioned in chapter *6* to chapter *11* of this guideline.

Note: However, if in the new addition, the space conditioning is provided by existing systems and equipment, then such existing systems and equipment need not comply with the provisions of the guideline.

3.2.2.2. Alterations to Existing Buildings

Any alterations to the existing building design and its systems shall demonstrate compliance to the guideline by meeting all the **applicable requirements** from chapter *6* to chapter *11* of this guideline.

For example, if the old air conditioners systems are replaced with new air conditioner systems in an existing building, then the new air conditioner systems shall comply with requirements mentioned in chapter *8* of this guideline

3.2.3. Compliance in Operation Stage (Chapter 12)

Chapter *12* specifies various post-occupancy energy efficiency strategies which the building occupants must adopt to reduce building energy use during the building operation. Both existing and new buildings shall comply with the requirements mentioned in Chapter *12* of this document.

4. How to use the Guideline

The Energy Efficiency Guideline for the buildings is designed in a simple and easy to understand format. The guideline uses the following colour coordinated format for chapters *6* to *12*:

1. The **bold text highlighted** in the yellow box specifies the **mandatory requirements** the users have to incorporate in the building design and operation practices for compliance with this document. In some cases, users are provided an option to design for higher efficiency in normal text. An example of mandatory requirements is shown below:

Box 5.2.2 : **Prescriptive requirements for Window to Wall Ratio (WWR)**

For Maldives, based on the energy simulation results, the optimum requirement for WWR is 40%.

However, the users can design for higher efficiency levels by reducing the WWR ratio to 30%

Additionally, under some topics, the **mandatory requirement and higher level of efficiencies are provided in the dark red-coloured table in bold and normal text respectively**. An example of the same is provided below:

Box 7 -A : Prescriptive requirements for non-centralized (Unitary AC system)

For all Single-phase single-split and unitary type air conditioners of both fixed speed and variable speed types compressors, for household use including the rated capacities of up to 30000 Btu/hr.

For all split, window AC having cooling capacity <4.5 kW (1.3 TR) and between 4.5 kW to 7.1 kW (1.3 TR to 2 TR), the minimum CSPF (cooling seasonal performance factor) should be, at least level 1:

Table 5: Minimum mandatory requirements and higher levels of efficiencies for unitary air conditioners

	Value of CSPF (Wh/Wh)		
Size category	**Efficiency level 1 (Mandatory (Hakathari rating level 2 - 3))**	Efficiency level 2 (Hakathari rating level 4)	Efficiency level 3 (Hakathari rating level 5)
For ACs with cooling capacities < 4.5 kW	**3.30 – 4.60**	4.60 – 5.30	≥5.30
For ACs with cooling capacities between 4.5 kW and 7.1 kW	**3.10 – 4.00**	4.00 - 5.10	≥5.10

Reference: Hakathari Labelling Programme for AC for Maldives can be referred for updated values.

1. Cooling Seasonal Performance Factor (CSPF): ratio of total amount of heat the equipment can remove from indoor air when operated for cooling in active mode to the total annual amount of energy consumed by the equipment during the same period. Its unit is Wh/Wh

2. For fixed speed air conditioners, CSPF =1.062 × 〖EER〗 tested at 100% capacity. Energy Efficiency Ratio (EER) is defined as ratio of total cooling capacity to effective power input at any given rating condition. Its unit is kW/kW

2. The text in the red box specifies examples, concepts of building physics along with references and provisions from other regulations and policies, etc. to guide the users for better understanding and applicability of the Energy Efficiency Guideline. An example of the same is shown below:

Box 5-E: Male Planning Regulation Provisions

In the Male planning regulation, under the criteria "Cantilevering to the street" stipulates that,

- Making a part of the building cantilever onto the road above the height of 30.48m is not permitted. It is permitted only if there is no adjacent building
- Above the height of 30.48m, roofs, concrete bricks, Sun shading devices, balconies, and space to keep materials used for building services such as air conditioning must not extend onto the street beyond more than 0.457m

5. Climate Classification & Analysis of Maldives

The climate classification for the Maldives is "**Tropical Monsoon Climate" as per the Koppen-Geiger system of Climate Classification.**

Maldives consists of tropical monsoon climate, also known as a tropical wet climate or tropical monsoon, and trade –wind seaside climate in climatic classification. In tropical monsoon climates, the monthly mean temperature generally remains above 29°C in the entire year. Twelve months of the years are divided into dry and wet seasons. The dry season is for four months only (from January to April) and has a minute influence on the whole climate, and the wet season lasts between May to December. The average annual temperature at Male is 28.9 °C and the average wind speed is 4.5 m/s.

Box 4-A: About Climatic Classification based on Köppen-Geiger system

The Köppen climate classification is one of the most widely used climate classification systems. This system, in general, recognizes five major climate types based on the annual and monthly averages of temperature and precipitation. The five climate groups, as shown in the above figure, are:

Group A: Tropical climates
Group B: Dry (arid and semiarid) climates
Group C: Temperate climates
Group D: Continental climates
Group E: Polar climates

These are the main group of the Koppen Geiger climate classification. The classification of the climate of any country, under the Köppen-Geiger system, is represented with the help of three letters. The second letter refers to the seasonal precipitation subgroup. The letter E stands for Polar climate zone and does not have a subgroup in terms of precipitation. The third and last letter of this type of climate classification method stands for rainfall and indicates the level of heat. This subgroup is not mentioned in the case of tropical Climate which is denoted by the letter A.

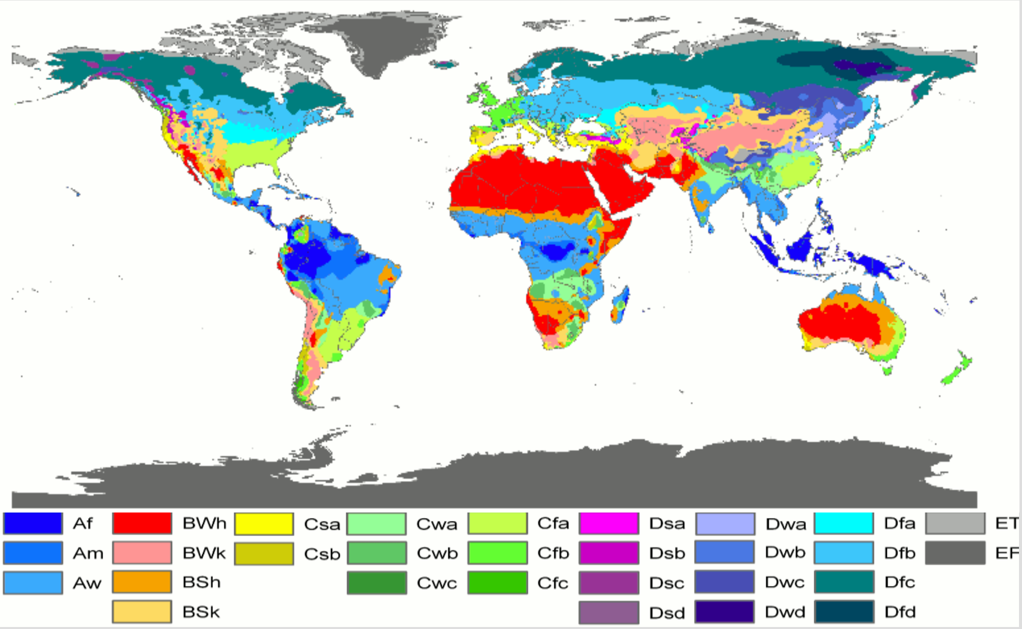


Figure 2: World Map of Climate classification based on Köppen-Geiger system

Thus, the climatic classifications are:

1. Af: Tropical Rainforest climate
2. **Am: Tropical monsoon climate**
3. Aw: Tropical Savannna climate
4. BWh: Hot desert climate
5. BWk: Cool desert climate
6. BSh: Hot Steppe climate
7. BSk: Cool steppe climate
8. Csa: Dry summer subtropical
9. Csb: Dry summer subtropical climate (cooler than Csa)
10. Cwa: Dry winter humid subtropical climate
11. Cwb: Dry winter maritime temperate climate
12. Cwc: Dry winter maritime temperate climate (cooler than Cwb)
13. Cfa: humid subtropical climate
14. Cfa: maritime temperate climate
15. Cfa: maritime subarctic climate
16. Dsa: Dry summer continental climate (with hot summer)
17. Dsb: Dry summer continental climate (with warm summer)
18. Dsc: Dry summer continental climate (with cool summer)
19. Dsd: Dry winter continental climate (with very cold winter)
20. Dwa: Dry winter continental climate (with hot summer)
21. Dwb: Dry winter continental climate (with warm summer)
22. Dwc: Dry winter continental climate (with cool summer)
23. Dwd: Humid continental climate (with very cold winter)
24. Dfa: Humid continental climate (with hot summer)
25. Dfb: Humid continental climate (with warm summer)
26. Dfc: Humid continental climate (with cool summer)
27. Dfd: Humid continental climate (with very cold winter)
28. ET: Tundra climate
29. EF: Ice cap climate
30. Cwc: Dry winter maritime temperate climate (cooler than Cwb)

The Koppen Climate Classification type for the tropical wet climate is “Am” (Tropical Monsoon Climate). March and April are considered warm months with an average temperature of 29.5 °C and December and January are the coldest months with an average temperature of 28.3 °C. There is an average of 150-160 days of rainfall in Male and Hulhumale. The average maximum rainfall is received in May i.e. 12.4 mm and the average minimum rainfall is received in March i.e. 4.4 mm.

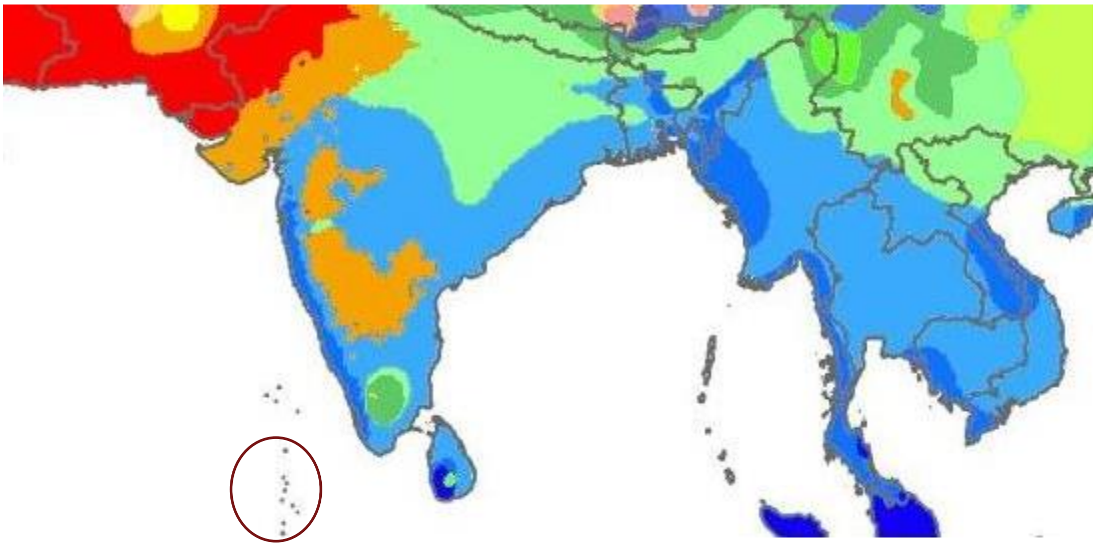


Figure 3: Climate classification of Male, Maldives based on Köppen-Geiger system

5.1. Climate analysis based on the information collected from Maldives Meteorological Service (MMS)

Maldives Meteorological Service (MMS) is the meteorological department of Maldives. This department provided the climate data comprising of Temperature (min. & max), Relative humidity, Wind speed, and Rainfall for the period 2008 -2018 for Male, Maldives. External climate components that affect the internal environment are air temperature, relative humidity, rainfall, wind, and solar radiation. The same has been analyzed in the subsequent sections.

5.1.1. Analysis of temperature data

Figure 4 analyses the monthly average temperature along with the minimum and maximum temperatures recorded in Male.

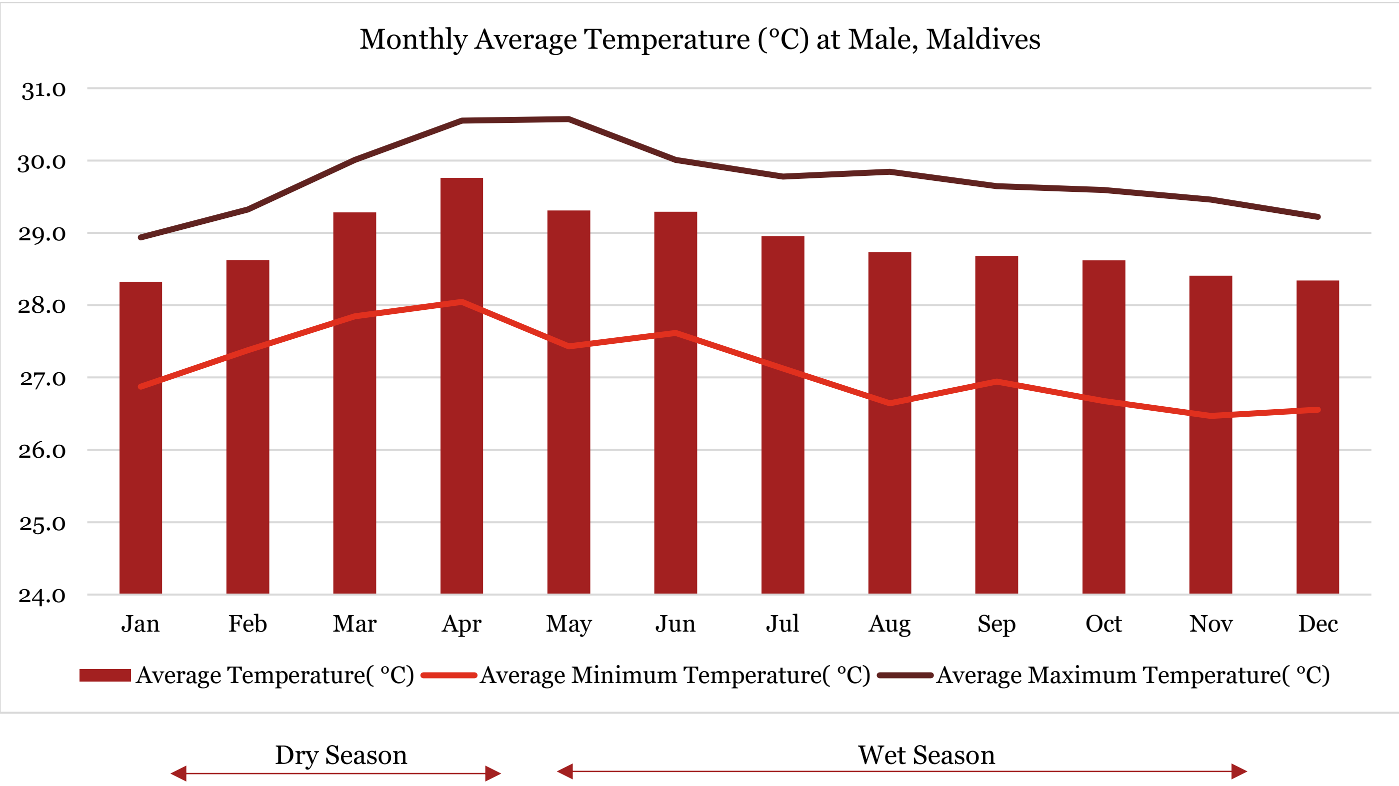


Figure 4: Monthly Average Temperature at Male, Maldives (°C)

Figure 4 shows the monthly average temperature range of Male in the years 2008 – 2018. It is observed that the temperature is almost constant and remains above the thermal comfort level throughout the year. The monthly average temperature increases during January-March, peaks in April, starts decreasing during May-August, and remains constant thereafter till the end of the year. The average temperature for the dry season is 29 °C with the highest average temperature of 29.8°C in April. The average temperature for the wet season is 28.8 °C with the lowest average temperature of 28.3°C in December. As the temperature remains above the thermal comfort level throughout the year, there is a significant energy demand for space cooling.

To study the impact of climate change in the Male region, the annual average temperature for the years 2008 to 2018 is analysed and the same is presented in *Figure 5*.

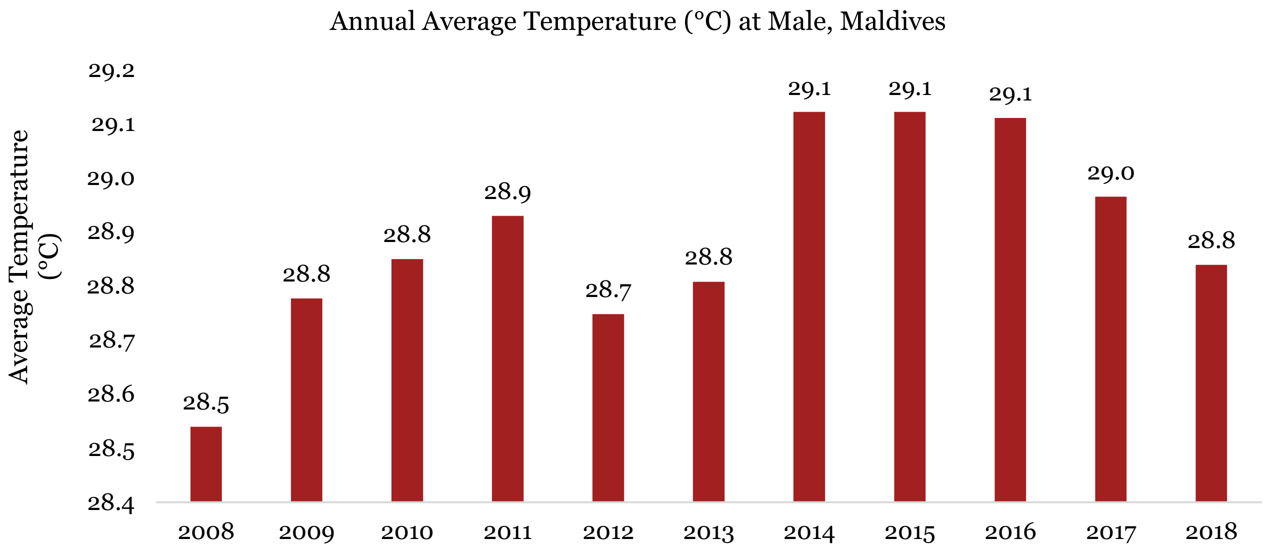


Figure 5: Annual Average Temperature at Male, Maldives (°C)

Figure *5* shows the annual average temperature of Male in the years 2008 - 2018. It can be concluded that the average temperature of the decade has been **28.9 °C** .

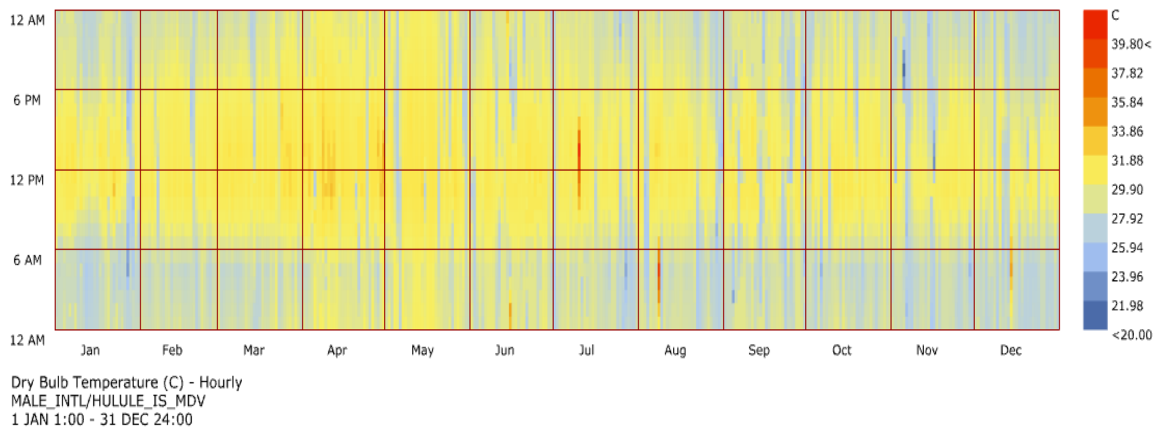


Figure 6: Daily Temperature in Male

Figure *6* shows the daily temperature range for Male. The temperature range is approximately between 29.9 °C and 31.8 °C during the day and between 21.9 °C and 23.9 °C at night. The average diurnal temperature difference was observed to around 8-10°C

5.1.2. Analysis of Relative Humidity Data

Relative humidity has a substantial impact on the thermal comfort level of building occupants in addition to the ambient air temperature.

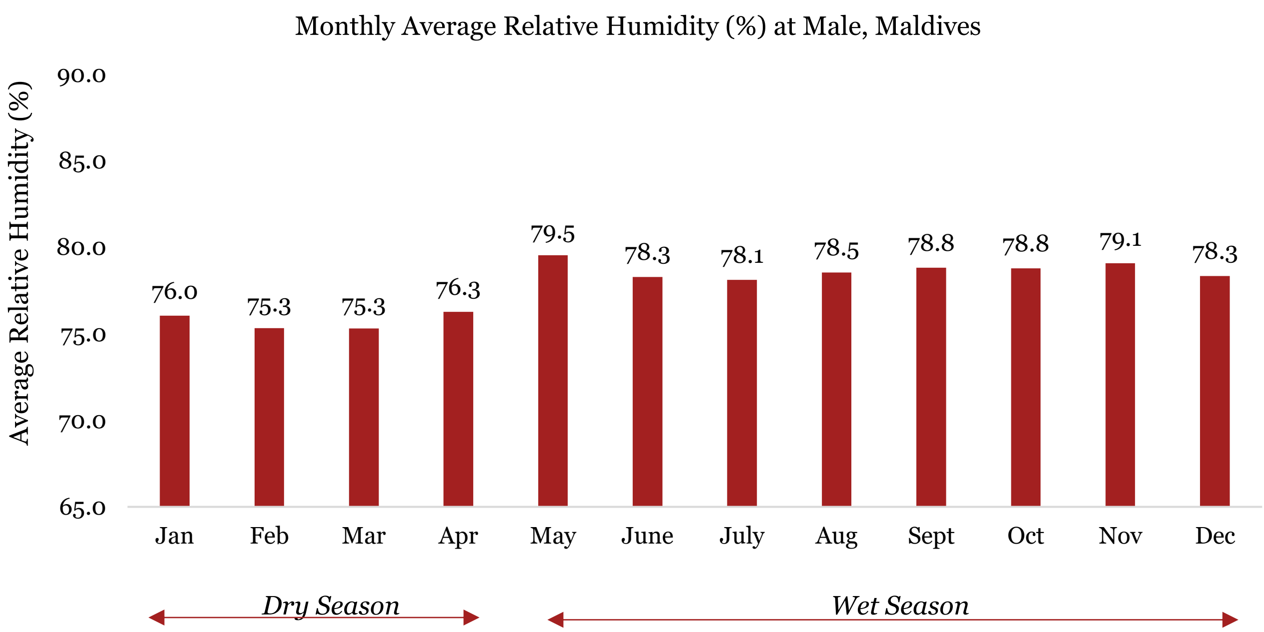


Figure 7: Monthly Average Relative Humidity at Male, Maldives (%)

Figure *7* shows the monthly relative humidity (in %) of Male, Maldives in the years 2008 – 2018. It is observed that the average relative humidity ranges from 75% to 80% throughout the year. It can be concluded that the relative humidity is high, above 75% throughout the year.

Box 4-B: Analysis of Humidity data

As seen in Figure *9* High temperature and high humidity cause discomfort if perspiration is not dissipated. A design strategy for this condition is to enhance air movement. In the second case, the dry air leads to a faster rate of evaporation. Here, high temperature and low humidity cause discomfort resulting in dehydration and heatstroke. A design strategy for this condition is to use water bodies for evaporative cooling.

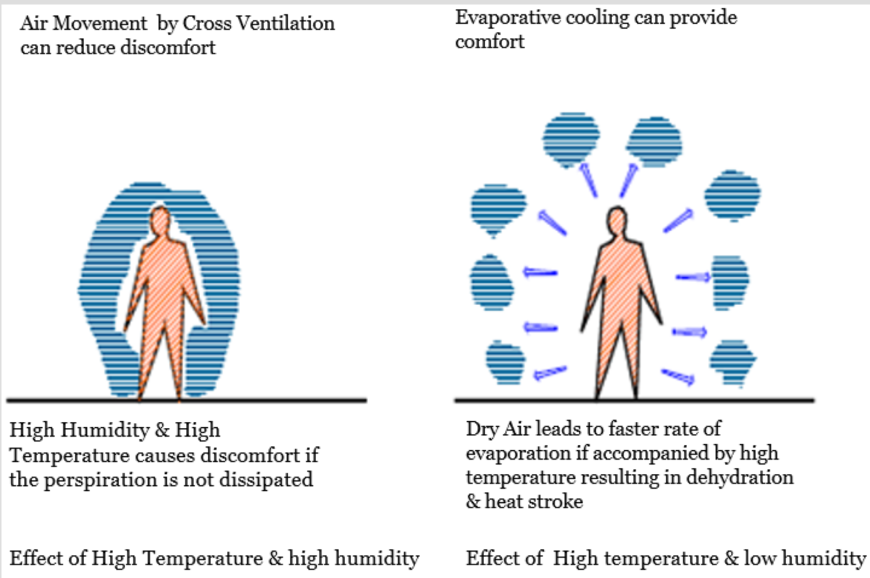


Figure 8: Image showing Relative humidity of human body at different conditions

5.1.3. Analysis of Rainfall Data

The annual daily average rainfall data in the years 2008- 2018 is presented below.

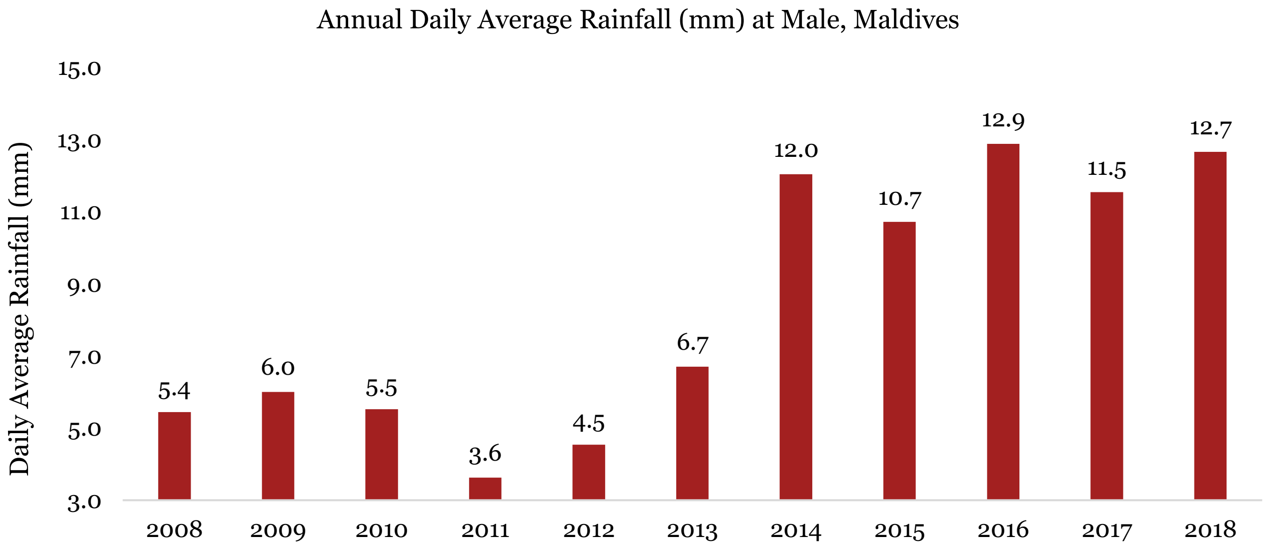


Figure 9: Annual Daily Average Rainfall at Male, Maldives (mm)

Figure *9* shows the annual daily average rainfall (in mm) of Male in 2008 – 2018. It can be observed that the rainfall increased during the years 2008 to 2010, then a sudden decrease in rainfall was observed in the years 2011 and 2012. The highest rainfall was recorded in the years 2016 and 2018. The analysis indicates that the overall rainfall has increased from 2008 to 2018 by 57%.

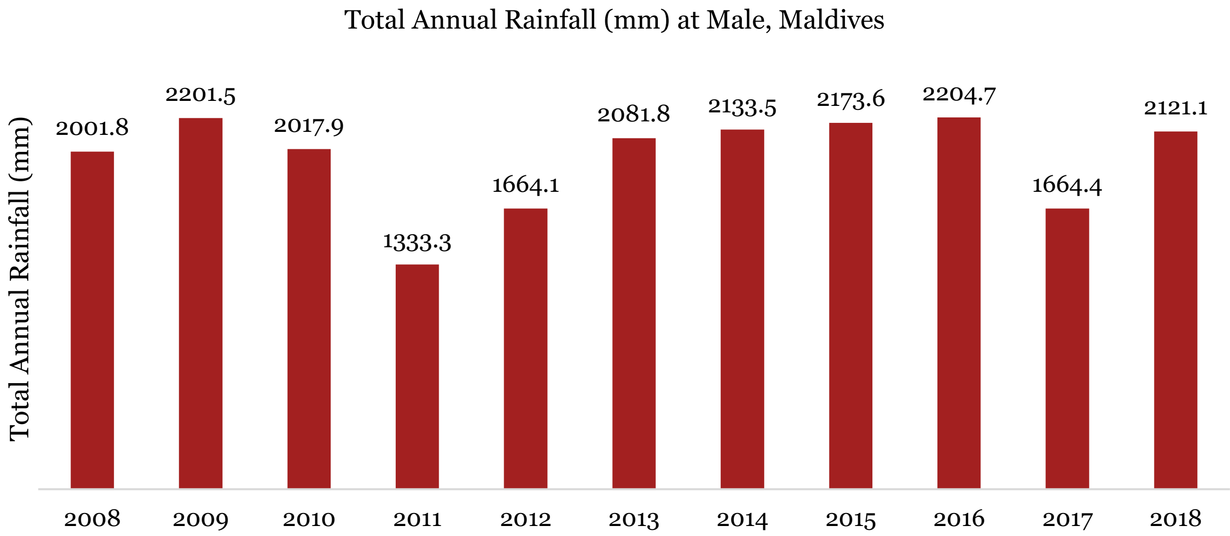


Figure 10 Total Annual Rainfall at Male, Maldives (mm)

Figure *10* shows the total annual rainfall (in mm) of Male, Maldives in the years 2008 – 2018. The annual average rainfall is approximately 2160mm.

5.1.4. Analysis of Wind Speed

The wind speed plays a significant role in ensuring proper design and orientation of windows that allow fresh air into the indoor spaces of the building to provide appropriate ventilation for building occupants.

The monthly average wind speed for different months in a year in Male, Maldives is presented below.

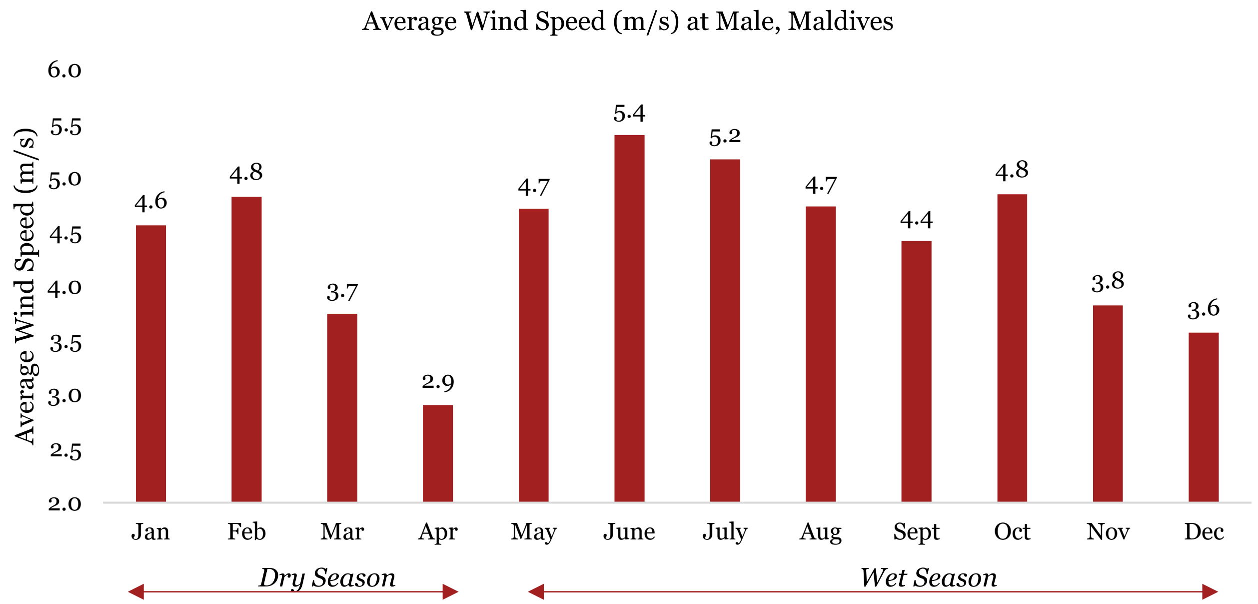
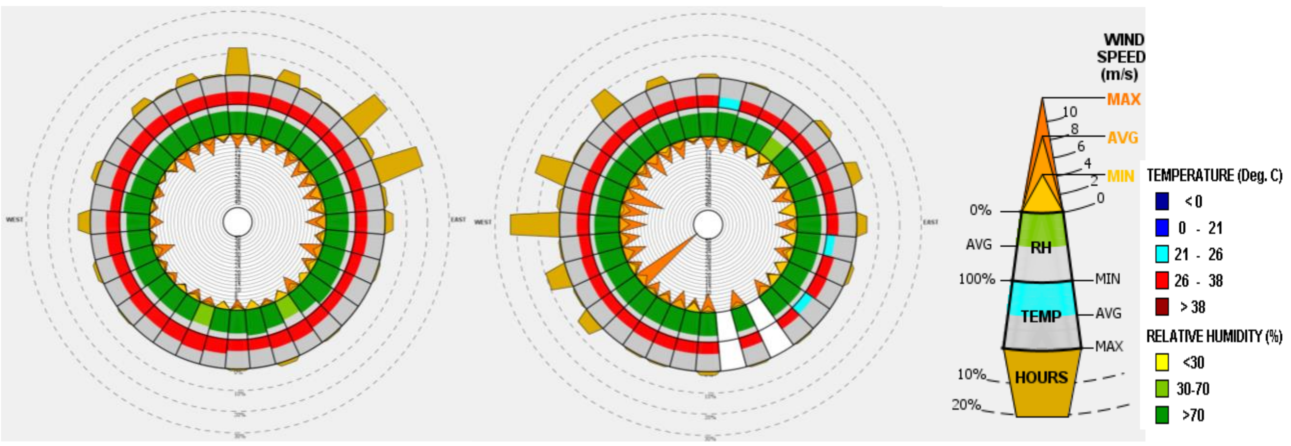


Figure 11: Monthly Average Wind Speed at Male, Maldives (m/s)

Figure *11* shows the monthly average wind speed (in m/s) of Male. It can be concluded from the above graph that the wind speed is highest in June and lowest in April. The average wind speed in the dry and wet seasons is 4.0 m/s and 4.6 m/s, respectively.

The annual wind-rose from January to December is shown in Figure *12*.



Wind-Rose for Dry season (Jan- April) in Male, Maldives

Wind-Rose for Wet season (May Dec) in Male, Maldives

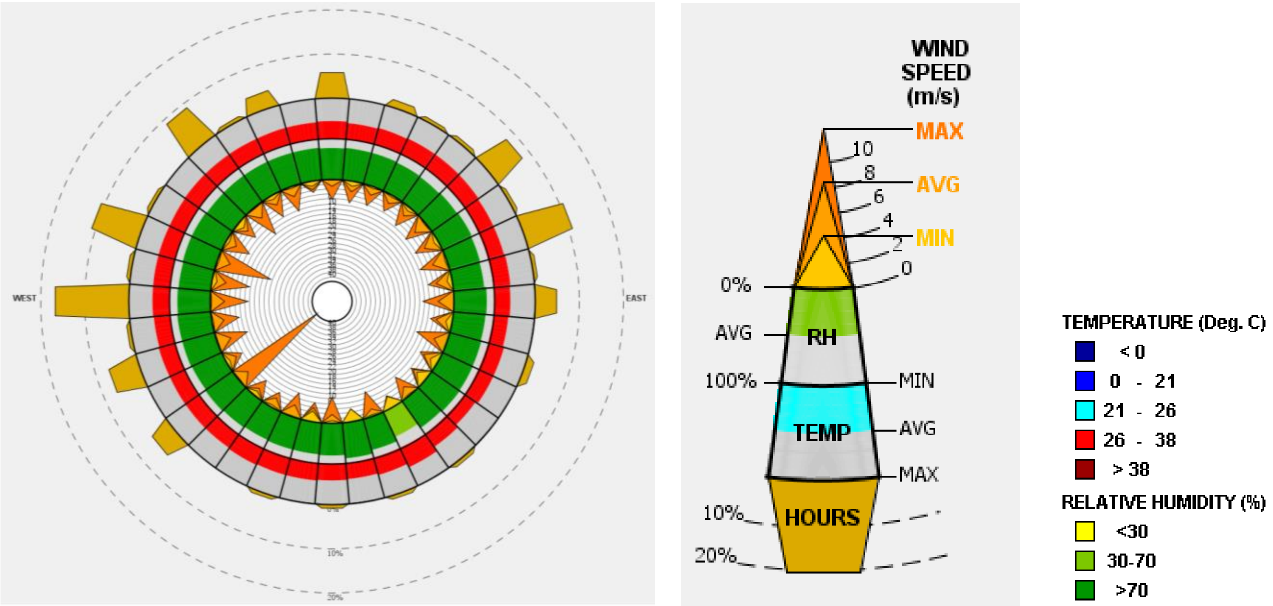


Figure 12: Wind-Rose diagram showing annual wind direction (m/s) for Male, Maldives

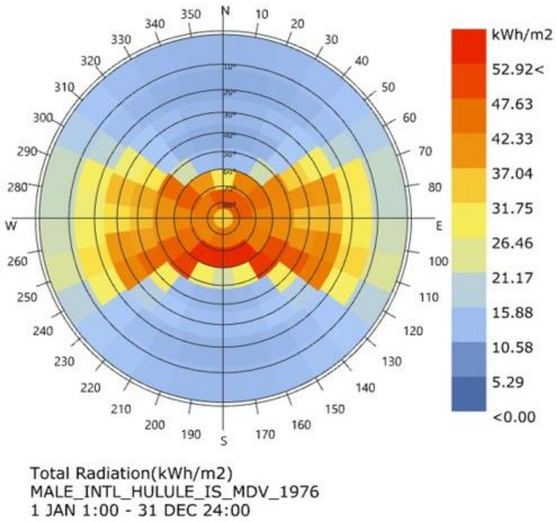
Figure *12* shows the annual wind-rose. The analysis above shows that:

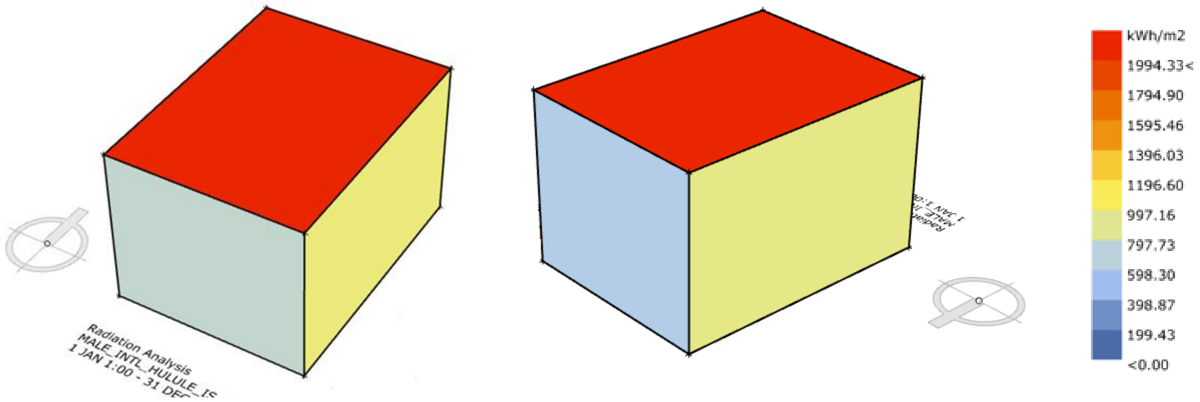
- Wind flows in high frequency from North East (NE) direction in the dry season
- Wind flows in high frequency from the west direction in the wet season
- Predominant wind direction is West for the most part of the year

Maldives experiences high relative humidity throughout the year. During the wet period, the air is warm and humid. Therefore, for thermal comfort in outdoor areas, maximizing the wind on site can be an effective strategy. By having enhanced wind movement, body heat dissipation can be increased which would make space users feel comfortable. Therefore, effective natural ventilation by harnessing West winds for outdoor spaces and mechanical ventilation for indoor spaces should be provided. The microclimate of the building site can also be improved through vegetation, shaded walkways, and seating areas etc.

5.1.5. Analysis of Solar Radiation

The direct solar radiation analysis studies the total amount of direct solar radiation energy falling over different surfaces (For example, building façade, roof etc,.) in buildings. It is expressed in kWh/Sqm. The higher the value of solar radiation, the higher would be the exposure intensity of that surface to direct solar radiation. High solar radiation would result in higher absorption of solar heat by the surface and a subsequent increase in surface temperature. Through building facades, high solar radiation can result in higher heat gains into the interiors. In the summer season, this means increased air conditioning load. While in the winter season, it means a lower heating load. The solar radiation analysis also helps in developing solar energy harness strategies for the project. Figure *13* shows the solar radiation analysis for all critical orientations and roofs of a building.





Solar Radiation received on East and South facades of a typical building

Solar Radiation received on North and West facades of a typical building

Figure 13: Analysis of Radiation for Male, Maldives

Figure *13* shows that the North facades receive the lowest solar radiation of 600 kWh/sqm, whereas the East and West facades receive the highest solar radiation of 1200 kWh/sqm. The South facades receive solar radiation of 1000 kWh/sq.m. However, the roofs receive solar radiation of 2000 kWh/sqm.

Box 4-C: Solar Radiation Basics

The electromagnetic radiation emitted by the sun is termed solar radiation. Part of the solar radiation is absorbed, scattered, and reflected by the parameters like water vapour, air molecules, clouds, pollutants, dust, etc. This is called diffuse solar radiation, which is the sunlight that has been scattered by molecules and particles in the atmosphere but that has still made it down to the surface of the earth. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation, traveling on a straight line from sundown to the surface of the earth. The sum of the diffuse and direct solar radiation is called global solar radiation received by a unit horizontal surface. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

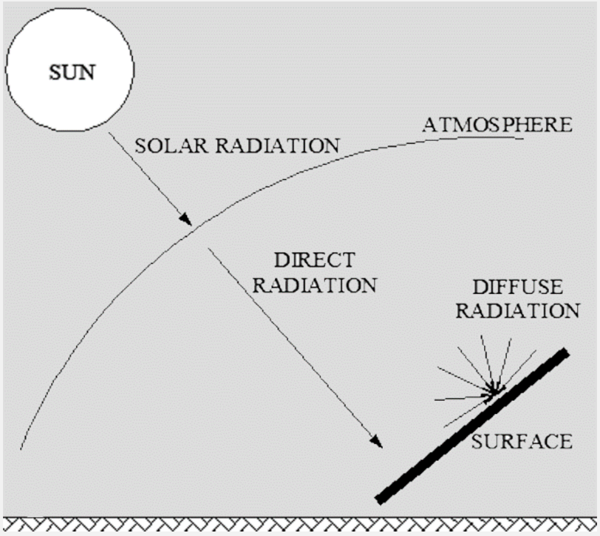


Figure 14: Types of solar radiation

Solar radiation plays a vital role in buildings. The building design should utilize solar radiation to cater to the lighting and heating requirement of the occupants to the maximum possible extent in the daytime from the radiation to provide comfort depending upon the climatic condition of the region. Hence, the architects must study the sun's movements while designing a building. The best practices in building designs that make the best use of solar radiation are discussed in further sections.

5.1.6. Psychrometric Analysis and Passive Strategies Evaluation

A psychrometric chart is a graphical representation of the psychrometric processes of the air. The psychrometric processes of air include physical and thermodynamic properties such as dry bulb temperature, wet bulb temperature, humidity, enthalpy, and air density. A typical psychrometric chart of air is illustrated in Figure 15 .

In the chart, the x-axis represents the dry bulb temperature of the air while the y-axis represents the moisture content of the air. The vertical scale or the y-axis is also called absolute humidity and can be shown as the humidity ratio in grams of water per kilogram of dry air, or as the vapor pressure. The curved line on the far left of the chart is the saturation line (100% Relative Humidity line) which represents the fact that at lower temperatures air can hold less moisture than at higher temperatures.

Each green dot on the chart represents the temperature and humidity of each of the 8760 hours in a year. The specific zones in the psychrometric chart represent different Design Strategies. The percentage of hours that fall into each of the 16 different Design Strategy Zones gives a relative idea of the most effective passive cooling strategies. Figure 15 analyses the distribution of psychrometric data of Male in the most effective Design Strategy Zone to create a unique list of design guidelines. Comfort criteria are defined using ASHRAE Standard 55 -2004 Comfort model.

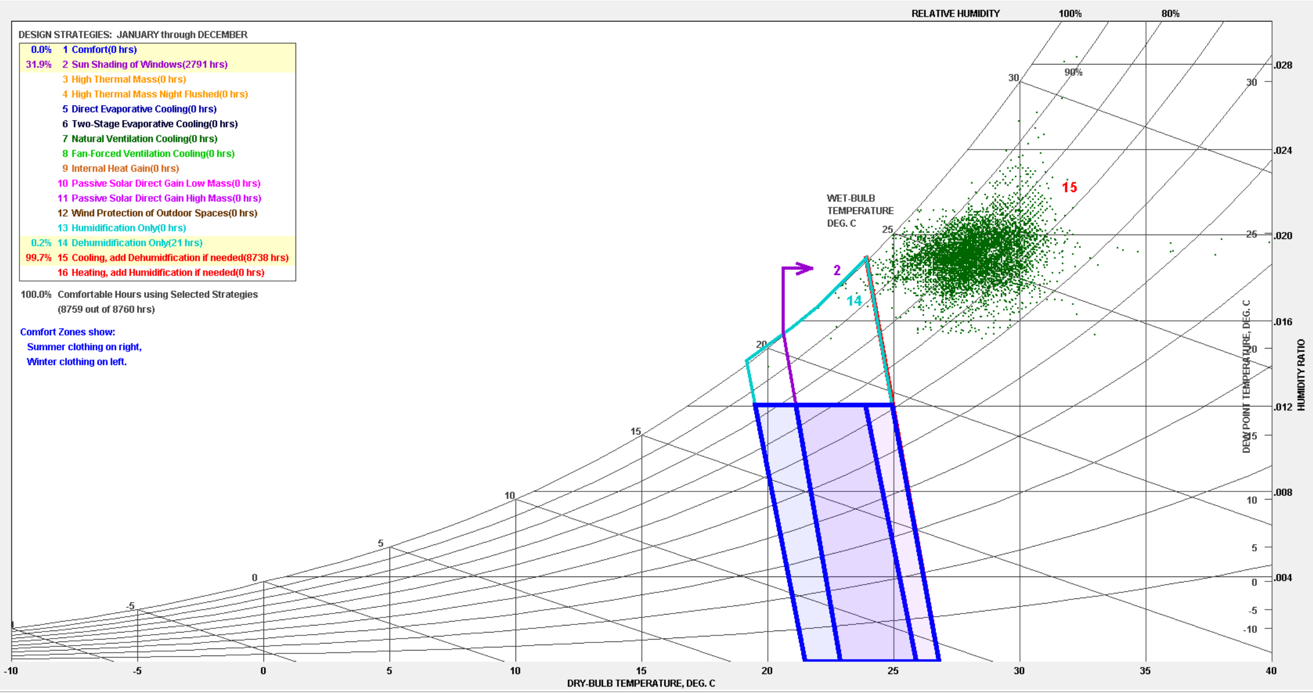


Figure 15: Psychrometric chart analysis for passive design strategies

The psychrometric chart analysis of a typical building structure in Male indicated that the occupants could not experience thermal comfort naturally without the air conditioners due to high humidity throughout the year in the region. Therefore, various passive and low-energy building design strategies can be effective to achieve better thermal comfort reduce the air conditioning load of the building. Some of the passive and low energy building design strategies are:

1. **Building Form and Orientation-** Building architectural form and orientation in a Tropical Monsoon climate can greatly affect the indoor climatic conditions, occupant comfort, and energy consumption for air conditioning. The orientation of buildings should be designed to reduce the solar heat gains inside the building. The optimum shape for minimizing solar gains is achieved by elongating the north and south walls, creating a prominent east-west axis. Eastern and western exposures should be minimized, since they are difficult to shade and receive longer periods of direct radiation. Southern and northern exposures are easier to shade, especially with roof overhangs.

2. **Solar shading** is the single most effective strategy which will be effective for 32% of the total hours in a year. It will be effective to reduce overheating in the summer and monsoon seasons. Solar shades are recommended in the East, West, and South facades of all buildings as shown in Figure *16*. More on solar shading is provided in section *6.3.3* of this document.

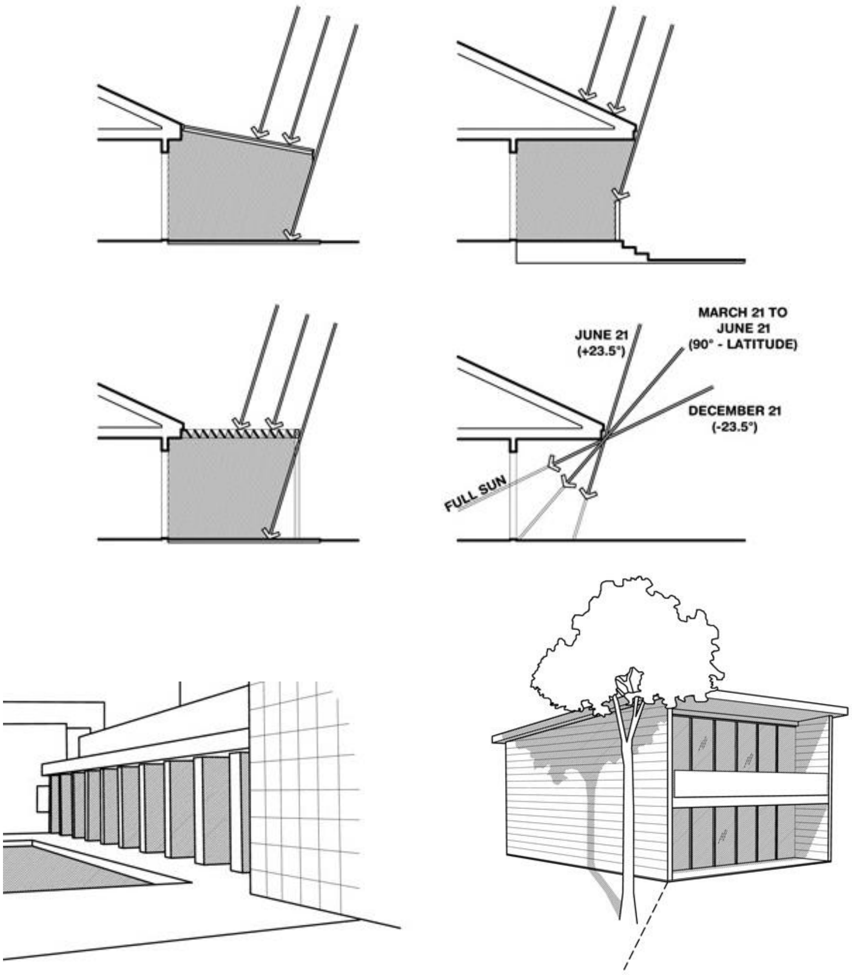


Figure 16: Solar shades are recommended in east, West and South facades of all buildings

Residential buildings should be provided with adequate openings in the external façade in order to facilitate for cross ventilation in the dwelling units.

3. **Reducing internal heat gains** will be effective during the summer and monsoon seasons. The internal heat gains can be reduced by optimizing occupant density, indoor lighting power, and equipment power of the building. The energy efficient LED and CFL light fixtures are recommended in the building to achieve optimized LPD (lighting power density) values for the buildings.

4. **Increased Natural ventilation** will help dissipate body heat more effectively during summer and monsoon periods. Ventilation on building sites can be improved by raising buildings on stilts, the orientation of building to enhance wind movement, providing cross or mechanical ventilation for indoor spaces.

5. **Window to wall area ratios:** High window-to-wall area ratio should be avoided in the South, East, and West facades in order to minimize the solar radiation. This would improve the thermal comfort indoors and reduce the air-conditioning load of the building. High window-to-wall area ratios may be provided in North-East and North-West facades.

6. **Reduce heat island effect on the roof:** The analysis shows that the roofs receive high solar radiation. These solar radiations can be reflected by using light-coloured finishes, high reflective finishes like white china mosaic tiles and high SRI paints. Terrace gardens can also be designed for accessible terraces to not only reduce heat island effect but also to prevent glare discomfort for terrace users.

7. **Renewable energy harness:** It will be very efficient to install the solar PV panels & solar thermals over the roof to harness maximum solar energy followed by south and west facades. This can also provide some insulation for the roof by shading.

8. **Building Envelope:** As observed from the analysis, the exterior walls in the South and West direction and the roof receive high solar radiation leading to heat gain into the interiors. Light-coloured finishes on facades can be used to prevent overheating of the building facades, reduce air conditioning load, and improve thermal comfort. Further, insulation is also required to reduce the conductive heat gains inside the building.

9. **Air conditioning** is required to achieve thermal comfort for 93% occupied period in a year. But this can be reduced if building design minimizes overheating.

The Energy Efficiency guidelines thus incorporate the above passive and active design strategies for various typologies of new and existing buildings in Male and Hulhumale.

5.1.7. Conclusion – Climate Classification Adopted in the Guideline

Based on the analysis, in the case of energy efficiency guideline for Maldives following characteristics of climate has been adopted:

a) **Climate –** Tropical Monsoon Climate

b) **Seasons –** Dry and Wet Season

c) **Mean annual temperature –** about 29 °C

d) **Average diurnal temperature difference-** 8 -10 °C

e) **Humidity –** high humidity above 75% throughout the year

f) **Annual average rainfall-** about 2160 mm for the years 2008 to 2018.

g) **Wind Speed -** Maximum wind flows in North East (ENE) direction in dry season, Maximum wind flows from west direction in wet season,

h) **Wind Direction -** Predominant wind direction is West for most part of the year

i) **Solar Radiation-** High solar radiations are observed on the East (1200 kWh/sqm) and West Façade (1200 kWh/sqm) and South facades (1000 kWh/sq.m). The roofs receive the highest solar radiation (2000 kWh/sqm).

6. Bio-Climatic building design strategies

6.1. About Bio-Climatic Building Design

Bio-climatic design refers to designing spaces or buildings in consideration to the local climate. The aim of the bio-climatic design is to provide comfort to the occupants by using natural sources. The focus is to incorporate passive design strategies which utilise the sun, wind, vegetation, etc. to provide adequate thermal and visual comfort inside the building.

Box 5-A: Bio-Climatic Design

A sequence of strategies is followed in bio-climatic designing of a building, namely site selection and orientation, building form, envelope design, and passive cooling as shown below:

Figure 17: Sequence of bio-climatic strategies

The solar heat gains and air movement majorly affect the energy balance of a building due to which the orientation of the building with the sun and the wind direction is considered as the main factor in bio-climatic strategies.

The bio-climatic design strategy has to be incorporated and decided in the early design phase of a building to maximize the potential of energy savings. It considers the micro-climatic conditions and includes the following principles.

- Trapping of heat in winters and release/avoid heat in summers
- Use of solar energy for heating in winters and daylighting
- Protection from incident solar radiation in summers by using shading and appropriate building envelope
- Removal of heat from the buildings in summers by means of passive cooling techniques
- Improving the indoor condition of the building to provide comfort by enhancing the cross-ventilation, optimum daylight, and fresh air while maintaining indoor comfort temperature
- Improving micro-climate around the building and built environment by using local sustainable materials, vegetation, reusing, and recycling resources.

The strategies for bio-climatic design are decided at the design phase and if incorporated, it helps in reducing the building's energy consumption and carbon footprint.

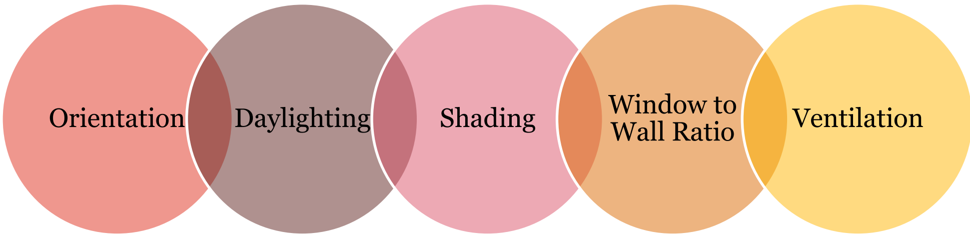
The design of any building plays a key role to define its characteristics post-commissioning. The energy consumption can be very high if the design of the building is not given appropriate consideration. Also, climate plays a major role in the behavior of the building. Therefore, appropriate design strategies have to be incorporated in the early design phase of the building keeping the local climate conditions into consideration.

Box 5 -B : **Hulhumale Planning and Development Regulation Provision**

Encouraging energy efficiency both at the construction stage and during the lifetime of the building e.g. By climate-sensitive design which takes account of the orientation and surrounding features to control wind effects while optimizing sunlight, daylight, and solar gain benefits.

6.2. Important Components of Bio Climate Design

The following are the vital components of Bio Climatic design that will help the practicing architects while designing Energy Efficient buildings in the Maldives.



6.3. Mandatory requirement for Bio Climate Design

Minimum mandatory requirements for achieving energy efficiency under each components are further explained in this section.

6.3.1. Building Form and Orientation

Building architectural form and orientation in a Tropical Hot climate can greatly affect the indoor climatic conditions, occupant comfort and energy consumption for air conditioning. In the Maldives, it was observed that the longer façade of most of the buildings are oriented in the East-West direction.

6.3.1.1. Recommendations for Building Form and Orientation

Based on the results of solar radiation analysis and energy simulations, **the recommended optimum orientation of buildings in the Maldives is facing the longer façade of the building to the South-North or North-South direction.**

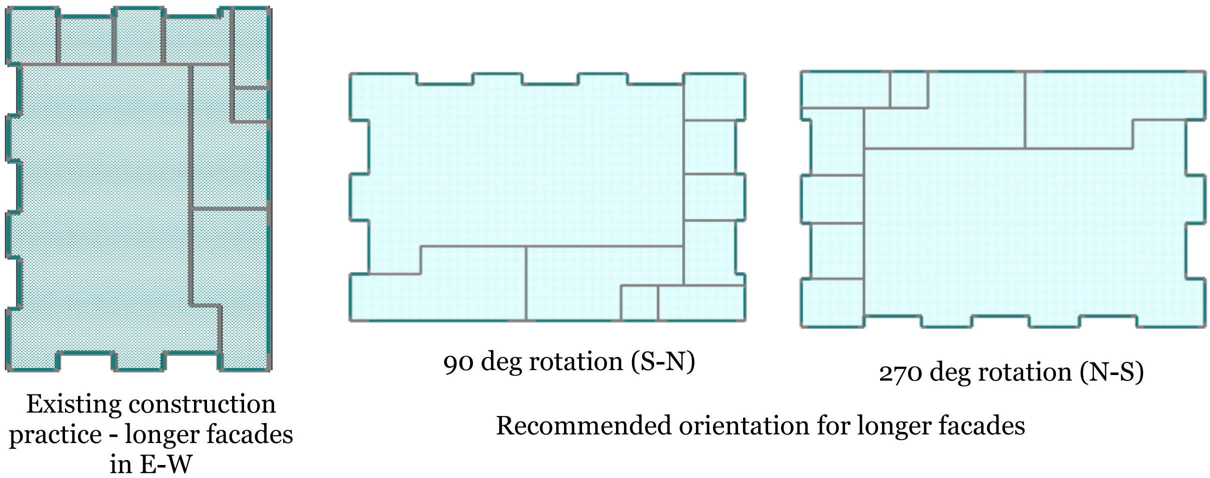


Figure 18: Image showing existing and recommended orientation of longer façade of building in Maldives

6.3.2. Window to Wall Ratio (WWR)

The window to wall ratio is defined as the ratio of the total area of the window to the total external wall area. Based on the surveys, the WWR for most of the buildings in the Maldives is found to be around 50-60%.

Box 5.2.2 : Prescriptive requirements for Window to Wall Ratio (WWR)

For the Maldives, based on the energy simulation results, the optimum requirement for WWR is 40% for all typologies except for residential buildings. In residential buildings, the WWR can be maintained 50% for ensuring optimum daylight and natural ventilation.

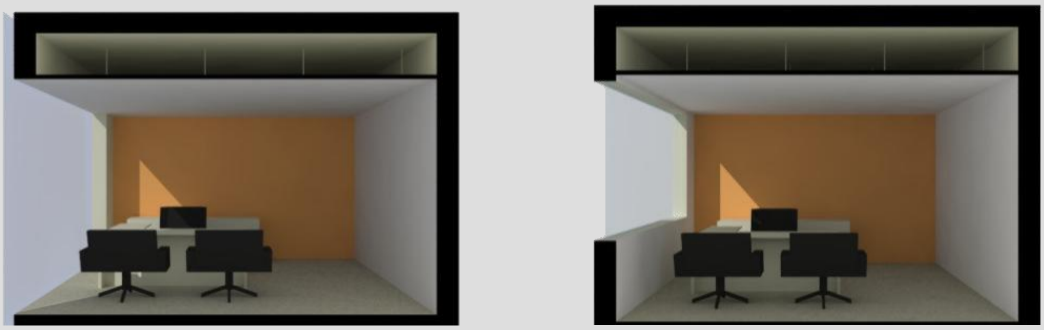
In case of design limitation or to accommodate certain preferences for the aesthetics of building design, the architects and the engineers can vary the value of the WWR from the recommended optimal value provided SHGC of the glass is maintained in accordance with Box 6.2.3 : Prescriptive requirements for SHGC value of window glass provided in section 7.2.3 of this guideline to reduce the overall heat gain in the building.

Box 5-C: WWR Case Examples

The below figure shows the comparison of two cases:

a. The first having a WWR of 80% - This case does not comply with the recommended WWR.

b. The second having a WWR of 40% - This complies with the recommended WWR.

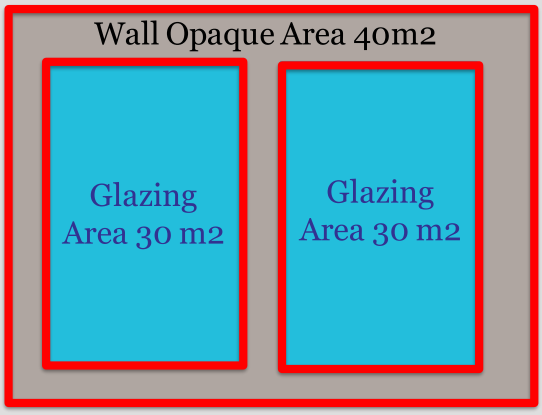


(a) (b)

Figure 19: Image showing comparison of WWR in two cases

In both cases, daylight on the task level is same. In the first case, an excess amount of sunlight enters the room, resulting in increasing the cooling demand of the room. On the other hand, lesser energy will be required to maintain the thermal comfort of the room in the second case.

A sample WWR calculation



$$\textbf{WWR} = \frac{30 + 30}{40 + 30 + 30}$$

$$\textbf{WWR} = \frac{60}{100}$$

$$\textbf{WWR} = 0.6$$

$$= \textbf{60\%}$$

Figure 20: Image showing sample calculation of WWR

6.3.3. Shading

Shading protects the building envelope from the incident solar radiation and thus reduces the heat gain into the building. In the Maldives, due to low Latitude, the sun angle is much higher during the day and throughout the year. This means the sun is overhead for most of the time, but shading is not provided for most of the buildings in the Maldives as observed during surveys and meetings with architects.

Box 5-D: Movement of the Sun

Solstice and Equinox are important as these parameters are the major climatic changes of a year and hence, indicate the change in the season of a location. Equinox is when the center of the visible Sun is directly above the Equator, whereas solstice occurs when the Sun appears to reach its most northerly or southerly excursion relative to the celestial equator on the celestial sphere. June 21 and December 21 are the two solstices that occur annually, and September 21 and March 21 are the two equinoxes as shown below.

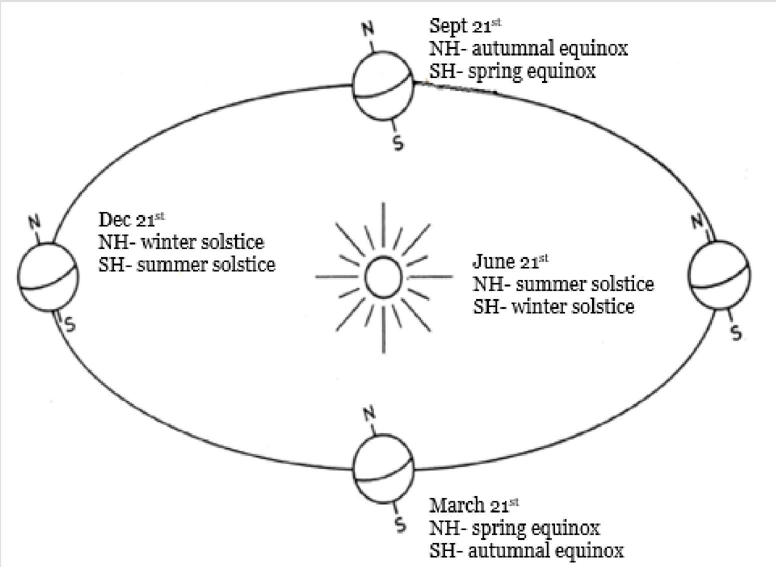


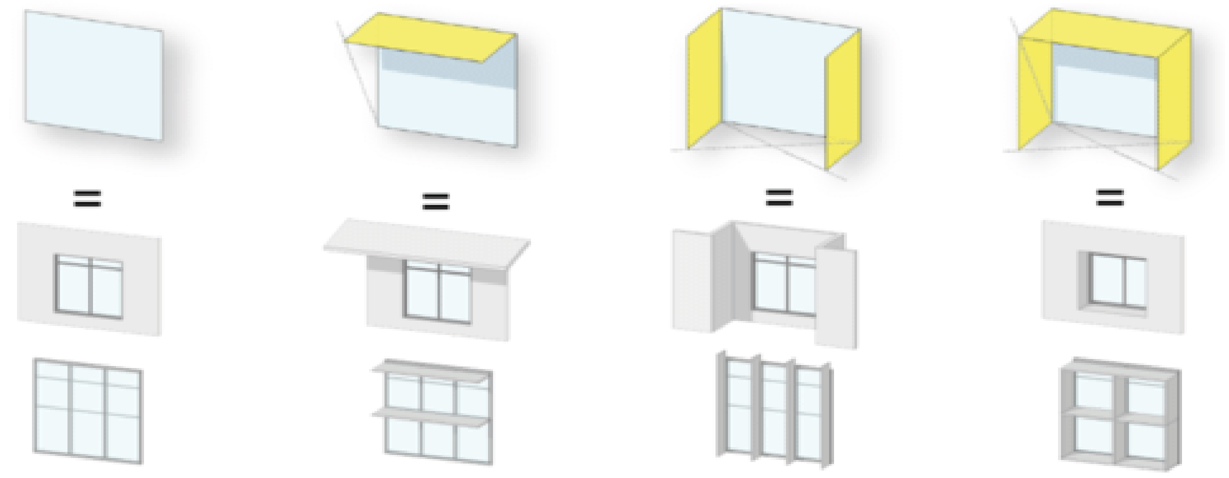
Figure 21: Image showing Equinox and Solstice

Box 5.2.3 : : Prescriptive requirements for shading

- **For shading, based on solar radiation and energy simulation analysis, a minimum mandatory requirement of 600 mm overhangs on all orientations shall be provided for optimum solar protection throughout the year**.
- **In cases, where-in provision of 600 mm overhangs is not possible, architects and engineers shall use the recessed window as shown in**
-
- ***Figure** 22* **(d) to comply with the minimum mandatory requirement for shading. More shading options are provided in section *6.3.3.1*.**
- **In cases, where-in lower floors of the building receive shading from the adjacent buildings or landscape, shading requirements are applicable only to the floors that do not receive any shading*.**

***Please refer to Appendix *14.1* to understand how the impact of shading from the adjacent**

Adding vertical Fins would help cut the low sun angle in the early and later time of the day on the East and West façade. Various method for providing shading is given in *Figure 22.*



(a) No Shading | (b) Horizontal Overhang | (c) Vertical Fins | (d) Combination of Overhang and Fins- use of recessed windows

Figure 22: Image showing use of methods of shading

Box 5-E: Male Planning Regulation Provisions

In the Male planning regulation, under the criteria "Cantilevering to the street" stipulates that,

- Making a part of the building cantilever onto the road above the height of 30.48m is not permitted. It is permitted only if there is no adjacent building
- Above the height of 30.48m, roofs, concrete bricks, Sun shading devices, balconies, and space to keep materials used for building services such as air conditioning must not extend onto the street beyond more than 0.457m

6.3.3.1. Shading options for different orientations

The shading design for different locations is dependent on their latitude and orientation. Each façade may require different approaches. The shading requirement may vary based on the direction of the façade as well. Also, the shading design or system may vary depending on the period for which the reduction in solar heat gain is critical and desired.

Box 5-F: Shading Angle

To receive glare-free daylight inside a room, the orientation of the building is taken into consideration. When the building has a North and South orientation, then horizontal shades can be used as overhangs on the south façade as shown below, whereas for East and West orientations, vertical shades or horizontal & vertical shades are used.

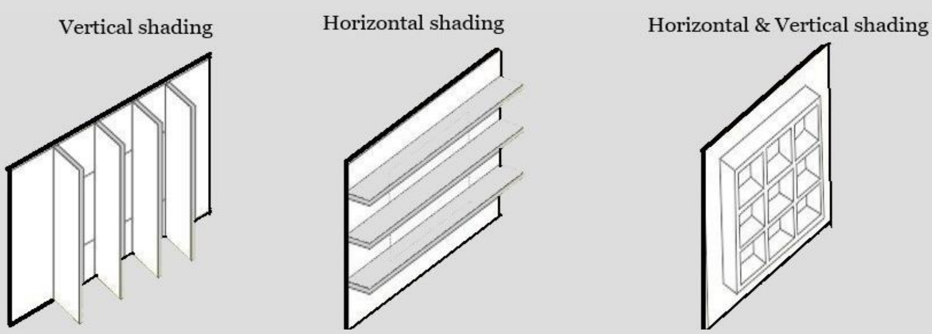


Figure 23: Image showing use of different types of shading

6.3.4. Daylighting

Daylight integration is controlled admission of diffused sunlight into the building spaces. Daylighting can reduce around 10% of the total building energy. It also helps in increasing the productivity and visual comfort of the occupants. The objective for applying a daylighting system should be decided in the design phase. The objectives of any daylighting system are as below.

- Redirecting daylight to under-lit areas/zones
- Improving daylight for task illumination
- Improving visual comfort and avoiding glare
- Reduce the use of artificial lighting and reduce peak power demand

Box 5-G: Maldives National Building Code Provision
Article G7.2 of Maldives National Building Code encourages that habitable spaces should provide adequate openings for natural light.

6.3.4.1. Recommendations for Daylighting

Any daylighting system consists of a blend of different technologies and architectural designs. The design feasibility, daylighting goals, and economic feasibility have to be analyzed w.r.t to these components in each building/project. The section below describes some of the techniques to achieve optimum daylighting in buildings.

6.3.4.1.1. Depth in the daylight penetration

The Thumb rule for proper lighting in an area is that **- the depth of daylight penetration is twice the window head height**. Figure *24* shows the penetration of daylight in an office room. The practical depth of a day-lighted zone is typically two times the window head height. In offices, there is usually a mix of open-plan offices and private offices. Hence, in order to get proper daylight penetration, the open office space/rooms/conference rooms must be located along the facade while the private offices/rooms/conference rooms must be located away from the façade i.e., at the core of the building.

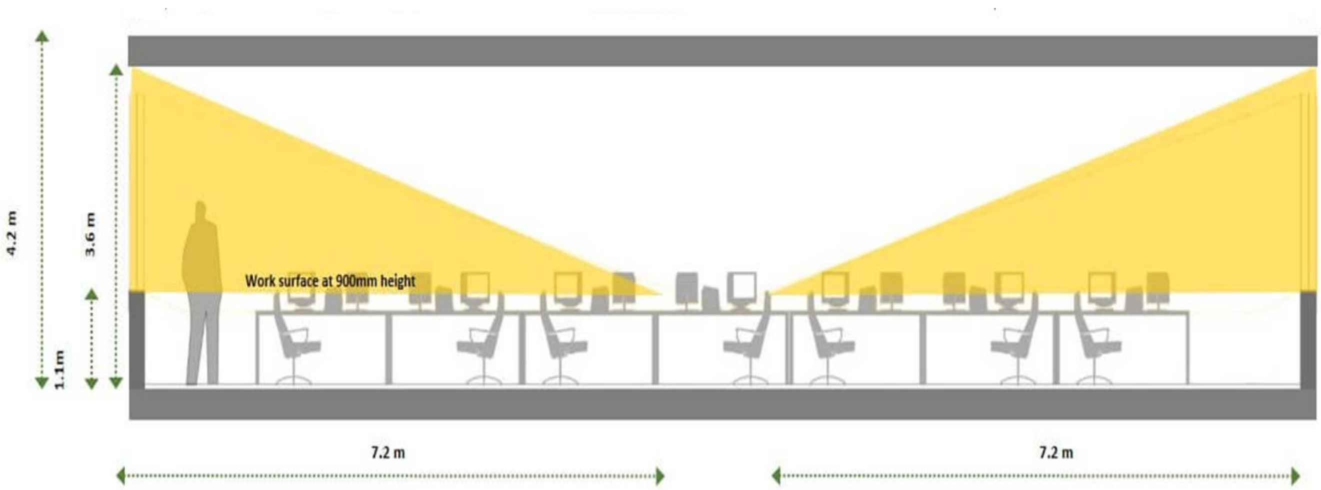


Figure 24: Image showing daylight penetration inside an office room

6.3.4.1.2. Daylight-optimized building footprint

The building footprint should be optimized for daylight. For Tropical Monsoon Climate, the building footprint should maximize north and south exposures and minimize east and west exposures. Deviation from due north-south should not exceed 15° in either direction for best solar access and ease of control. Images show some of the ideal practices of North-South orientation.

North- South orientations can be used in creative ways to generate a variety of built and open spaces as shown below in Figure *25*.

Figure 25: Best orientation of existing building planforms

North-South orientations can be used in case of unfavorable orientation of the plot as shown below in Figure *26*.

Figure 26: Image showing different design options for unfavorable orientation

In Figure *27*, the buildings in case 1 and case 2 have a smaller Perimeter to Area (P/A) ratio. As a result, these buildings have lower solar heat gain. Whereas in case 3 and case 4, buildings have a larger P/A ratio due to which a large portion of the buildings is exposed to direct sunlight and consequently increases the cooling demand of the buildings.

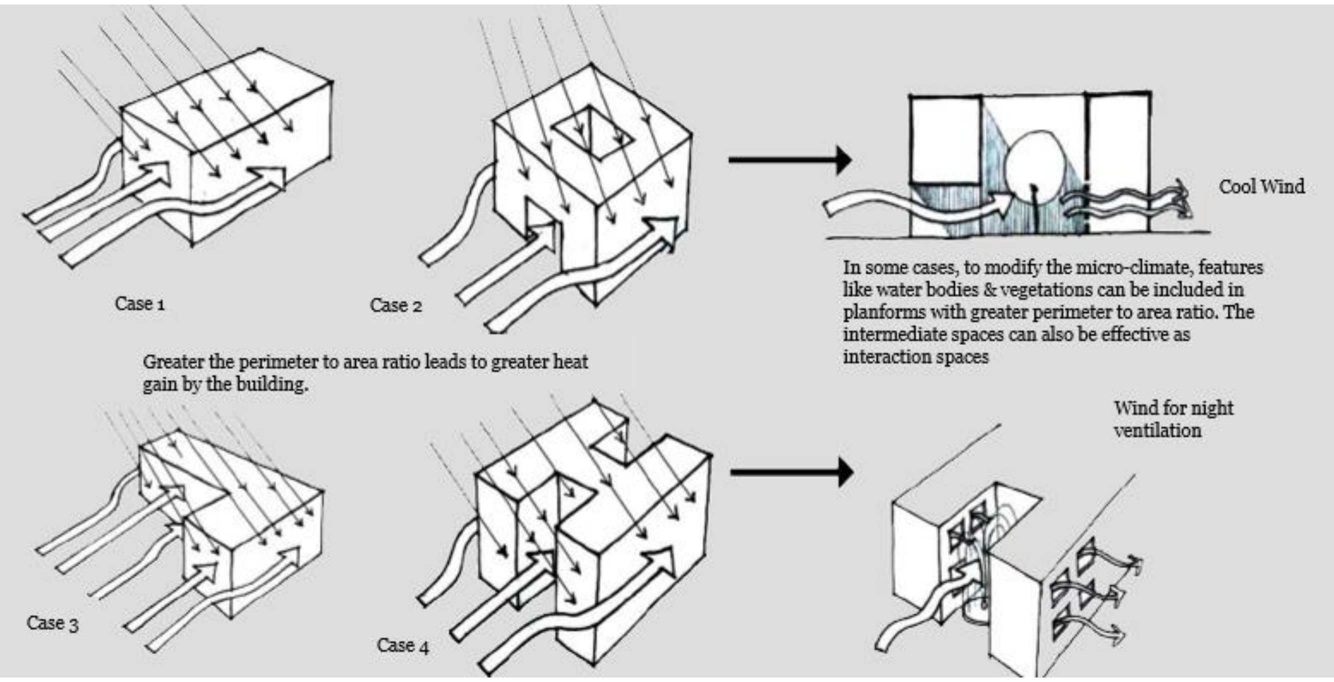
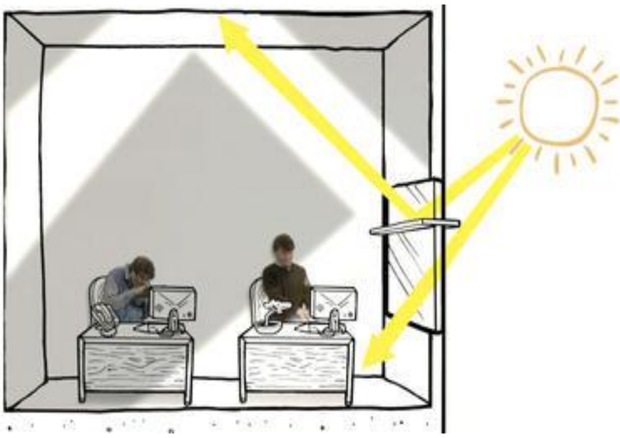


Figure 27: Image showing building response to various Perimeter to Area ratio for Tropical Monsoon Climate

6.3.4.1.3. Daylighting devices

The daylighting devices are generally of two categories:

- **Daylight redirection devices -** either light shelves or louvered. Both the categories of daylighting devices redirect the incoming beam of sunlight to the ceiling of a room. Hence, these devices help in both glare control and daylight penetration.
- **Tubular daylight devices** – These devices have highly reflective film inside a tube to channel light from a lens at the roof, to a lens at the ceiling plane. These can be used in spaces where it is not possible to provide fenestration such as the basement.



(a)

Image source: Web research

(b)

Image source: Web research

Figure 28 (a, b): Images showing daylight redirection device and tubular daylight device

6.3.4.1.4. Daylighting responsive lighting controls

Daylighting design will not be enough to save energy unless the artificial lights are dimmed or turned off when there is sufficient illumination from daylight. Daylight-responsive lighting controls consist of continuous dimming or stepped-ballasts in the light fixtures that modulate the artificial lighting with the help of sensors that detects daylighting. Some of the good practices include installing daylight-responsive controls in all regularly occupied daylit spaces and installing occupancy sensors to reduce lighting loads inside the building. Figure *29* shows the working of a daylight-responsive control system. The daylight-responsive sensors can be installed strategically that is in indoors or outdoors to capture the right amount of daylight.

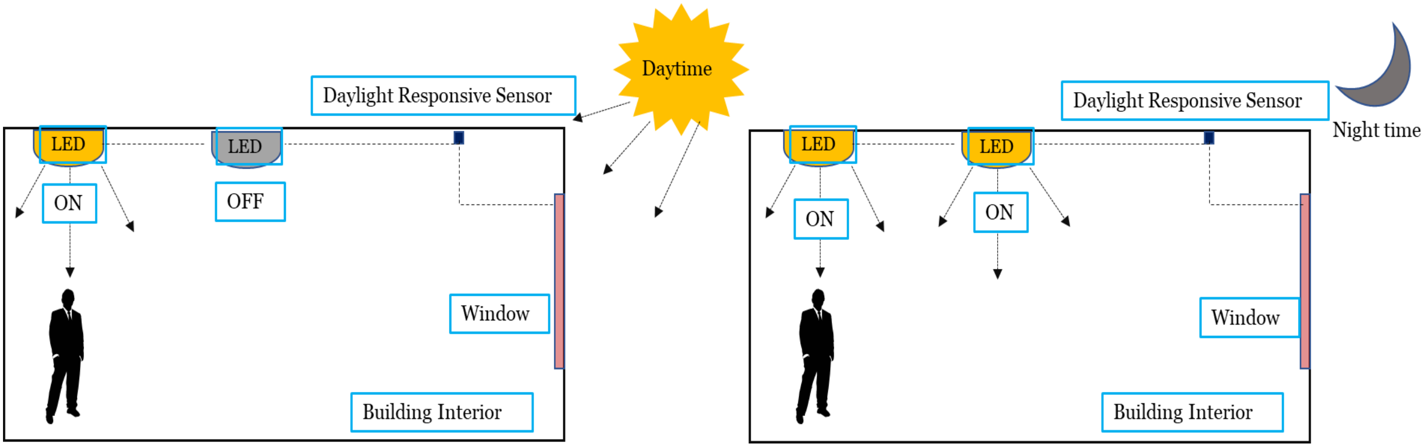
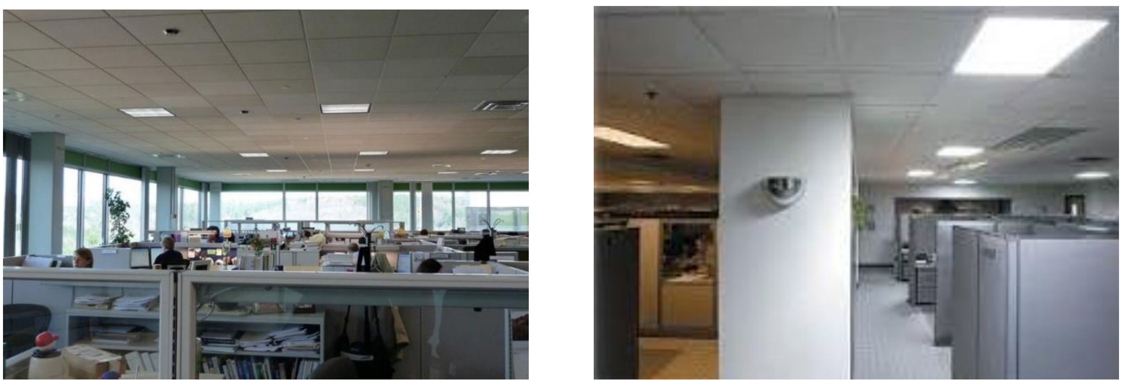


Figure 29 : Images showing working of daylight-responsive controls

6.3.4.1.5. Daylight-optimized interior design

Daylight optimized interior design takes into account various parameters such as the interior layout of buildings, furniture design, placement of interior partitions, and room surface finishes. In the figures below, two daylight practices in **office space** are presented. In the first example Figure *30* (a), the office has an **open plan layout with good daylight strategies like low height and non-opaque partitions**. Hence daylight is available on the workstation. **In an open plan layout, conference/meeting rooms can be placed towards the core of the building**. However, in the second image Figure *30* (b), a partitioned layout has been shown, with a high opaque partition which results in poor daylight in the interior spaces. Thus, the office is dependent on artificial lighting throughout the day, increasing the overall energy consumption.



(a) (b)

Figure 30 (a, b): Images showing daylight practices

6.3.4.2. Daylighting goals and design

During the design process, the following design strategies should be explored:

- Increase perimeter daylight zones by adopting narrow floorplate and maximize the usable daylight area
- Allow daylight penetration high in a space. Windows located high in a wall or clerestories will result in deeper light penetration
- Reflect daylight within a space to increase room brightness
- Avoid direct daylight on critical task areas
- Understand the different building orientation to get benefit from different daylighting strategies.

The daylighting goals for building design are as below and should be explored during the design phase.

1. ***Usable daylighting in minimum 70% of the building***
2. ***Illuminance level in the indoor work areas as per EN 12464-1:2019.***

Recommended illuminance levels for different areas is provided in Table *1*.

Table 1: Illuminance level in different areas (extracted from EN 12464-1:2019)

Area	Illuminance (lux)
Educational	
Classrooms	300
Technical drawing room	750
Computer practice room	300
Retail premises	
Sales area	300
Hotels and restaurants	
Kitchen	500
Dining area	300
Self-service area	200
Conference room	500
Healthcare	
General Lighting	100
Reading lighting	300
Simple examinations	300
Examination and treatment	1000
Offices	
Filing, copying, etc.	300

Area	Illuminance (lux)
Writing, typing, reading	500
Technical drawing	750
Conference and meeting	500
Reception	300
Archives	200
Theatres, concert halls	
Dressing room	300
Foyers	200
Auditorium	100
Places of Public assembly	
Entrance Halls	100
Cloak Rooms	200
Lounges	200
Ticket Offices	300
Other spaces	
Lifts	100
Corridors and stairs	100
Toilets	100
Canteens	300
Plant/mechanical room	150-300
Storeroom	100

Note:

1. The required illuminance levels can be achieved with combination of daylight and artificial lighting. Requirements for artificial lightings is provided in chapter 9 of this document.
2. Illuminance level requirements for more areas is provided in EN 12464-1:2019 standard.
3. For a particular task/area, all the building typologies can refer to the standard EN 12464-1:2019 for the illuminance level that best describes the function of the task/area, if that task/area is not mentioned in the above table.

Box 5-H: Illuminance & Lux basics

- Lux: The amount of light that is cast on a surface is called illuminance, which is measured in lux. This can be thought of as light intensity within a specific area.
- Lumens: The total output of visible light from a light source is measured in lumens. Typically, the more lumens a light fixture provides, more the brighter it is.
- One lux is equal to one lumen per square meter (lux = lumens/m^2).

6.3.5. Ventilation

Ventilation is a prerequisite for maintaining good indoor air quality and avoiding any health hazards for the occupants. Ventilation enables the circulation of fresh air inside the building. There are two methods to achieve ventilation in a building known as the passive and active methods.

In the passive method, various design strategies are incorporated in the building to facilitate the natural circulation of air. This method is also known as natural ventilation. While in the active method, mechanical systems such as exhaust fans that consume energy are installed to force air circulation in the building.

This section provides minimum mandatory requirements for achieving natural ventilation in the building design strategies that significantly reduce energy consumption in buildings by reducing/eliminating the need for employing mechanical systems for ventilation.

Box 5-I: Maldives National Building Code Provisions

- Article G4.2 states that the spaces within buildings shall be provided with adequate ventilation consistent with their maximum occupancy.
- Article G5 states that the building should maintain good indoor air quality (IAQ) to avoid health hazards and odours along with ensuring the renewal of fresh air.

6.3.5.1. Natural ventilation (NV)

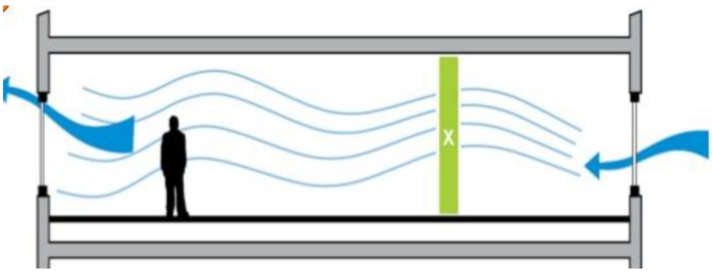


Image source: Web research

Figure 31: Natural ventilation

Natural ventilation is the process of supplying and removing air from an indoor space without using mechanical systems. This refers to the flow of outside air from one opening (window or door) and crossing it throughout the indoor or outdoor spaces, creating pressure difference and removing from another opening/s (window or door). This wind-driven ventilation occurs due to different pressure created by wind around a building and openings are strategically formed on the perimeter of the building so that it permits the air to flow through the building. Natural ventilation is one of the commonly intentionally introduced strategies to control indoor air quality and achieve thermal comfort in spaces like residences.

Role in energy efficiency: Natural ventilation is considered to be one of the energy efficient ways to achieve thermal comfort in spaces as it does not need any mechanical or energy consuming equipment. Natural ventilation reduces energy consumption (for thermal comfort) through openings in the building and is driven by natural forces of wind and/or temperature without the aid of mechanical means. Apart from being energy efficient, several other benefits like reduced energy cost, low maintenance cost, improved air quality, consistency in maintaining temperature, and reduced carbon emission are achieved with NV.

6.3.5.1.1. Design recommendation for natural ventilation

Natural ventilation in buildings is achieved by removing existing air from the space by supplying fresh outside air into the space. For a particular building, the strategy for natural ventilation varies based on the design of the buildings, internal thermal loads, and positions of openings (windows/doors). In general, three strategies are adopted for designing for natural ventilation:

1. Single side ventilation
2. Cross ventilation
3. Stack ventilation

Single Side Ventilation – In single side ventilation, one window or opening of the space is kept open for ventilation purposes. Based on the outdoor conditions (hot or cold) and air temperature, the window is kept open for an adequate period. This period can be shorter or longer until it is ensured that the existing air in a room is replaced. It is to be noted that cold air creates draughts even at very low wind speeds, the windows are quickly closed again after a set period. High wind speeds and low outdoor temperatures further limit the amount of time that the windows are open. It is reversed in the case of hot air.

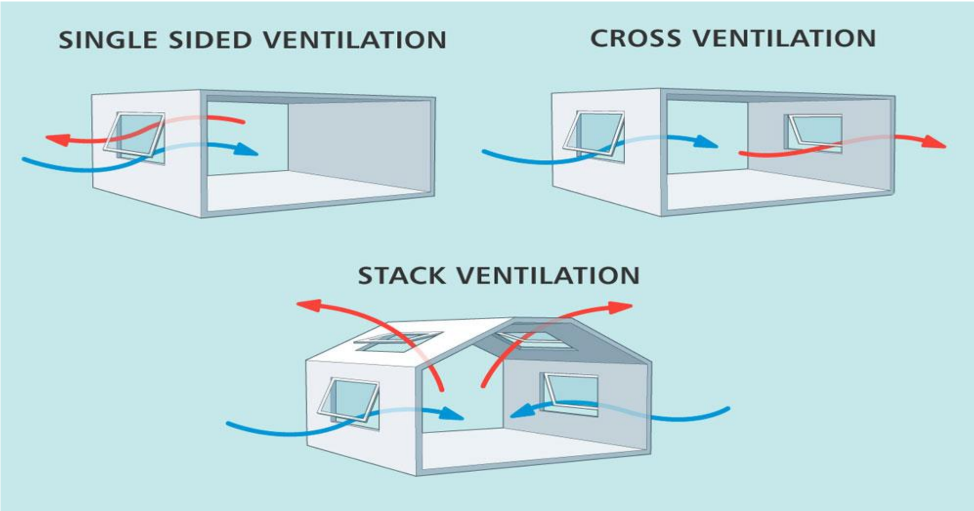


Image source: Web research

Figure 32: Different type of ventilation

Cross Ventilation - Cross ventilation is achieved using windows on both sides of the room, creating a current of air across the room. When the windows on both sides of the room are open, the overpressure on the side of the building facing into the wind, and/or low pressure on the opposite, sheltered side, will create a current of air through the room from the exposed side to the sheltered side. To ensure optimal airflow with as few drafts as possible, the windows on the side of the building that is facing the wind are not opened as much as the windows on the sheltered side. **It is highly recommended to design with cross ventilation for the climatic conditions of Maldives. Being an island country, advantages of sea breeze can be taken on higher floors for all the building typologies.**

Stack Ventilation – Stack effect arises as a consequence of temperature difference. Warm air rises up due to its less density as compared to cold air. When this warm air rises to the roof of the space/room, it creates a slight vacuum in the lower levels, which in turn pulls fresh outside air through windows/openings at lower levels and creates natural airflow. The process depends upon the height difference of the windows/openings that let outdoor air in and exhausts the existing air out of the space. **It is highly recommended to get the benefits of stack ventilation for the space with higher ceiling heights like assembly halls, libraries, etc.**

6.3.5.2. Mixed Mode Ventilation

A mixed mode ventilation system is a combination of natural ventilation and mechanical ventilation. This strategy offers indoor climate control by enhancing indoor air quality by lowering CO2 levels, creating a healthier environment, and improving occupant productivity. By using natural ventilation strategies to ventilate during the day or night (night cooling), mixed mode ventilation reduces the use of mechanical systems and possibly the size of the system.

A mixed mode ventilation system utilizes sensors to monitor indoor and outdoor temperatures, CO2 levels, and humidity as shown in Figure *33*. Based on the data collected by sensors the system automatically chooses natural ventilation or mechanical ventilation depending upon which system is most optimal to use. The system then switches back to natural ventilation when appropriate. The system responds to outdoor conditions like too hot, too cold, rainy, humid, etc. It adjusts the building openings and operations of mechanical systems to achieve thermal comfort in indoor spaces.

Strategy: Night cooling to remove the heat gain in days times and get the building ready for operations the next day by reducing temperatures in indoor spaces.

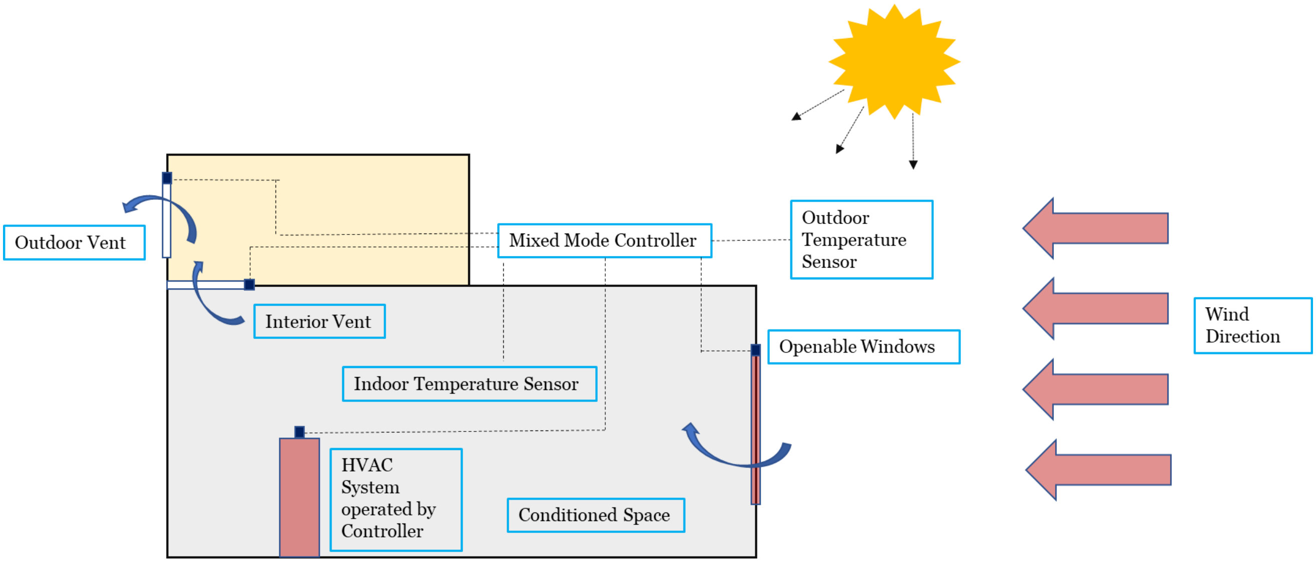


Figure 33: Illustration of Mix-Mode Ventilation

Box 5.2.5 : **Prescriptive requirements for ventilation**

1) Meet the air changes per hour for particular spaces as mentioned in the table given in Appendix *14.2*. The ASHRAE 62.1-2016 standard shall be referred for calculating the air changes per hour.

2) The energy performance or service value measured in terms of air delivery in cubic meters per minute/input power in watts of the ceiling fans shall be at least Efficiency level 3 or above as prescribed in the Indian Standards IS 374:2019. The energy performance for the ceiling fans is provided in the table below.

Table 2: Efficiency levels for ceiling fans

EE level	Ceiling fan with Blade sweep<1,200mm	Ceiling fan with Blade sweep>=1,200mm
Efficiency Level 3 or Minimum Mandatory Efficiency level	**>=4.1 - <4.6**	**>=5.0 - <5.5**
Efficiency Level 4	>=4.6 - <5.1	>=5.5 - <6.0
Efficiency Level 5	>=5.1	>=6.0

Note: The IS Standard is referred because the ceiling fan operation pattern, by the occupants, in the Maldives is similar to the Indian context due to similar climatic conditions.

Box 5-J: Good Practices to enhance Cross Ventilation

In the figure below, the living zone mentioned in the image is the space that occupants commonly use, demanding air movement for natural ventilation and good thermal comfort level. Hence, as shown in the figure, the inlet openings placed at high levels, as in Case 1 and Case 2, do not allow the wind movement towards the living zone, irrespective of the positioning of the outlet openings.

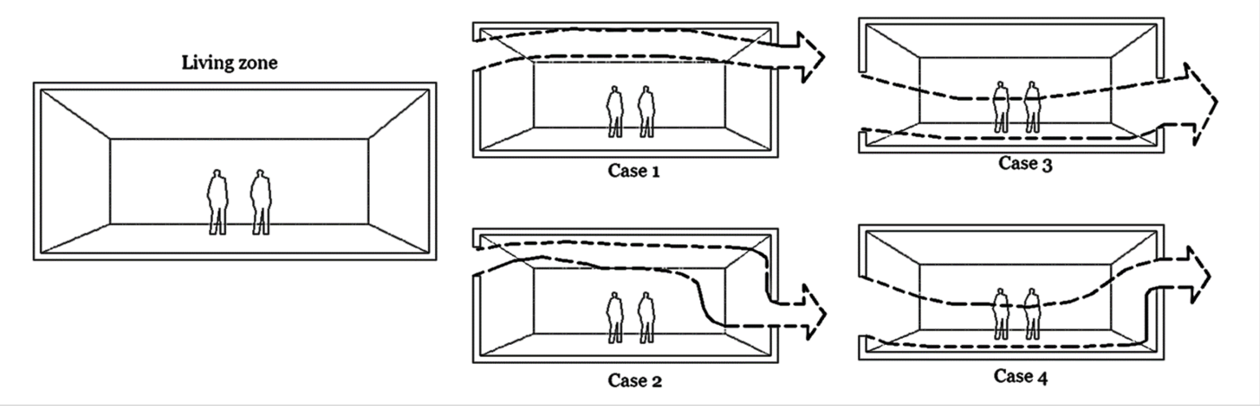


Figure 34: Image showing different practices of cross ventilation

The figure below shows the good and bad positioning of openings like sashes, louvers, and canopies used for ventilation.

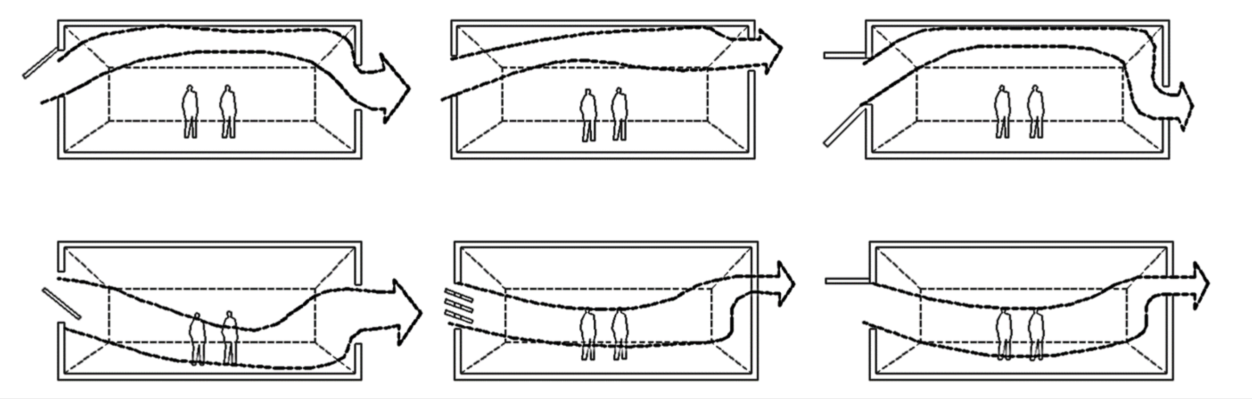


Figure 35: Image showing ventilation with the use of openings like sashes, louvres and canopies

7. Building Envelope

7.1. About Building Envelope

The building envelope refers to the exterior façade that comprises opaque components and fenestration systems. Opaque components include walls, roofs, slabs on grade (in touch with the ground), basement walls, and opaque doors. Fenestration systems include windows, skylights, ventilators, and doors that are more than one-half glazed.

The building envelope protects the building's interior and occupants from the weather conditions and shields them from other external factors such as noise, air pollution, etc. The building envelope design plays a critical part in the visual and thermal comfort of the occupants and consequently the energy consumption in the building.

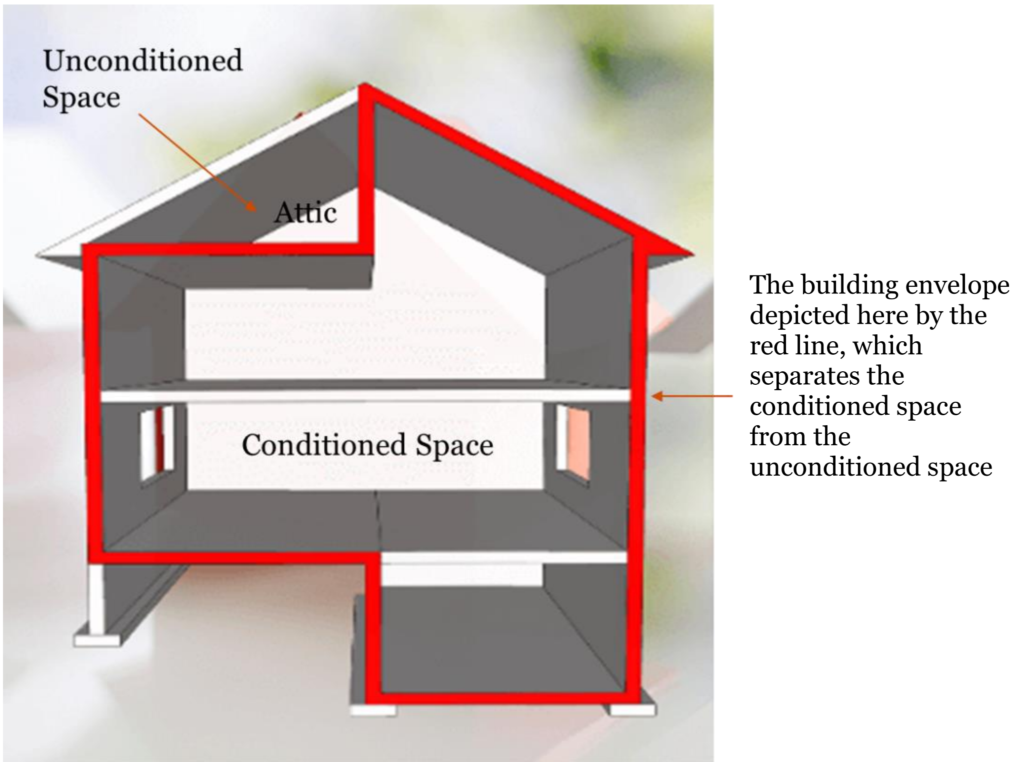


Figure 36: Image showing various elements of building envelope

Heat transfer through the building takes place through three modes of heat conduction, convection and radiation. The conductive heat transfer across the building envelop depends on the thermal conductivity of the building material used. Different material showcases different thermal conductivity properties. Also, the walls & roof are composed of many layers. Hence, it is necessary to evaluate overall thermal resistance and heat transfer coefficient i.e., thermal transmittance (U-Factor).

Box 6-A: Thermal Resistance & Overall thermal transmittance (U-Factor)

Thermal Resistance of a material is the measure of resistance to heat flow across it. It depends on the thermal conductivity of the material & its thickness. Mathematically,

$$R = d/k \qquad m^2.\ K.\ W^{-1}$$

Where,
R is the thermal resistance
d is the thickness of the material in meters (m)
k is the thermal conductivity of the material in W/m K

But the building envelope, say, for example, the wall assembly is made up of layers of different material and each layer/material has unique thermal resistance or thermal conductivity property. Hence, to evaluate the heat transfer across the envelope, it is necessary to determine the combined thermal resistance of the wall assembly considering all the layers. This is obtained by calculating the thermal transmittance or the U factor.

For example, consider a wall made of material 1, 2 and 3

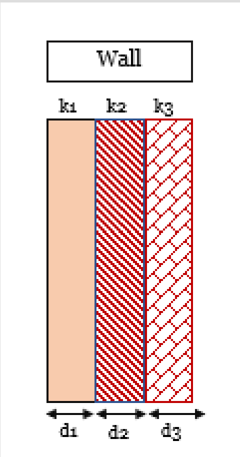


Figure 37: Cross-section of the wall

d1, d2 and d3 are the thickness of the materials
k1, k2 and k3 are the thermal conductivities of the material

then,

Thermal resistance of each material is

Material 1 (R1) = d1/k1
Material 2 (R2) = d2/k2
Material 3 (R3) = d3/k3

The total thermal resistance offered by the wall is given by

$$\text{Total Thermal Resistance } (R_t) = R1 + R2 + R3$$

Surface Resistance

In the above example, only the conductive heat transfer across the wall was considered to calculate the total thermal resistance of the wall assembly. But in the actual case, all three modes of heat transfer are prevalent across the building envelope that should be considered while calculating total thermal resistance and thermal transmittance. For the calculation of the thermal transmittance (U-factor) under ordinary building conditions, the seasonal mean values of the exterior surface thermal resistance (Rse) and the interior surface thermal resistance (Rsi) can be obtained from Table A1. These values are the result of empirical studies and merely represent magnitudes of order. They consider both convection and radiation influences.

Table A1: Values of Surface Film Resistance Based on Direction of Heat Flow

Rsi			**Rse**		
Direction of Heat Flow			Direction of Heat Flow		
Horizontal	Up	Down	Horizontal	Up	Down
0.13	0.10	0.17	0.04	0.04	0.04

Therefore, total Thermal resistance (R_T) = R_{si} + R1 + R2 + R3 + R_{se}

Total thermal transmittance from the wall (U-Factor) = 1/R_T

Thermal Resistance of Unventilated Air Layers

Table A2 gives the thermal resistances of unventilated air layers (valid for emittance of the bounding surfaces > 0.8). The values under "horizontal" should be used for heat flow directions ± 30° from the horizontal plane; for other heat flow directions, the values under "up" or "down" should be used.

Table A2: Thermal Resistances of Unventilated Air Layers Between Surfaces with High Emittance

Thickness of Air Layer (mm)	Thermal Resistance ($m^2 \cdot K \cdot W^{-1}$)		
	Direction of Heat Flow		
	Horizontal	**UP**	Down
5	0.12	0.10	0.10
7	0.12	0.12	0.12
10	0.14	0.14	0.14
15	0.16	0.16	0.16
25	0.18	0.17	0.18
50	0.18	0.17	0.20
100	0.18	0.17	0.20
300	0.18	0.17	0.21

Source: ECBC India

A sample problem on U- Value Calculation across a Wall

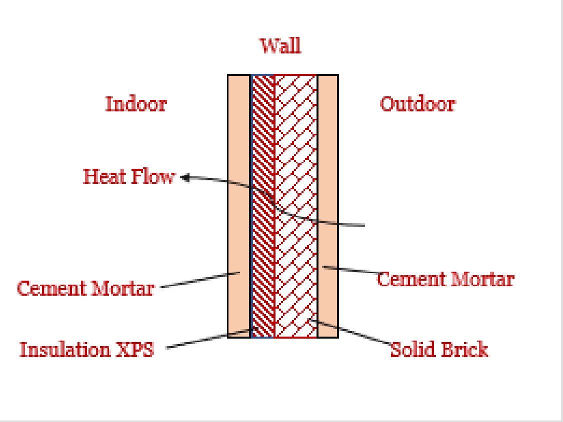


Figure 38: Different layers of the wall

Table A3: Summary table showing total thermal resistance from the wall

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m2K/W)
Cement Mortar	0.015	1.05	0.014
Insulation (XPS)	0	0.03	0.000
Solid Brick	0.2	0.72	0.278
Cement Mortar	0.015	1.05	0.014
Total Resistance (R_T)			0.306

Total Thermal Resistance = Sum of the thermal resistance of each layer

$$\mathbf{R_T = R_{Cement\ Motor} + R_{Insulation\ (XPS)} + R_{Solid\ Bricks} + R_{Cement\ Motor}}$$

$$\text{U-Value} = 1/R_T = 1/0.306$$

U-Value = 3.26 W/m²K

The total thermal resistance (R) and the thermal transmittance (U) value for the commonly used building materials in the Maldives is given below :

Table 3: Summary table showing R & U value of commonly used building materials in Maldives

Commonly used building material	Typical Thickness (m)	R-value (m^2K/W)	U-value (W/m^2K)
Wall Assembly			
RC material	0.236	0.337	2.97
Solid Masonry block	0.236	0.462	2.16
Roof Assembly			
RC slab	0.186	0.305	3.27
Timber forming & mineral wool insulation	0.235	4.758	0.21

***Refer to appendix *14.4* for the detailed calculations.**

7.2. Mandatory requirements for building envelope

Generally, the architect is responsible for designing the building envelope and he/she has to ensure that the building envelope is energy efficient and complies with the minimum requirements of the building components mentioned in the guidelines.

7.2.1. Optimal U-value of Wall assembly

The energy consumption of a building can be reduced through a proper selection of wall construction material. For a mid-rise or high-rise building, the heat gain from the walls is significant. Therefore, there is a potential to save energy by selecting materials with optimum thermal characteristics. The optimal U-value of the wall is deduced after several energy simulation runs. Different U-values of wall assembly were analysed, keeping all the other parameters of the current building design and construction practices unchanged. Based on the energy simulation analysis, an approximate reduction of 66.67% in the wall U-value from the current construction practices resulted in a decrease in the EPI of the building.

Box 6.2.1 : **Prescriptive requirement for U-value of wall assembly**

The maximum allowable U-value of wall assembly shall be 1.2 W/m²K for the optimum reduction in heat gains for buildings.

However, the user can design for higher efficiency levels by reducing the U-value of the wall assembly to 0.9 W/m²K

Box 6-B:An example of establishing the required U-Value of wall assembly

200 mm Autoclaved Aerated Concrete (AAC) with 15 mm plaster on both side .U Value 0.77 W/m²K

300 mm Autoclaved Aerated Concrete (AAC) with 15 mm plaster on both sides.U Value 0.54 W/m²K

Figure 39: Image showing various techniques for establishing desired U-value of the wall assembly

7.2.2. Optimal U-value of Roof assembly

Solar radiation is highest on any horizontal surface; therefore, the roof of a building receives the highest incident solar radiation annually. The energy consumption of a building can be reduced through a proper selection of roof construction material. For low-rise buildings, the heat gain from the roof is significant. Therefore, there is a potential to save energy by selecting materials with optimum thermal characteristics. The optimal U-value of the roof is deduced after several energy simulation runs. Different U-values of roof assembly were analysed, keeping all the other parameters of the current building design and construction practices unchanged. Based on the energy simulation analysis, an approximate 82% reduction in U-Value from the current construction practices resulted in a decrease in the EPI of the building.

Box 6.2.2 : **Prescriptive requirement for U-value of roof assembly**

The maximum allowable U-value of roof assembly shall be 0.9 W/m²K for the optimum reduction in heat gains for buildings.

However, the user can design for higher efficiency levels by reducing the U-value of the roof assembly to 0.6 W/m²K

Box 6-C:An example of establishing the required U-Value of wall assembly and roof assembly

Glass Wool Insulation 100mm thickness U value 0.32-0.44 W/m2K

Rock Wool Insulation 100mm thickness U value 0.35-0.44 W/m2K

Extruded Polystyrene Insulation100mm thickness U value 0.29-0.36 W/m²K

Polyurethane foam board Insulation100mm thickness U value 0.22-0.29W/m²K

Figure 40: Image showing various insulation material for roof and wall assembly for establishing required U-value

Typical Roof assembly configuration in Maldives :

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m2K/W)
Glass Wool Insulation	0.05	0.04	**1.25**
Aluminum Sheet	0.005	200	**0.000025**
Total Resistance (R_T)			**1.25**
U-Value (1/ R_T)			**0.8**

Box **6**-D: SRI (Solar Reflectance Index) & Cool Roof Concept

Solar Reflectance Index (SRI)

The ability of the roof's surface to reject the solar heat is measured using SRI. The SRI value of a roof determines its ability to re-radiate the heat back to the atmosphere. The re-radiation of the solar heat from the roof surface leads to a reduction in solar heat gain in the building resulting in cooler indoor temperatures thereby reducing the use of air conditioners. A higher value of SRI indicates a higher ability of the roof to reject the solar heat absorbed. Its scale ranges from 0 to 100. A standard black has a 0 SRI value and a standard white has a 100 SRI value. The procedure for calculating the SRI value for material is provided in standard ASTM E 1980. High SRI materials are recommended on the roof surface to reduce solar heat gain.

Cool Roof

In hot climates, a very effective way of achieving energy efficiency is through a cool roof by reducing the HVAC energy costs. In this, a high emissivity surface is provided at the roof that would emit the solar radiation but not absorb thereby reducing the solar heat gain.

Light-coloured or white coloured materials are used for low-sloped roofs and for high sloped roofs, roofing material manufacturers have developed colours other than white that have high emittance. Low maintenance & increased life expectancy of the roof are additional benefits of the cool roof. The properties of such materials can be obtained from Cool Roof Council Europe.

Some cool roof techniques are given below

Cool Roof through white Coating

Cool Roof using Metal roof

Cool Roof through China Mosaic

Cool Roof using Landscaping

Source: coolroofs-eu.eu

Figure 41: Image showing various Cool Roof technology

7.2.3. Optimal SHGC of Glass

Fenestration or glass windows can impact the energy consumption of a building significantly. Glass allows the heat to ingress and traps it inside the building. It does not allow the heat to dissipate back into the environment. The Solar Heat Gain Coefficient (SHGC) of the glass determines the radiation transmitted inside the space. Therefore, the selection of glass material with desired property is crucial to reduce the energy consumption of the building. For the Tropical Monsoon Climate of Maldives, it is important that the heat gain from glass is reduced for avoiding heating of the building interior.

In the building surveys, the SHGC value of the glass materials used in the current practices was not able to establish due to a lack of information. However, it was observed that in some buildings, blue tints were used to reduce solar heat gains, and hence an approximate SHGC value of 0.7 was assumed to identify the optimal SHGC value that would lower the EPI. The optimal SHGC of glass is deduced after several energy simulation runs. Different SHGC of glass were analysed, keeping all the other parameters of the current building design and construction practices unchanged.

Box 6-E: Solar Heat Gain Coefficient (SHGC)

Conduction is the predominant mode of heat transfer across Fenestration (Glass Window). However, heat gain through fenestration also depends on the direct & indirect solar radiation regardless of the outside temperature. This heat gain from glass is measured using the Solar Heat Gain Coefficient (SHGC) which is the ratio of solar heat that passes through fenestration to the total incident radiation that falls on the fenestration. The solar heat gain includes the direct or diffused solar radiation which gets transmitted (through conduction, convection & re-radiation) into the interior space through the fenestration which causes an increase in the heat load in the interior space.

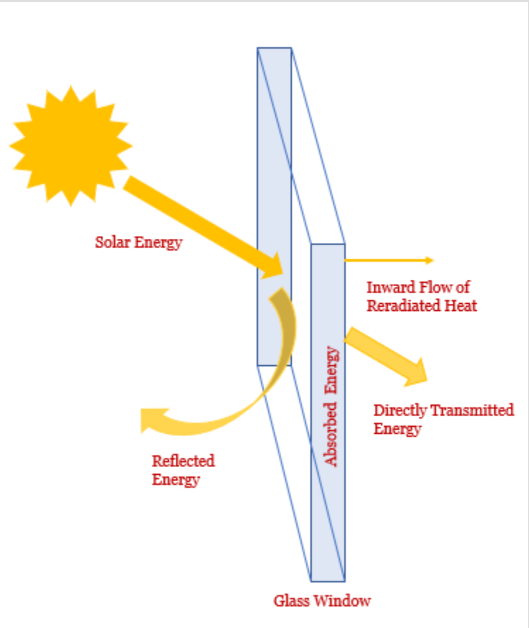
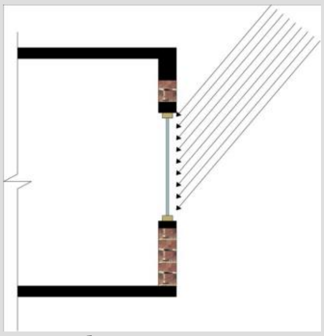


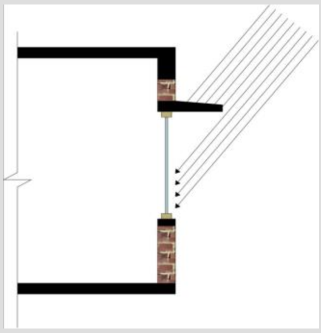
Figure 42: SHGC through Glass Window

A glass window with a low value of SHGC would cause lower heat gain in the interior space. While a glass window with a high value of SHGC would result in higher heat gain in the interior space. The choice of the SHGC value depends on the local climatic conditions where the building is situated.

Calculating Effective SHGC in case of shading provided at the fenestration



Glass SHGC =0.41



Effective SHGC = 0.24

Figure 43: Glass Window with & without shading

*Refer appendix *14.3* for detailed calculation of Effective SHGC

Box 6.2.3 : **Prescriptive requirements for SHGC value of window glass**

The effective SHGC value for glass shall be in accordance with Table *4*, based on WWR of the building. Both single- and double-glazed glass units can be used to achieve the required SHGC level. Shading should be used to reduce the effective SHGC from glazing.

Table 4: Threshold SHGC for different WWR

WWR	SHGC
≤30%	0.60
31-40%	0.50
41-50%	0.40
51-60%	0.30
≥61%	0.25

SHGC can be decreased further by covering the glass area for restricting the incident solar radiation on glass surface but this would reduce the visibility through the windows and fenestrations. Therefore, the SHGC value of below 0.25 is not considered. The SHGC value for the glass is different for different glass material which can obtained from glass manufacturers. Table 3 recommends SHGC values for different WWR values.

Box 6-F: Various technologies for establishing U-value for glasses

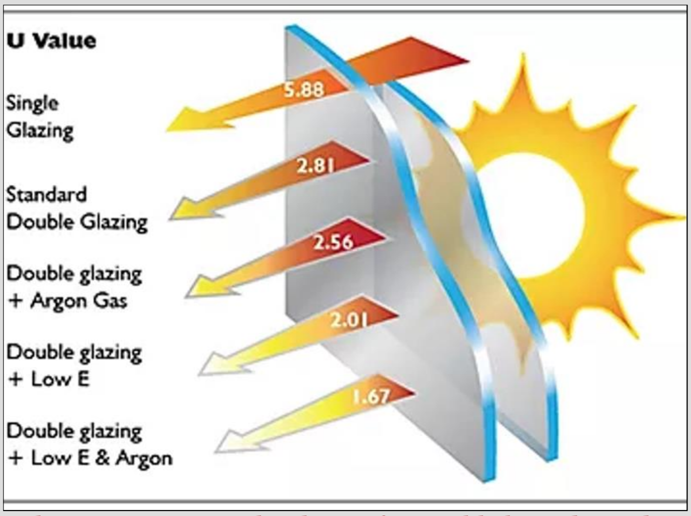


Figure 44: Image showing various technologies for establishing desired U value for glasses

8. Thermal comfort systems and Controls

BS EN ISO 7730 (UK standard) defines thermal comfort as ‘that condition of mind which expresses satisfaction with the thermal environment.', i.e. the condition when someone is not feeling either too hot or too cold. Human thermal comfort has several parameters to define ‘thermally comfortable environment’. It cannot simply be expressed in degree Celsius (or Fahrenheit) as it varies from person to person and climate to climate. Environmental parameters like air temperature, air velocity, relative humidity & radiant temperature and personal parameters like clothing, metabolic heat (activity level) & wellbeing defines the thermal comfort of each person.

To achieve thermal comfort in buildings the external heat gains, which are primarily caused by sunlight or any other external source of heat, and internal heat gains, which are caused by people, equipment, lighting etc., are minimized.

8.1. Importance of thermal comfort

Thermal comfort is an important aspect in representing human satisfaction. It is defined as “the condition of mind which expresses satisfaction with the thermal environment” – ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Thermal comfort is important for occupants’ health, wellbeing, and productivity. It is considered as a critical parameter for buildings like offices, public buildings like airports, malls, and residential buildings.

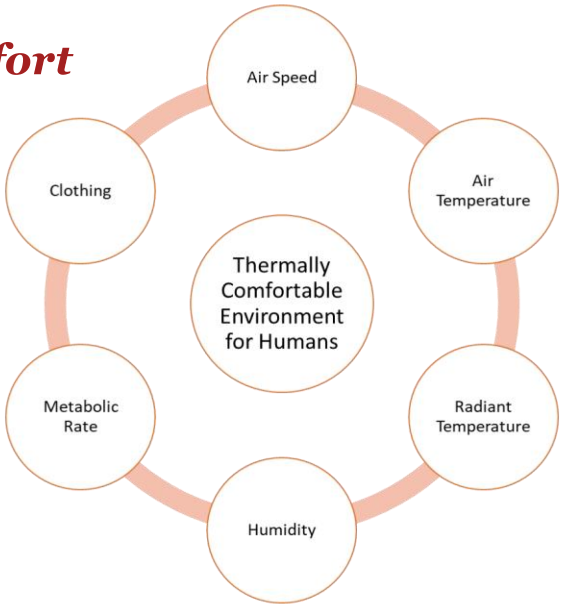


Figure 45: Importance of thermal comfort

8.2. Ways to achieve comfort in buildings

To achieve thermal comfort in buildings, environmental and occupants’ personal parameters should be within ranges as per globally adopted ranges. There are multiple ways to achieve thermal comfort in buildings like naturally ventilated (NV), mixed mode (MM) and air-conditioned (AC).

A building gains the heat generated by solar radiation and other external sources. This heat gets transferred into the building through conduction, convection, and radiation process. Further, the heat gets trapped in the indoor spaces within the building, changing the temperature, velocity, and humidity level of air in the building and eventually creating a discomfort situation for the occupants. Also, the occupants and equipment generate heat, which adds up to the discomfort situation.

Strategies like NV, MM, and AC ensure the thermal comfort of occupants in the building. The NV and MM strategies are discussed in section 6.3.5 of this document. This section provides minimum mandatory requirements for air conditioner systems.

8.3. Air Conditioning systems

Air conditioning is the process of removing heat and moisture from an indoor occupied space in order to improve the thermal comfort of occupants. As a result, air conditioning maintains temperature, humidity, motion, and purity/quality of air in the spaces.

Heating, Ventilation and Air Conditioning (HVAC) refer to the equipment, distribution systems, and terminals that provide, either collectively or individually, the heating, ventilation, or air conditioning requirement to a building or a portion of a building. The HVAC system accounts for a significant share in the overall building's energy use. HVAC energy use in a commercial building can increase/decrease significantly depending on how efficiently the combination of airside systems and central plan operates. Proven technologies and design concepts can be used to build energy efficiencies in the system and generate significant energy and cost savings.

HVAC systems also affect the health, comfort, and productivity of occupants. Issues like user discomfort, improper ventilation, lack of air movement and poor indoor air quality, and poor acoustic design are linked to HVAC system design and operation and can be improved. The best HVAC design considers all the interrelated building systems while addressing indoor air quality, thermal comfort, energy consumption, and environmental benefits. Optimizing both HVAC design and its benefits requires that the architect and mechanical system designer address these issues early in the schematic design phase and continually revise subsequent decisions throughout the design process. It is also essential to establish a process that monitors the proper installation and operation of the HVAC system. An effective commissioning plan for each of the systems at full load and part load with calibration of controls and commissioning is essential to the optimal performance of the building.

8.4. Different technologies and systems

There are different kinds of technologies for air conditioning or space cooling. The HVAC system is broadly classified as:

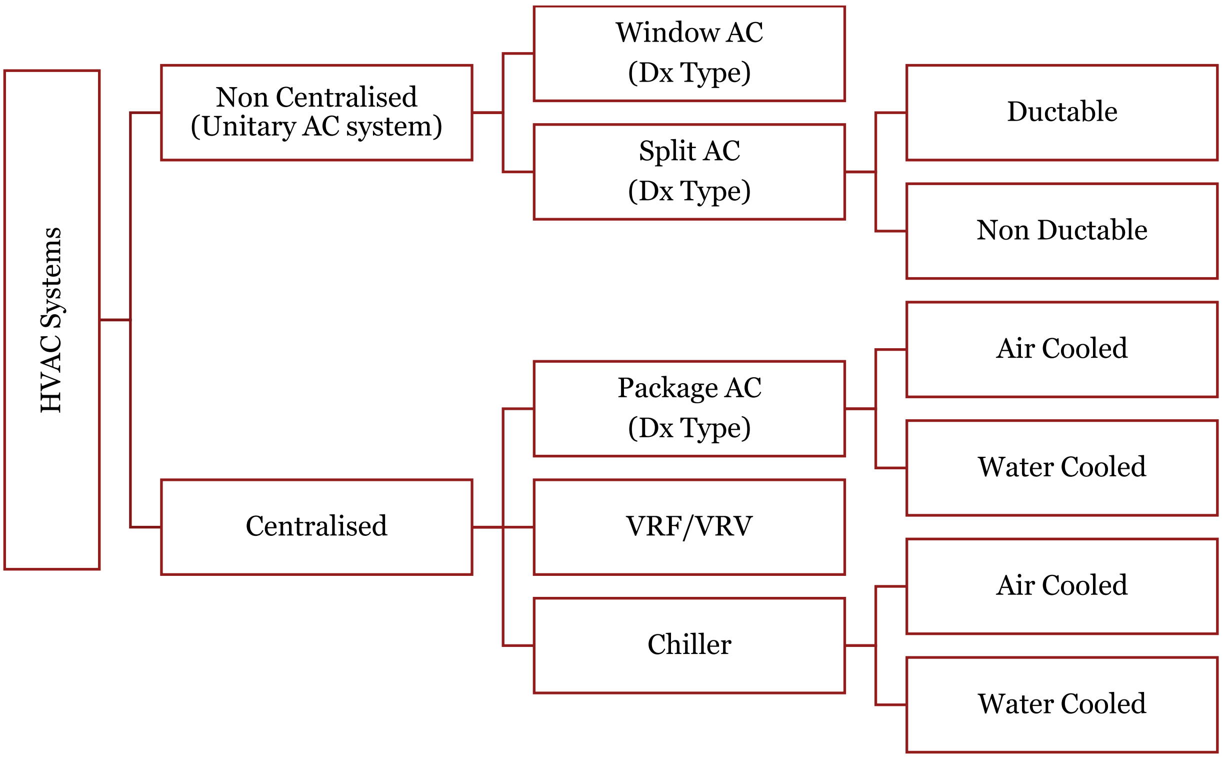


Figure 46: Different types of air conditioning systems

All these technologies are for active space cooling. These are most commonly used/adopted technologies in the Maldives presently.

8.5. Cooling load calculations

- The calculation of design load for the cooling system for sizing the air conditioning system shall be as per the latest ASHRAE standards or equivalent standards.
- Indoor conditions for an air-conditioned space shall be for a dry bulb temperature of 24°C ± 1°C and relative humidity of 55% ± 5%.
- Outdoor condition as per the Maldives' climate analysis is 29°C

8.6. Minimum mandatory requirements for HVAC systems

The minimum mandatory along with higher efficiency levels for HVAC is provided below.

Box 7 -A : Prescriptive requirements for non-centralized (Unitary AC system)

Applies to all single-phase, single-split, and unitary type air conditioners of both fixed speed and variable speed types compressors with the rated capacities of up to 24,226 Btu/hr.

For all split AC having cooling capacity <4.5 kW (1.3 TR) and between 4.5 kW to 7.1 kW (1.3 TR to 2 TR), the minimum CSPF (cooling seasonal performance factor) should be, at least level 1:

Table 5: Minimum mandatory requirements and higher levels of efficiencies for unitary air conditioners

	Value of CSPF (Wh/Wh)		
Size category	**Efficiency level 1 (Mandatory)**	Efficiency level 2	Efficiency level 3
For ACs with cooling capacities < 4.5 kW	**3.30 – 4.60**	4.60 – 5.30	≥5.30
For ACs with cooling capacities between 4.5 kW and 7.1 kW	**3.10 – 4.00**	4.00 - 5.10	≥5.10

Reference: Hakathari Labelling Programme for AC for Maldives

Points to remember:

1. One TR = 3.51 kW

2. Cooling Seasonal Performance Factor (CSPF): ratio of the total amount of heat the equipment can remove from the indoor air when operated for cooling in active mode to the total annual amount of energy consumed by the equipment during the same period. Its unit is Wh/Wh

3. For fixed speed air conditioners, CSPF =1.062 × 〚EER] tested at 100% capacity. Energy Efficiency Ratio (EER) is defined as the ratio of total cooling capacity to effective power input at any given rating condition. Its unit is kW/kW

Box 7-B : Prescriptive requirements for Centralized AC systems (Unitary AC system)

1. VRF/VRV (variable refrigerant flow/ variable refrigerant volume)

Variable Refrigerant Flow (VRF) systems shall meet or exceed the efficiency requirements specified in Table *6* as per the ANSI/AHRI Standard 1230.

Table 6: Minimum mandatory requirements for VRF/VRV

	For heating and cooling or both modes	
Size Category (kWr)	**EER (energy efficiency ratio)**	**IEER (integrated energy efficiency ratio)**
<40 kWr	**3.28**	**4.36**
>=40 and < 70 kWr	**3.26**	**4.34**
>=70 kWr	**3.02**	**4.07**

Points to remember:

1. EER - Defined as "the ratio of the cooling capacity of the unit (in Btu per hour) to the power input (in Watts)". This is calculated at 95/75 degrees DB/WB (AHRI Standard Rating Conditions)

2. IEER – Actual efficiency calculated at different loads (outdoor temperatures ranging from 65 to 95 degrees F) and then given weights to obtain an overall efficiency value.

$$IEER = (0.02 * A) + (0.617 * B) + (0.238 * C) + (0.125 * D)$$

Whereas:

A = EER at 100% net capacity at AHRI standard condition (95 deg F)
B = EER at 75% net capacity and reduced ambient (81.5 deg F)
C = EER at 50% net capacity and reduced ambient (68 deg F)
D = EER at 25% net capacity and reduced ambient (65 deg F)

2. Chillers

- **Chillers shall meet or exceed the minimum efficiency requirements presented in Table *7* and Table *8* under ANSI/ AHRI 550/ 590 conditions.**
- **To show compliance to Efficiency level 1, the minimum requirement of both COP and IPLV requirement of Efficiency level 1 shall be met. To show compliance with Efficiency levels 2 and 3, the minimum requirement of either COP or IPLV of respective efficiency levels shall be met.**

a) Air Cooled Chillers

Table 7: Minimum mandatory requirements and higher levels of efficiencies for air cooled chillers

	Efficiency level 1 (Mandatory)		Efficiency level 2	
Size Category (kWr)	**EER**	**IPLV**	EER	COP
<260	**2.8**	**3.5**	3.0	4.0
>=260	**3.0**	**3.7**	3.2	5.0

Points to be remembered:

It is recommended to install air-cooled chiller in all buildings with a cooling load less than 530 kW. For buildings with a cooling load equal to or greater than 530 kW, the number of air-cooled chillers shall be restricted to 33% of the total installed chilled water capacity.

EER - Defined as "the ratio of the cooling capacity of the unit (in Btu per hour) to the power input (in Watts)". This is calculated at 95/75 degrees DB/WB (AHRI Standard Rating Conditions)

IPLV – is used to signify the cooling efficiency related to a typical (hypothetical) season rather than a single rated condition. The IPLV is calculated by determining the weighted average efficiency at part-load capacities specified by an accepted standard.

IPLV = 1 / (0.01 / A + 0.42 / B + 0.45 / C + 0.12 / D), where

A = kW/ton at 100%
B = kW/ton at 75%
C = kW/ton at 50%
D = kW/ton at 25%

b) Water Cooled Chillers

Table 8: Minimum mandatory requirements and higher levels of efficiencies for air cooled chillers

	Efficiency level 1 (Mandatory)		Efficiency level 2		Efficiency level 3	
Size Category (kWr)	**EER**	**COP**	EER	COP	EER	COP
<260	**4.7**	**5.8**	5.2	6.9	5.8	7.1
≥260 & <530	**4.9**	**5.9**	5.8	7.1	6.0	7.9
≥530 &<1,050	**5.4**	**6.5**	5.8	7.5	6.3	8.4
≥1,050 &<1,580	**5.8**	**6.8**	6.2	8.1	6.5	8.8
≥1,580	**6.3**	**7.0**	6.5	8.9	6.7	9.1

Points to be remembered:
1 TR = 3.51 kW
COP = Output heating or cooling in Wh / input electrical energy in Wh

8.7. Additional Recommendations for HVAC systems

8.7.1. Controls in Air Conditioning

8.7.1.1. Time Clock Control

All mechanical cooling systems should have time clock control which can:

- Start and stop the system under different schedules for three different day-types per week,
- Retain programming and time setting during the loss of power for at least 10 hours, and
- Include an accessible manual override that allows temporary operation of the system for up to 2 hours

Recommended for buildings (offices, schools, college, hospital, mall) with air conditioning system size greater than 100 TR (excluding unitary ACs of all sizes) or conditioned area greater than 2000 sqm.

8.7.1.2. Temperature Control

All mechanical cooling equipment should have temperature control mechanisms. Each floor or a building block shall be installed with at least one control to manage the temperature. Control should meet following:

- For hotels, thermostat control for each guest room in hotel, each conference room and banquet hall
- For educational buildings, thermostat control for each classroom, staff room, lecture room, computer rooms
- For offices, thermostat control for each cabin, conference room, meeting room and common office floor area
- For malls, shopping complex, thermostat control for each shop. Public/common area to be control centrally
- For hospitals, thermostat control for in and outpatient rooms

Recommended for mentioned buildings having central AC system or non-central AC systems installed for thermal comfort applications.

8.7.1.3. Occupancy Control

Occupancy controls should be installed to de-energize or to throttle to minimise the ventilation and/or air conditioning systems when there are no occupants in places such as:

- Guest rooms in hotels
- Conference room, meeting room in hotels and offices
- Classroom, staff room for educational buildings with ACs

Recommended for mentioned buildings having central AC systems or non-central AC systems installed for thermal comfort applications.

8.7.1.4. Dampers

In central air conditioning systems, all air supply and exhaust equipment shall have dampers that automatically closes:

- When spaces are not in use
- When supply fan shutdowns

Exempted for the exhaust system for kitchen ventilation and spaces being served by natural ventilation.

8.7.1.5. Motor Efficiency

In central air conditioning systems (Chiller-based), all motors of air handling units (AHU) on supply fans, return fans and exhaust fans shall comply with motor efficiency IE2 (as per IS 12615). It is preferable to have VFD on motors.

8.7.1.6. Pump Efficiency

In central air conditioning systems (Chiller-based), all primary and secondary pumps shall have minimum of 70% efficiency. Application of variable frequency drive (VFD) shall be done on secondary pumps.

8.7.1.7. Energy Recovery

All hotels, offices, malls which are served by central air conditioning systems (chiller based) shall have provision for air-to-air recovery of heat. It can be done with help of technologies for recovering heat from exhaust air and supplying it to supply air.

In hospitals, heat recovery can be done for spaces serving common areas like reception, corridors, washrooms etc.

8.7.1.8. Service Water Heating

All hotels and hospitals, having a built-up area greater than 2000 sqm, shall have solar water heating systems for at least 20% of hot water requirements. The remaining demand can be met by conventional water heating systems.

The equipment efficiency for solar water heating and electrical or gas shall meet the country standards if any.

8.7.1.9. Building Energy Management systems (BEMS)

Energy management of commercial buildings is one of the key priority areas for the building owners. A building energy management system is a sophisticated method to monitor and control the energy needs of a building. A typical BEMS can manage the HVAC, lighting, and security measures of a building. It can be applied to residential as well as commercial buildings. It has huge potential on energy savings of hotels, hospitals, malls, schools, colleges, office buildings.

Applicability: BEMS can be installed in any building where the capacity of the central air conditioning plants is greater than 300 TR.

Recommended features: HVAC and lighting control and data monitoring, fire safety and security, building utilities control, and data monitoring

8.7.2. Not In-Kind/Innovative Space Cooling Solutions

Innovative cooling systems can be installed in place of conventional systems. All such systems shall be meet the minimum (mandatory) equipment efficiency levels as per section *8.6*. Also, the systems could be complying with the additional recommendations as per section *8.7.1* as applicable. The possible technologies could be:

a) **Solar Air Conditioning** – As the Maldives has an abundance of solar radiation throughout the year, solar air conditioning can help building owners in reducing the energy consumption for space cooling applications.

Figure 47: Solar Air Conditioning

b) **District Cooling** – is a strategy for addressing the space cooling demand of large mix-use (cluster of commercial, residential, office buildings) in greenfield developments. The technology is feasible for:

- Large mix use greenfield development
- 24x7 variable load with some anchor loads
- Space cooling demand of 8000-10000 TR/sqkm

Huge infrastructure development in the Maldives is foreseen in near future, especially in Hulhumale. The possibility of incorporating district cooling at the master planning level is beneficial. District Cooling is a fundamental aspect of utility in order to increase the sustainability of urban development. It is the backbone of a green and smart city.

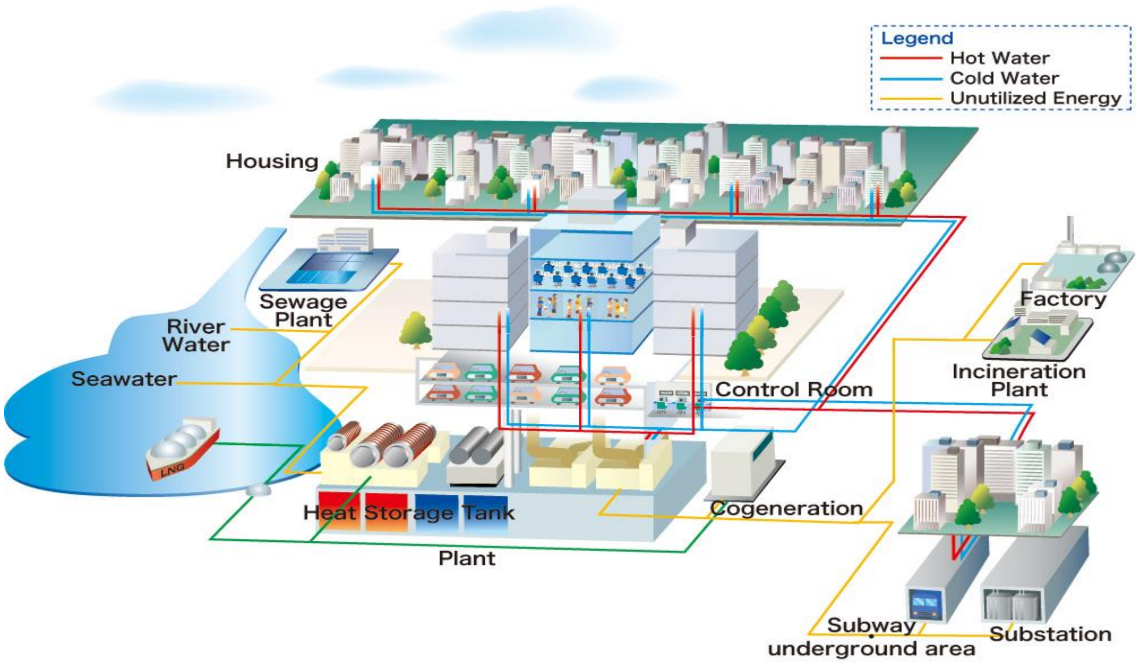
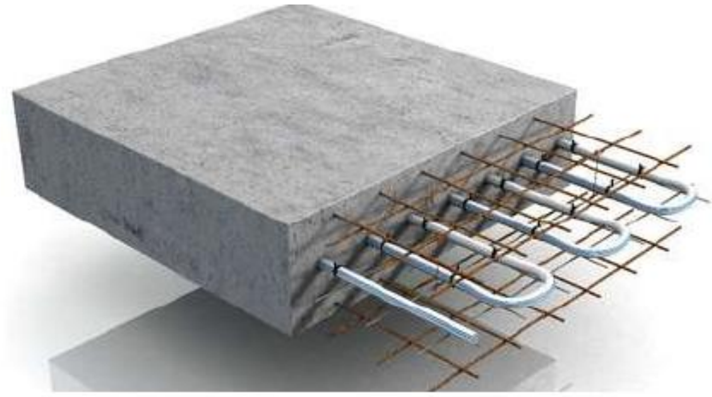


Image Source: Web research

Figure 48: District Cooling

c) **Radiant Cooling** – Radiant cooling is the use of cooled surfaces to remove sensible heat primarily by thermal radiation and only secondarily by other methods like convection. ASHRAE defines radiant systems as temperature-controlled surfaces where 50% or more of the design heat transfer takes place by thermal radiation. Radiant cooling systems offer lower energy consumption than conventional cooling systems[3]. The energy saving from radiant cooling energy is dependent on the climate, but on average, the energy savings are in the range of 30% compared to conventional systems in the US.



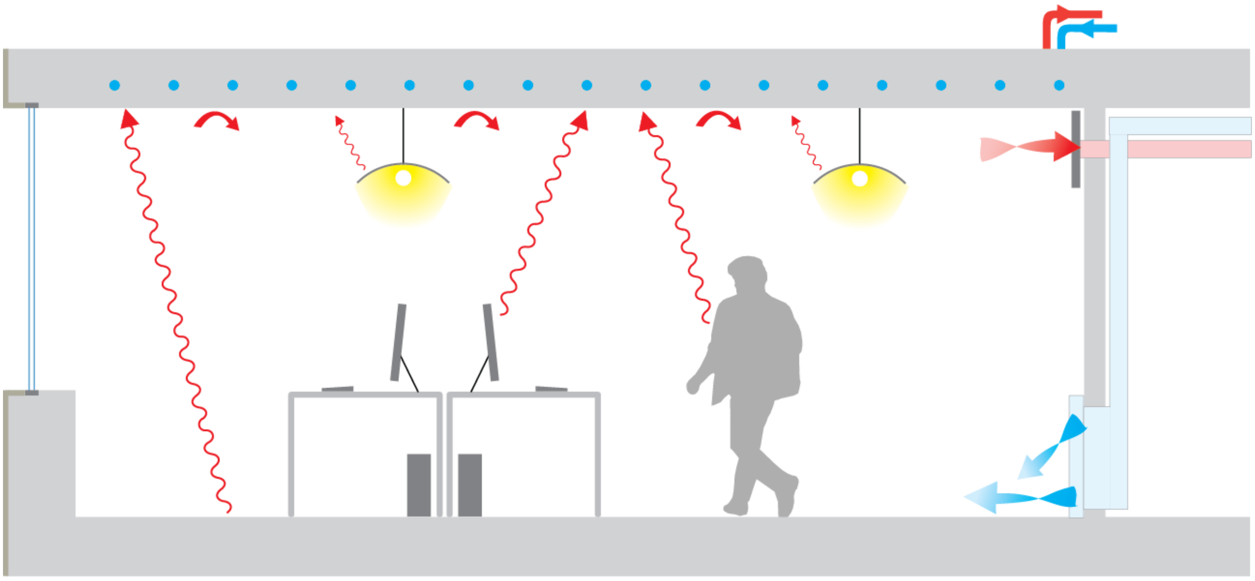


Image source: Web search

Figure 49: Radiant cooling

Box 7-C : Prescriptive requirements for not in-kind technologies

Buildings opting for any above listed not in-kind cooling solution for more than 50% of air conditioning shall be meeting the efficiency level 2 as mentioned in section *8.6* as applicable.

Buildings opting for any above listed not in-kind cooling solution for more than 90% of air conditioning shall be meeting the efficiency level 3 as mentioned in section *8.6* as applicable.

8.7.3. Infiltration/Air leakages

Infiltration can be understood as the uncontrolled inward air leakage through cracks and crevices in external surfaces of buildings, around windows and doors due to pressure differences across these caused by factors such

[3] Based on research conducted by the Lawrence Berkeley National Laboratory

as wind or indoor and outside temperature differences (stack effect), and imbalance between supply and exhaust air systems.[4]

Due to infiltration, the loss of heat from cooled air to the external (ambient) air is observed in the buildings and this eventually results in loss of cooling energy and thermal discomfort to the occupants of buildings.

The following areas of the building envelope, of all except naturally ventilated buildings or spaces, shall be properly sealed, caulked, gasketed or weather-stripped:

- Joints around fenestration, skylights, and door frames
- Openings between walls and foundations, and between walls and roof, and wall panels
- Openings at penetrations of utility services through roofs, walls, and floors
- Site-built fenestration and doors
- Building assemblies used as ducts or plenums
- All other openings in the building envelope
- Exhaust fans shall be fitted with a sealing device such as a self-closing damper
- Operable fenestration should be constructed to eliminate air leakages from the fenestration frame and shutter frame

It is also recommended to use existing infrastructure efficiently by closing windows/doors of the air-conditioned spaces so as to avoid heat transfer between cooled air and ambient air.

Air leakage parameters[5]

1. Air leakage index

For the parameter air leakage index the building envelope area, S (m2), is defined as the internal surface area of the external facade and is calculated from the dimensions bordering the internal volume V (m3) of the building under test. This area is given by the total of the walls, top floor ceiling (or underside of the roof) depending on where the air barrier is and, in special circumstances (see below), the inclusion of the area of the lowest floor, with no deductions for partitions and division walls with adjacent buildings or attached garages.

The area of the lowest floor area is included in the envelope area when it is not ground supported. In this case, there is the potential for air leakage through it. Examples of this are a suspended timber ground floor in a dwelling and a car park beneath an office building. The area of ground-supported concrete floors is not included in the envelope area. Basement concrete walls are classified the same as ground-supported floors and are not included in the envelope area.

2. Air permeability

Air permeability is the air leakage parameter used in the provisional European Standard prEN 13829. It has also been found advantageous to use it, for reasons of simplicity, in air leakage standards for both non-domestic and domestic buildings under the regulatory specification in the Building Regulations Approved Document Part L. In this parameter, the ground floor area is included in the building envelope area, ST (m2), for all building types.

Testing of air leakage:

An air leakage test is carried out for checking the tightness of a building. The test is carried out by mounting a fan (or fans) in a suitable aperture within the building envelope to either depressurize or pressurize the building. An

[4] ECBC 2017
[5] CIBSE Technical Memoranda TM23: 2000 (Testing buildings for air leakage)

internal/external pressure difference is created across the building envelope, with a maximum difference of typically 50-60 Pa is aimed for.

The details of this test can be referred in the standard CIBSE Technical Memoranda TM23: 2000 (Testing buildings for air leakage).

9. Artificial Lighting systems and control

Being an energy guzzler component in buildings, lighting systems need attention to reduce energy consumption in buildings. In addition to providing visual comfort to occupants, the lighting system also contributes to cooling load as it generates heat when in operation. The following guidelines are applicable to:

- Interior spaces of buildings
- Exterior areas like building façade, entry, exit, common areas etc.

Exemptions:

- Process lighting like theatrical productions, TV broadcasting, data centers
- Entertainment facilities like football grounds, hotel ballrooms, night clubs, public parks, public monuments, athletic facilities
- Special purpose luminaires for medical, dental, research labs, showrooms such as jewelry
- Task lightings
- Emergency lightings

Recommended illuminance levels for different areas are provided in section *6.3.4* of this document.

9.1. Mandatory requirements for artificial lighting

The minimum mandatory requirements for interior and exterior lighting systems are provided below.

Box 8-A: Prescriptive requirements for indoor lighting

The lighting power density (LPD) for a space in a building must not exceed the following values in Table 9.

Table 9: Interior lighting power densities requirements

Application Category	Efficiency level 1 LPD (W/m2)	Efficiency level 2 LPD (W/m2)	Efficiency level 3 LPD (W/m2)
Hotel			
Guest room	9	7.5	4.5
Lobby	11	9	5.5
Dining/restaurant	9	7	4.5
Business			
Open plan office	10	8.5	6
Enclosed office	10	8.5	6
Sales area	14	11	9
Hospital			
Reception	8	6.5	5
Exam/treatment	13	10.5	7
Corridor	9	7.5	5

Application Category	Efficiency level 1 LPD (W/m2)	Efficiency level 2 LPD (W/m2)	Efficiency level 3 LPD (W/m2)
Educational			
Staff Rooms	11	9	7
Classroom/lecture	13	11	9
Library	11	10	9
Residential			
Family dining	11	10	9
Assembly room	10	9	8
Food preparation	12	11	10
Reading room	10	9	8
Common areas of any typology			
Restroom	8	6	4
Corridor	7	4.5	2.5
Parking area	3	2	1.5
Lobby	9	7.5	4.5
Conference/meeting	11	9	6
Staircase	5	4.5	3.5

Points to remember:

1. Lighting power density (LPD) is defined as the maximum lighting power consumed in the space divided by the total floor area of that space

2. The LPD shall include all power used by luminaires including lamps, ballasts, regulators and control devices.

3. Luminaire efficacy for different lighting technology shall be in the range as shown in table below:

Table 10: Luminous Efficacy of lighting technologies

Lighting Technology	Luminous Efficacy (lm/W)
LED	90-120
CFL	50-70
FTL	70-90

Luminaire efficacy is the 'Light output of an entire luminaire divided by the total power consumed by the lamps and ballasts'. It is expressed in lumens per Watt (lm/W).

Box 8-B: Prescriptive requirements for exterior lighting

The connected lighting power density of exterior lighting applications shall not exceed the limits as per Table 11**:**

Table 11: Exterior lighting power densities requirements

Application Category	Efficiency level 1 LPD (W/m2)
Building entrance	10 W/m2 of canopied area
Building exit	60 W/lin m of exit door width
Building façade	5.0 W/m2 of vertical façade area
Emergency signs	1
Walkways, pathways	2
Landscaping	0.5

9.2. *Lighting Controls Recommendations*

9.2.1. *Area Controls*

Area controls are used to turn off lights when they are not in use. All lighting systems must have switching or control capabilities to allow lights to be turned off when they are not needed.

- All spaces enclosed by walls or ceiling height partitions shall be provided with one manually operated on/off lighting control (switch) for each space. Each space must have its own switching; gang switching of several spaces is not permitted for internal spaces
- All manually operated switching devices must be located so that personnel can see the controlled area when operating the switch(es). In public areas, such as lobbies, concourses, etc., the switches may be located in areas accessible to authorized personnel only.

9.2.2. *Occupancy Sensors*

Occupancy sensors shall be provided for:

- All meeting rooms, conference halls, staff rooms, banquet halls to control 80% of lighting
- All public washrooms of offices, hotels, and government buildings to control 80% of lighting
- Corridors of hotels and hospitals

Occupancy sensors shall turn off the lighting fixtures within 15 minutes of an occupant leaving the space. Light fixtures controlled by occupancy sensors shall have a wall-mounted, manual switch capable of turning off lights when the space is not occupied.

Exemptions: Lighting systems designed for emergency, security and firefighting purposes.

9.2.3. *Daylight Sensors*

Lighting fixtures installed near windows (within daylight extent) shall be equipped with either a manual control device to shut off luminaires, installed within the daylit area, during the potential daylit time of a day or an automatic control device that:

- Has a delay of minimum 5 minutes, or
- Can dim or step down to 50% of total power.

Overrides to the daylight controls shall not be allowed.

9.2.4. *Controls for Exterior Lighting*

It is recommended to integrate exterior lighting with renewable energy (solar PV). Photo sensor-based or timer-based applications can be to switch on/off exterior lights automatically.

10. Plumbing Systems

In the Maldives, the freshwater source is scarce as there are no river streams and the groundwater is depleted due to salt-water intrusion because of over-extraction. Buildings receive metered desalinated water for captive use, thereby making water a valued resource in the Maldives. With the increase in population in the coming years, water shortage will be an imminent threat that the Maldives will face unless good water management strategies are adopted to ensure the long-term sustainability of water resources. Installing water-efficient plumbing fixtures, harvesting rainwater, and increasing awareness amongst the building occupants on responsible water consumption can ensure optimal utilization of water resources in the Maldives. The surveys of buildings in the Maldives revealed that none of the buildings use low-flow water fixtures in washrooms. However, very few buildings did employ a dual flush system and flow sensors on the taps a as water conservation strategy.

This chapter provides the minimum requirements for plumbing fixtures and rooftop rainwater harvesting systems to achieve water efficiency.

Box 9-A : **Prescriptive requirements for plumbing fixtures**

For all the building typologies, the water-efficient plumbing fixtures shall be installed with the following flowrate values in Table *12*.

Table 12: Mandatory efficiency requirements for plumbing fixtures

Fixture Type	Maximum Flow Rate/Consumption	Duration	Estimated daily uses per person
Water Closets	6 LPF (Full-flush)	1 flush	1
	3 LPF (Half-flush)	1 flush	4
Urinals	4 LPF	1 flush	2
Faucets/Taps	6 LPM	15 seconds	4
Showerhead/Rain Showers/Handheld Spray	10 LPM	8 minutes	1

Source: Uniform Plumbing Code India & IGBC

Points to remember:

1. Flowrate values are at a designed water flow pressure of 3 bar.
2. Estimated daily usage per person is based on a regular building occupant spending 8 hours per day in the building.
3. Faucets/Taps are used for handwashing in restrooms and canteen are considered. Faucets/Taps used for dishwashing and washing clothes are not considered.
4. Plumbing fixtures do not include the irrigation system.

Box 9-B : Prescriptive requirements for rainwater harvesting

In all the building typologies, a rainwater harvesting system, capturing at least 25% of run-off volumes from the roof area for collection and reuse, shall be provided to reduce dependence on piped water supply.

The rainwater harvesting system should cater to at least average rainfall data for the wet season of 9.5 mm per day.

However, users can design rainwater harvesting that captures higher levels (>25%) of run-off volumes from roof areas to achieve a higher efficiency level.

Run-off coefficient for typical roof surface in Maldives:

Table 13: Run-off coefficient for typical roof surface in Maldives

S. No	Surface Type	Runoff Coefficient
1	Cement tiles	0.62 to 069
2	Sheet Metal	0.8 to 0.85
3	Clay tiles (Machine made)	0.30 to 0.39
4	Clay tiles (Hand-made)	0.24 to 0.31

Source: Guidelines and Manual for Rainwater Harvesting in Maldives

Points to remember:

1. Run-off volume is the total amount/quantity of water that flows on the surface of the ground due to precipitation (rain). Run-off coefficient accounts for various losses such as evaporation, infiltration, and others to determine the quantity of rainwater that is harvestable from a roof surface. Therefore, the total volume of rainwater available from the roof is the product of total rainfall, the surface area of the roof, and the run-off coefficient of that particular roof surface.
2. The average rainfall days of 15 days per month in the wet season is considered to arrive at the amount of rainwater that can be harvested.
3. For the design manual and guideline for rainwater harvesting systems in the Maldives, refer to document "Guidelines and Manual for Rainwater Harvesting in Maldives" published by the Government of the Republic of Maldives, 2009

Box 9: Provisions from National Water & Sewerage Policy -2017

Policy Goal 2: Adopt cost-effective, environment-friendly, appropriate technologies in developing water supply and sewerage system

2.1 Ensure climate-resilient concepts are used when designing water and sewerage systems integration of renewable energy, rainwater harvesting, groundwater recharging, and greywater use for non-potable water uses.

2.2 Promote efficiency in water use by adopting appropriate technologies and equipment to ensure long-term sustainability and cost-effectiveness

11. Renewable energy systems

The renewable energy systems that harness energy from renewable sources such as solar or wind in buildings help offset electricity procured from the utilities. Correspondingly, reducing a significant amount of GHG emissions because the utilities use fossil fuel for electricity generation. The solar radiation analysis of the Maldives showed that the roof of the buildings in the Maldives receives higher solar radiation during most part of the year. Therefore, rooftop solar systems can harness maximum solar energy to cater to the electricity and hot water demand respectively from the building, making it self-sufficient. Also, the use of rooftop solar system provides shading on the roof that further helps in reducing heat ingress through the roof. However, in the current practice, most of the buildings in the Maldives do not use onsite renewable energy systems. This chapter provides the recommended requirements for renewable energy systems.

Box 10: **Prescriptive requirement for renewable energy systems**

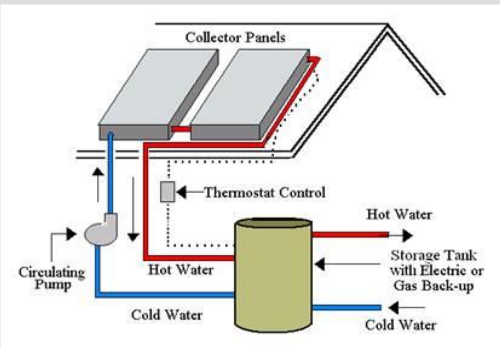
In all the building typologies, renewable energy systems should offset at least 2.5 % of the building energy costs.

However, the user can design for higher renewable energy utilization levels to reduce the dependency on electricity from the utilities. But the maximum amount of electricity generated from the renewable energy systems in a month should not be higher than the monthly electricity requirement of the location/building. Also, the load-bearing structure (in case of solar PV) should be in line with the local structural requirements to ensure the capability of the building to withstand the installed RE system.

Here, the renewable energy systems refer to solar energy systems considering high solar radiation received by the region, and the recommendations are provided based on international best practices.

Box 10: Some of the examples of solar technologies

Use of solar photo voltaic roof top system for electricity generation



Solar Water Heater for hot water applications

Image source: Web research

Figure 50: Image showing various roof top solar technologies

12. Building Operations

The thermal comfort and lighting systems have a significant share (up to 80%) in the overall energy consumption of a building. Thereby, installing energy efficient systems alone cannot reduce energy consumption unless these systems are operated at optimum level and regularly maintained to realize desired performance level. Proper operation and maintenance of these systems will not only ensure a reduction in energy consumption from these systems but also improve the operational life of the systems. This chapter provides minimum requirements for optimal operation and maintenance of major energy-consuming systems in buildings that the building occupants shall adhere to post-occupancy.

Box 11 :Prescriptive requirement for building operation

All the existing and new buildings (post-occupancy) for all typologies shall:

a) **Ensure operating temperature of air conditioning systems to be 25°C ± 1°C**

b) **Perform periodical checks of equipment performances**

- **Once in a year for chillers, cooling towers, AHUs, pumps and motors etc.**
- **Bi-yearly for unitary air conditioning products**

c) **Create awareness (like signages) and training modules for occupants to disseminate knowledge for energy efficiency. Create building level promotional programs to support energy efficiency.**

Figure 51: Image showing use of energy efficiency signage

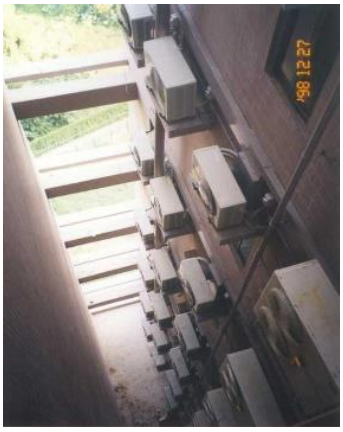
12.1. Additional Recommendations

a) Develop general building operation and maintenance plan including:

- Sequence of building operation
- Building occupancy schedule
- Equipment run time schedule
- Setpoints of HVAC equipment
- Lighting levels throughout the building
- Minimum outside air requirements
- System narrative (project design brief report) which describes entire system of building
- Preventive maintenance plan for equipment

b) Perform time to time cleaning and/or changing of filters once in every two weeks during the cooling season specifically for air conditioning systems.

c) Strategical placement of outdoor units of unitary air conditioners so that the heat rejected from the outdoor units does not enter the adjacent building.



(a) Incorrect Placement

(b) Correct Placement

Figure 52: Image showing placement of AC outdoor units

d) Mandating detailed energy assessment and post-occupancy evaluation of buildings every three years and accordingly offering incentives/penalties on a performance basis.

13. Whole Building Performance Method

The Whole Building Performance method is an alternative compliance path to the prescriptive approach mentioned in chapters 6 to 12. It applies to all the building typologies covered by these guidelines.

Whole Building Performance method essentially involves simulation of the building energy performance through modelling and analysis of a building using a computer-based dynamic thermal analysis software. The objective of building performance simulation is to quantify the aspects related to the design, construction, and operation of buildings. The simulation could provide insights into several characteristics of energy performance such as energy use, end use-wise breakdown, peak electrical and thermal load, thermal comfort, daylighting, and visual comfort. These insights can help in the development of energy efficient design and operation of buildings.

13.1. Demonstrating compliance through Whole Building Performance Method

To comply with these guidelines through the Whole Building Performance method, the EPI ratio of the building must be equal to or less than 1. When showing compliance through this path, it is not necessary to comply with the higher levels of efficiency of Chapters 6 through 12. However, the efficiency value of individual building envelope components and HVAC system shall not be higher than the maximum allowable values provided in these chapters.

Annual energy performance intensity shall be calculated in terms of kilowatt-hours per unit area of the building. It shall include all end-uses (electrical and non-electrical). For non-electrical end-uses, their energy use shall be converted to electrical energy using a factor of 0.75 kWh per megajoule.

It shall be noted that the simulated results of the building energy performance are not a prediction of the actual performance of the building once it is operational. The actual operational energy performance varies with the outdoor weather conditions, occupant behavior, operation of lighting and appliances, operation pattern of the HVAC system, its condition and maintenance, etc.

13.2. Documentation requirements

The compliance shall be documented and submitted to the authority having jurisdiction. The following information shall be submitted:

1. Description of the project, its location, weather conditions, space types, built-up, conditioned and unconditioned area, schedule of operation
2. Summary of building envelope describing opaque and non-opaque building envelope assembly and the corresponding thermal properties, airtightness
3. Summary of internal loads including occupants, lights, equipment, and appliances
4. Description of the HVAC system applied in baseline and proposed cases. This shall include the type, capacity, the efficiency of its components
5. List of energy efficiency features of the proposed design
6. Software used for building energy performance simulation
7. Summary of simulation results including annual energy use for proposed and baseline, peak electrical and thermal loads, end use-wise breakdown of peak loads and energy use, number of hours that the

HVAC system is not able to meet thermal comfort requirements. Such number of hours shall not exceed 300 for either case and shall not differ by more than 50 for baseline and proposed case.

13.3. Simulation requirements

13.3.1. Simulation software

The simulation software shall be a computer-based, dynamic thermal modelling program for modelling and analysis of energy use in buildings. The software shall be approved by the authority having jurisdiction and shall meet the following modelling requirements:

1. Analyze and report energy use on an hourly basis for 8,760 hours of the year,
2. Model hourly and daily changes in internal loads, thermostat settings, HVAC system operation,
3. Behavior of thermal mass of the building,
4. Multiple thermal zones (10 or more),
5. Impact of natural ventilation,
6. Part-load performance and temperature-responsiveness of HVAC systems,
7. Air-side and water-side economizers with integrated controls,

The software shall report hourly energy use and shall have the capacity to perform hourly design load calculations for different HVAC systems and report the system and component capacity, required air and water flows.

The software shall be tested according to the BESTEST methodology as described in ASHRAE Standard 140-Method of Test for the Evaluation of Building Energy Analysis Computer Programs.

13.3.2. Weather data

Hourly values of weather components such as air temperature, humidity, solar radiation, cloud cover, wind speed and direction shall be used for the proposed project location. For cities or regions for which no weather data is available, the modeler shall use the weather data which best represents the weather conditions of the project locations.

13.3.3. Compliance calculations

The proposed and baseline energy performance shall be simulated using:

1. Same simulation program
2. Same weather data
3. Same occupant and equipment load, thermostat setting and operation profiles

13.3.4. Approved software

1. Design Builder
2. DOE2
3. eQuest
4. EnergyPlus
5. HAP
6. IDA-ICE

7. IES VE
8. OpenStudio
9. Trace700
10. TRNSYS
11. Visual DOE

13.4. Maximum allowable EPI Ratios

Table 14: Maximum allowable EPI ratios for different building typologies

Typology	Compliant	Efficiency Level 1	Efficiency Level 2
Government Buildings	1.00	0.85	0.65
Commercial Buildings	1.00	0.85	0.65
Hotels and Guesthouses	1.00	0.85	0.65
Residential Buildings	1.00	0.75	0.55

The following example demonstrates the calculation of EPI ration for the purpose of showing compliance with Table *14*.

An office building in Male is in its design stage. The design team is proposing energy efficient features in the building and has followed the whole building performance approach to demonstrate compliance with these guidelines. The team has used eQuest building energy modelling software for this purpose and has generated a 'Baseline' and an energy efficient 'Proposed' case to demonstrate energy performance improvement. The following table describes various building parameters in the Baseline and how these are improved in the Proposed case.

Table 15: A sample case on improving various building parameters

Parameter	Standard case	Proposed case
Orientation	E-W	N-S
Window-Wall Ratio	70%	30%
Shading	600mm overhang on South facade	600mm overhang on all facades+600mm fins on East and West
Wall U-value	1.2W/m².K	0.3W/m².K
Roof U-value	0.9W/m².K	0.3W/m².K
Glass SHGC	0.4	0.25
Lighting Power Density	6W/m²	3W/m²
Cooling setpoint	23°C	25°C
CSPF	4.0	5.1
EPI	**106kWh/m²**	**67kWh/m²**

The EPI ratio calculated for the Proposed case comes out to be **0.63** which makes the proposed case compliant at **Efficiency Level 2** level as per Table *14*.

14. Appendix

14.1. Impact of shading from adjacent buildings and shading requirements

The impact of shading from adjacent buildings and the need for additional shading devices could be assessed using the metric 'Angle of visible sky (θ)'. The metric quantifies the view to sky from the centre of the window. For a window having no obstruction/adjacency and external shading, the value of θ would be 90°. The availability of daylight inside a space is proportional to θ.

Section 2.1.6 of '[Site layout planning for daylight and sunlight]' published by the Building Research Establishment (UK) provides guidelines on the value of θ and its implication on the availability of daylight inside the space. These guidelines can be summarized as below:

- θ more than 65° – a conventional window design should give reasonable results
- Between 65° and 45° – enlarged windows or changes to room layouts should be considered in order to provide adequate daylight
- Between 45° and 25° – adequate daylight would not be provided unless very large windows are used
- Less than 25° – it is often impossible to provide reasonable daylight, even if the whole wall is glazed

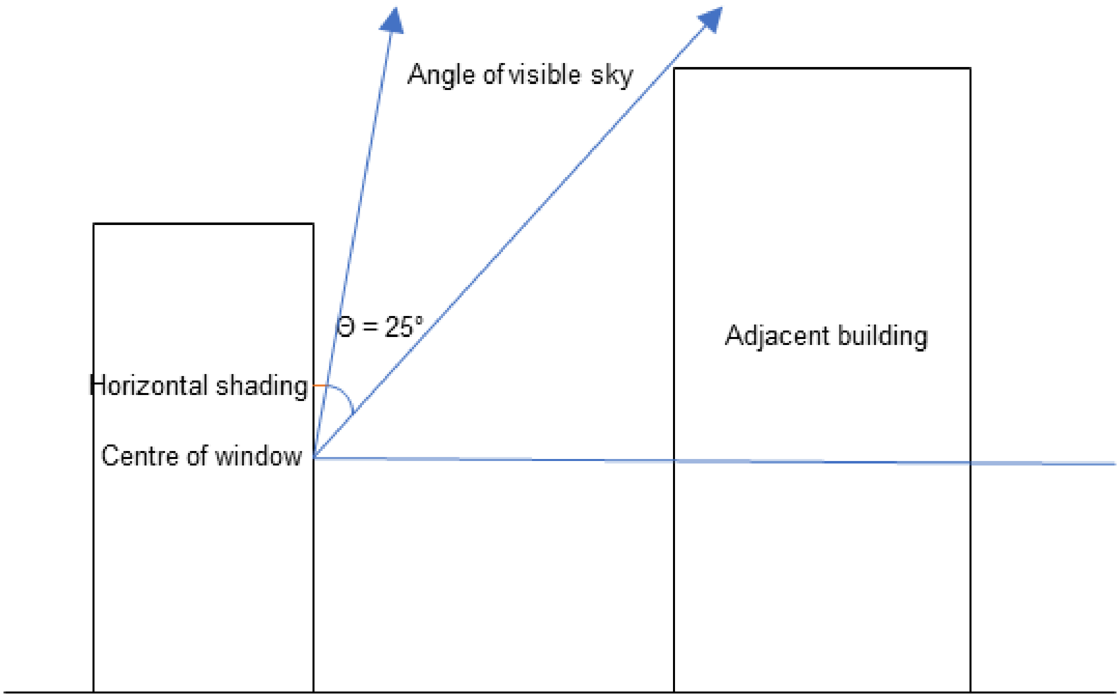


Figure 53: Calculating angle of visible sky, θ, based on adjacent buildings and external shading

For θ less than 45°, providing adequate daylight could be challenging unless very large windows are provided. Thus, for such cases, the prescriptive requirements for shading mentioned in box 5.2.3 can be waived-off to ensure that there is no obstruction to due to shading.

14.2. Reference ventilation rates for various space types

Table 16: Reference to ASHRAE 62.1, Table 6.1: Minimum ventilation rates in breathing zone [6]

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/ person	L/s· person	cfm/ft²	L/s·m²	#/1000 ft² or #/100 m²		
Animal Facilities							
Animal exam room (veterinary office)	10	5	0.12	0.6	20	2	
Animal imaging (MRI/CT/PET)	10	5	0.18	0.9	20	3	
Animal operating rooms	10	5	0.18	0.9	20	3	
Animal postoperative recovery room	10	5	0.18	0.9	20	3	
Animal preparation rooms	10	5	0.18	0.9	20	3	
Animal procedure room	10	5	0.18	0.9	20	3	
Animal surgery scrub	10	5	0.18	0.9	20	3	
Large-animal holding room	10	5	0.18	0.9	20	3	
Necropsy	10	5	0.18	0.9	20	3	
Small-animal-cage room (static cages)	10	5	0.18	0.9	20	3	
Small-animal-cage room (ventilated cages)	10	5	0.18	0.9	20	3	
Correctional Facilities							
Booking/waiting	7.5	3.8	0.06	0.3	50	2	
Cell	5	2.5	0.12	0.6	25	2	
Dayroom	5	2.5	0.06	0.3	30	1	
Guard stations	5	2.5	0.06	0.3	15	1	
Educational Facilities							
Art classroom	10	5	0.18	0.9	20	2	
Classrooms (ages 5 to 8)	10	5	0.12	0.6	25	1	
Classrooms (age 9 plus)	10	5	0.12	0.6	35	1	
Computer lab	10	5	0.12	0.6	25	1	
Daycare sickroom	10	5	0.18	0.9	25	3	
Daycare (through age 4)	10	5	0.18	0.9	25	2	

[6] Source: https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2
Remark: Breathing zone ventilation rates could be calculated by following the procedure given in section 6.2 of ASHRAE 62.1

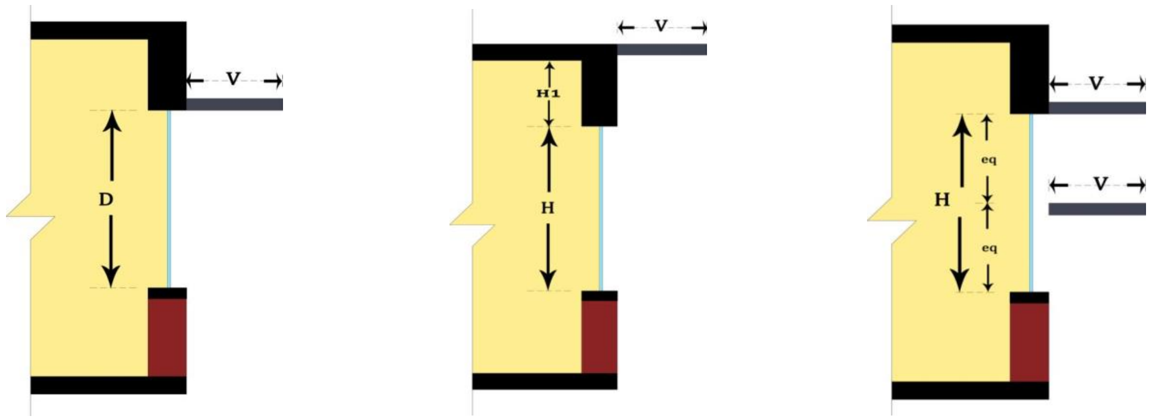
Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/ person	L/s· person	cfm/ft²	L/s·m²	#/1000 ft² or #/100 m²		
Lecture classroom	7.5	3.8	0.06	0.3	65	1	✓
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3	150	1	✓
Libraries	5	2.5	0.12	0.6	10		
Media center	10	5	0.12	0.6	25	1	
Multiuse assembly	7.5	3.8	0.06	0.3	100	1	✓
Music/theater/dance	10	5	0.06	0.3	35	1	✓
Science laboratories	10	5	0.18	0.9	25	2	
Educational Facilities (continued)							
University/college laboratories	10	5	0.18	0.9	25	2	
Wood/metal shop	10	5	0.18	0.9	20	2	
Food and Beverage Service							
Bars, cocktail lounges	7.5	3.8	0.18	0.9	100	2	
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9	100	2	
Kitchen (cooking)	7.5	3.8	0.12	0.6	20	2	
Restaurant dining rooms	7.5	3.8	0.18	0.9	70	2	
Break rooms	5	2.5	0.06	0.3	25	1	✓
Coffee stations	5	2.5	0.06	0.3	20	1	✓
Conference/meeting	5	2.5	0.06	0.3	50	1	✓
Corridors	—	—	0.06	0.3	—	1	✓
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	2	2	
Barracks sleeping areas	5	2.5	0.06	0.3	20	1	✓
Bedroom/living room	5	2.5	0.06	0.3	10	1	✓
Laundry rooms, central	5	2.5	0.12	0.6	10	2	
Laundry rooms within dwelling units	5	2.5	0.12	0.6	10	1	
Lobbies/prefunction	7.5	3.8	0.06	0.3	30	1	✓
Multipurpose assembly	5	2.5	0.06	0.3	120	1	✓
Banks or bank lobbies	7.5	3.8	0.06	0.3	15	1	✓
Bank vaults/safe deposit	5	2.5	0.06	0.3	5	2	✓
Computer (not printing)	5	2.5	0.06	0.3	4	1	✓
Freezer and refrigerated spaces (<50°F [10°C])	10	5	0	0	0	2	
Manufacturing where hazardous materials are not used	10	5.0	0.18	0.9	7	2	

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/ person	L/s· person	cfm/ft²	L/s·m²	#/1000 ft² or #/100 m²		
Manufacturing where hazardous materials are used (excludes heavy industrial and chemical processes)	10	5.0	0.18	0.9	7	3	
Pharmacy (prep. area)	5	2.5	0.18	0.9	10	2	
Photo studios	5	2.5	0.12	0.6	10	1	
Shipping/receiving	10	5	0.12	0.6	2	2	
Sorting, packing, light assembly	7.5	3.8	0.12	0.6	7	2	
Telephone closets	—	—	0.00	0.0	—	1	
Transportation waiting	7.5	3.8	0.06	0.3	100	1	✓
Warehouses	10	5	0.06	0.3	—	2	
Breakrooms	5	2.5	0.12	0.6	50	1	
Main entry lobbies	5	2.5	0.06	0.3	10	1	✓
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3	2	1	
Office space	5	2.5	0.06	0.3	5	1	✓
Reception areas	5	2.5	0.06	0.3	30	1	✓
Telephone/data entry	5	2.5	0.06	0.3	60	1	✓
Birthing room	10	5	0.18	0.9	15	2	
Class 1 imaging rooms	5	2.5	0.12	0.6	5	1	
Dental operatory	10	5	0.18	0.9	20	1	
General examination room	7.5	3.8	0.12	0.6	20	1	
Other dental treatment areas	5	2.5	0.06	0.3	5	1	
Physical therapy exercise area	20	10	0.18	0.9	7	2	
Physical therapy individual room	10	5	0.06	0.3	20	1	
Physical therapeutic pool area	—	—	0.48	2.4	—	2	
Prosthetics and orthotics room	10	5	0.18	0.9	20	1	
Psychiatric consultation room	5	2.5	0.06	0.3	20	1	
Psychiatric examination room	5	2.5	0.06	0.3	20	1	
Psychiatric group room	5	2.5	0.06	0.3	50	1	
Psychiatric seclusion room	10	5	0.06	0.3	5	1	
Speech therapy room	5	2.5	0.06	0.3	20	1	
Urgent care examination room	7.5	3.8	0.12	0.6	20	1	
Urgent care observation room	5	2.5	0.06	0.3	20	1	
Urgent care treatment room	7.5	3.8	0.18	0.9	20	1	
Urgent care triage room	10	5	0.18	0.9	20	1	

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/ person	L/s· person	cfm/ft²	L/s·m²	#/1000 ft² or #/100 m²		
Auditorium seating area	5	2.5	0.06	0.3	150	1	✓
Courtrooms	5	2.5	0.06	0.3	70	1	✓
Legislative chambers	5	2.5	0.06	0.3	50	1	✓
Libraries	5	2.5	0.12	0.6	10	1	
Lobbies	5	2.5	0.06	0.3	150	1	✓
Museums (children's)	7.5	3.8	0.12	0.6	40	1	
Museums/galleries	7.5	3.8	0.06	0.3	40	1	✓
Places of religious worship	5	2.5	0.06	0.3	120	1	✓
Sales (except as below)	7.5	3.8	0.12	0.6	15	2	
Barbershop	7.5	3.8	0.06	0.3	25	2	✓
Beauty and nail salons	20	10	0.12	0.6	25	2	
Coin-operated laundries	7.5	3.8	0.12	0.6	20	2	
Mall common areas	7.5	3.8	0.06	0.3	40	1	✓
Pet shops (animal areas)	7.5	3.8	0.18	0.9	10	2	
Supermarket	7.5	3.8	0.06	0.3	8	1	✓
Bowling alley (seating)	10	5	0.12	0.6	40	1	
Disco/dance floors	20	10	0.06	0.3	100	2	✓
Gambling casinos	7.5	3.8	0.18	0.9	120	1	
Game arcades	7.5	3.8	0.18	0.9	20	1	
Gym, sports arena (play area)	20	10	0.18	0.9	7	2	
Health club/aerobics room	20	10	0.06	0.3	40	2	
Health club/weight rooms	20	10	0.06	0.3	10	2	
Spectator areas	7.5	3.8	0.06	0.3	150	1	✓
Stages, studios	10	5	0.06	0.3	70	1	✓
Swimming (pool and deck)	—	—	0.48	2.4	—	2	
Common corridors	—	—	0.06	0.3		1	✓
Dwelling unit	5	2.5	0.06	0.3	F	1	✓

14.3. Effective SHGC Calculation

To obtain effective SHGC, it is required to calculate the projection factor. Projection factor is the ratio of the distance the overhang projects from the window surface to its height above the sill of the window it shades. The projection factor characterizes the shading impact.



Projection factor = v/D

Projection factor= v/(H+H1)

Projection Factor = (v/(H/2)) + (v/(H/2)) = 4v/H

Figure 54: Image showing different shading configuration

Based on the projection factor value, M-factor is identified using table give in ECBC

		Overhang "M" Factors for 4 Projection Factors				Vertical Fin "M" Factors for 4 Projection Factors				Overhang +Fin "M" Factors for 4 Projection Factors			
Project Location	Orientation	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +
North latitude 15° or greater	N	.88	.80	.76	.73	.74	.67	.58	.52	.64	.51	.39	.31
	E/W	.79	.65	.56	.50	.80	.72	.65	.60	.60	.39	.24	.16
	S	.79	.64	.52	.43	.79	.69	.60	.56	.60	.33	.10	.02
Less than 15° North latitude	N	.83	.74	.69	.66	.73	.65	.57	.50	.59	.44	.32	.23
	E/W	.80	.67	.59	.53	.80	.72	.63	.58	.61	.41	.26	.16
	S	.78	.62	.55	.50	.74	.65	.57	.50	.53	.30	.12	.04

Figure 55: Table for calculating M-factor based on projection factor values

The Effective SHGC is calculated by formula

Effective SHGC = Glass SHGC * M

Source: ECBC India

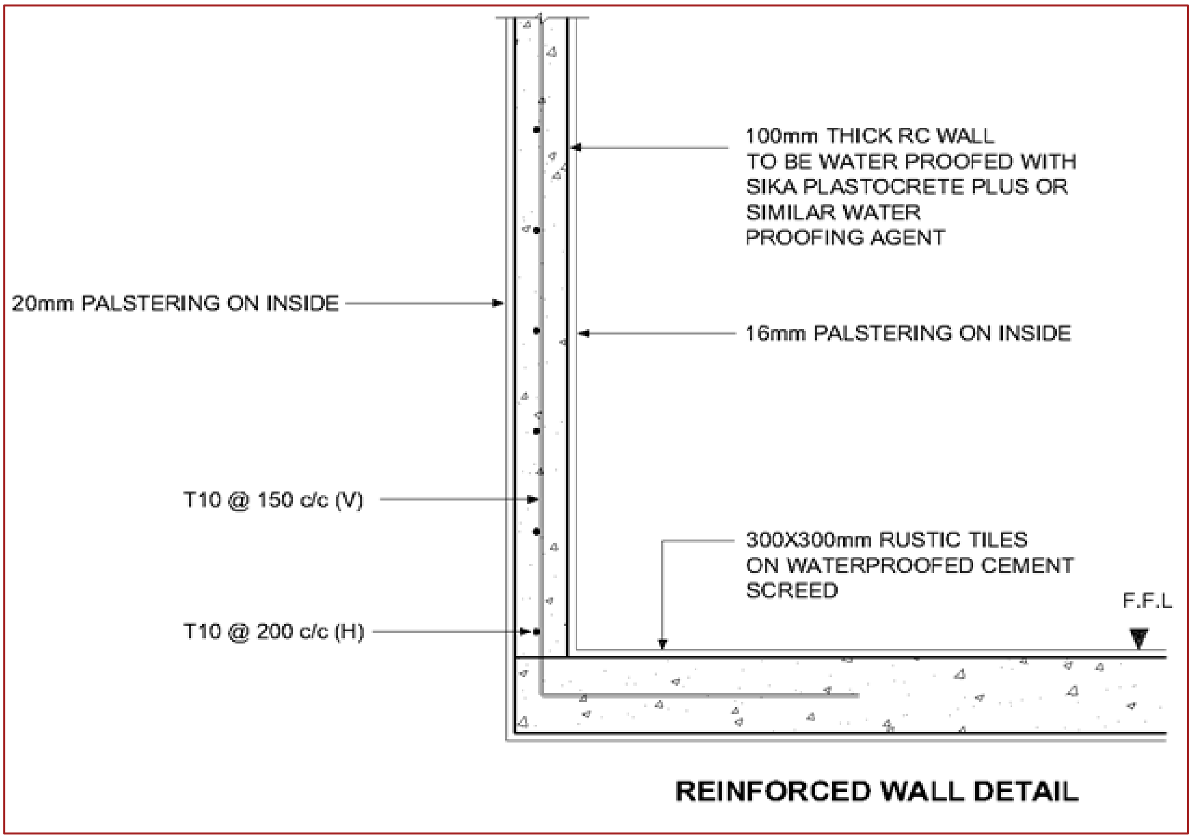
14.4. Thermal Resistance (R-value) & Thermal Transmittance (U value) calculations for commonly used building materials in Maldives

Typical Building Envelope Materials used in Maldives

a) **Walls:** In all the building typologies, Masonry cement blocks are common wall materials with plaster and paint. RC walls are also in some cases with plasters and paint. The widespread availability of imported construction material has led to the adoption of cement blocks as the major material used in constructing walls.

b) **Roof:** The most common roofing in all the building typologies is RC flat slab. Lysaght roofing sheets are used as well, either with timber forming or steel truss & rock wool insulation.

c) **Fenestrations:** In all the building typologies, windows & glazing are permitted only on the external faces on the roadside with an Aluminum window with simple glass (6 to 10 mm) in single glazing. In Commercial and Government buildings, curtain wall glazing systems are used while in residential and hotels/resorts, tempered glass is used in shops and ground floor areas.



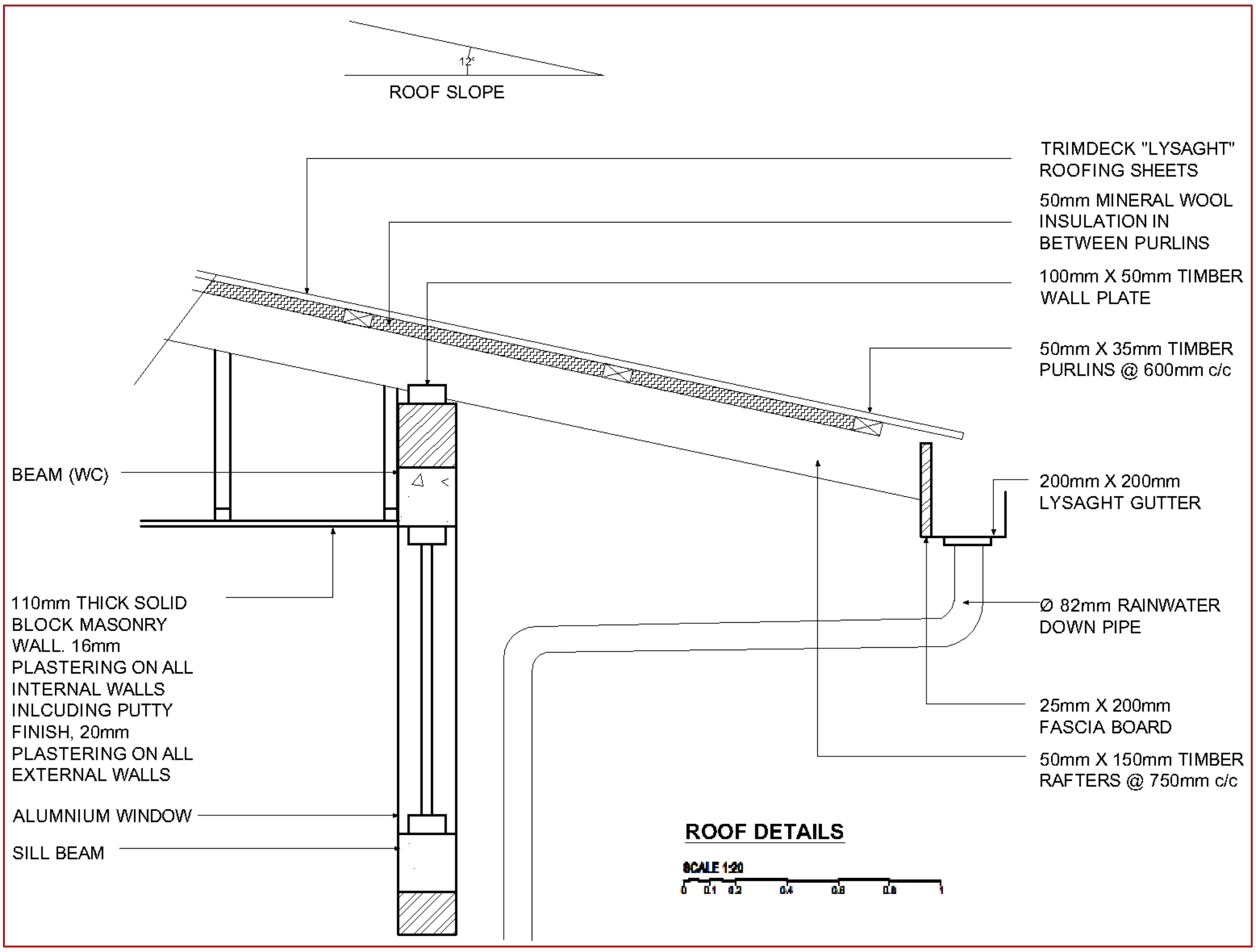


Figure 56: Typical wall & roof details of a building in Maldives

The total thermal resistance (R) and the thermal transmittance (U) value for commonly used building materials in the Maldives is given below :

A. Wall Assembly

1. U- Value of the typical wall with RC Material

Thermal Resistance R = Thickness/ thermal conductivity

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m^2K/W)
RC Material	0.2	1.6	0.125
Inner Plaster	0.016	0.17	0.094
Outer Plaster	0.02	0.17	0.118
Total Resistance (R_T)			**0.337**

Total Thermal Resistance = Sum of the thermal resistance of each layer

$$\mathbf{R_T = R_{reinforced\ concrete} + R_{inner\ plaster} + R_{outer\ plaster}}$$

$$\text{U-Value} = 1/\ R_T$$

$$= 1/\ 0.337$$

U-Value of wall with RC material= 2.97 W/m²K

2. U- Value of the typical wall with Masonry block

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m²K/W)
Masonry block	0.2	0.8	0.25
Inner Plaster	0.016	0.17	0.094
Outer Plaster	0.02	0.17	0.118
Total Resistance (R_T)			**0.462**

Total Thermal Resistance = Sum of the thermal resistance of each layer

$$R_T = R_{masonry\ block} + R_{inner\ plaster} + R_{outer\ plaster}$$

$$\text{U-Value} = 1/ R_T$$

$$= 1/ 0.462$$

U-Value of wall with masonry block = 2.16 W/m²K

B. Roof Assembly

1. U- Value of the typical roof with RC slab

Thermal Resistance R = Thickness/ thermal conductivity

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m²K/W)
RC Material	0.15	1.6	0.093
Inner Plaster	0.016	0.17	0.094
Outer Plaster	0.02	0.17	0.118
Total Resistance (R_T)			**0.305**

Total Thermal Resistance = Sum of the thermal resistance of each layer

$$R_T = R_{reinforced\ concrete\ slab} + R_{inner\ plaster} + R_{outer\ plaster}$$

$$\text{U-Value} = 1/ R_T$$

$$= 1/ 0.305$$

U-Value of roof with RC slab= 3.27 W/m²K

2. U- Value of the typical roof assembly with Timber forming & Mineral wool insulation

Thermal Resistance R = Thickness/ thermal conductivity

Layers/Surface	Thickness (d) (m)	Conductivity (k) (W/m K)	Resistance (r=d/k) (m²K/W)
Mineral Wool	0.05	0.035	1.428
Timber Purlins	0.035	0.15	0.233
Timber Rafters	0.15	0.15	1

Total Resistance (R_T)			4.758

Total Thermal Resistance = Sum of the thermal resistance of each layer

$$\mathbf{R_T = R_{mineral\ wool} + R_{timber\ purlins} + R_{timber\ rafters}}$$

$$\text{U-Value} = 1/\ R_T$$

$$= 1/\ 4.758$$

U-Value of the roof assembly with timber forming & mineral wool insulation = 0.21 W/m²K

Commonly used building material	R-value (m²K/ W)	U-value (W/m²K)
Wall Assembly		
RC material	0.337	2.97
Masonry block	0.462	2.16
Roof Assembly		
RC slab	0.305	3.27
Timber forming & mineral wool insulation	4.758	0.21

Source for the thermal conductivity values of building material: science-direct

14.5. Summary of technical provisions of the EE Guideline

1. Recommendations for minimum energy efficient building design criteria under Prescriptive Method

Table 17: Recommendations for minimum energy efficient building design criteria under Prescriptive Method

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for minimum energy efficient building design criteria</th></tr>
<tr><td rowspan="4">1)</td><td rowspan="4">Bio-Climatic Design</td><td>a) Orientation</td><td>Orientation of building to the longer façade of the building to South-North or North-South direction.</td></tr>
<tr><td>b) Window to Wall Ratio (WWR)</td><td>WWR is 40% for all typologies except for residential buildings for ensuring optimum daylight and natural ventilation
For residential buildings, WWR to be maintained at 50% for ensuring optimum daylight and natural ventilation
To accommodate design limitations and user preferences on aesthetics of building design, the architects and the engineers can vary the value WWR from the recommended optimal value provided SHGC of the glass is maintained as mentioned in the guideline.</td></tr>
<tr><td>c) Shading</td><td>For shading, based on solar radiation and energy simulation analysis, a minimum mandatory requirement of 600 mm overhangs on all orientations shall be provided for optimum solar protection throughout the year.
In cases, where-in provision of 600 mm overhangs is not possible, architects and engineers shall use a recessed window to comply with the minimum mandatory requirement for shading.
In cases, where-in lower floors of the building receive shading from the adjacent buildings or landscape, shading requirements are applicable only to the floors that do not receive any shading.</td></tr>
<tr><td>d) Ventilation</td><td>meet the air changes per hour for particular spaces as mentioned in the guidelines in appendix 14.2
It is recommended that the energy performance or service value which is measured in terms of air delivery in cubic metres per minute / input power in watts of the ceiling fans shall be at least Efficiency level 3 as prescribed in the Indian Standards IS 374:2019. The energy efficiency values are mentioned in the table below.
<table>
<tr><th>EE level</th><th>Ceiling fan with Blade sweep<1,200mm</th><th>Ceiling fan with Blade sweep>=1,200mm</th></tr>
<tr><td>Efficiency Level 3</td><td>>=4.1 - <4.6</td><td>>=5.0 - <5.5</td></tr>
</table>
The IS Standard is referred because the ceiling fan operation pattern, by the occupants, in the Maldives is similar to the Indian context due to similar climatic conditions.</td></tr>
</table>

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for minimum energy efficient building design criteria</th></tr>
<tr><td rowspan="3">2)</td><td rowspan="3">Building Envelope</td><td>e) U-value for wall material</td><td>The maximum allowable U-value of wall assembly shall be 1.2 W/m^{2}K for the optimum reduction in heat gains for buildings.</td></tr>
<tr><td>f) U-value for roof material</td><td>The maximum allowable U-value of roof assembly shall be 0.9 W/m^{2}K for the optimum reduction in heat gains for buildings.</td></tr>
<tr><td>g) SHGC value for glass</td><td>The effective SHGC value for glass shall be in accordance with Table 3, based on the WWR of the building. Both single- and double-glazed glass units can be used to achieve the required SHGC level. Shading should be used to reduce the effective SHGC from the glazing.
<table><tr><th>WWR</th><th>SHGC</th></tr><tr><td>30%</td><td>0.60</td></tr><tr><td>30-40%</td><td>0.50</td></tr><tr><td>40-50%</td><td>0.40</td></tr><tr><td>50-60%</td><td>0.30</td></tr><tr><td>60-70% or more</td><td>0.25</td></tr></table></td></tr>
<tr><td rowspan="2">3)</td><td rowspan="2">Thermal Comfort/ Building Operation</td><td>h) Non-centralized (Unitary AC system)</td><td>Applies to all single-phase, single-split, and unitary type air conditioners of both fixed speed and variable speed types compressors with the rated capacities of up to 24,226 Btu/hr.

For all split, having cooling capacity <4.5 kW (1.3 TR) and between 4.5 kW to 7.1 kW (1.3 TR to 2 TR), the minimum CSPF (cooling seasonal performance factor) should be, at least level 1:
<table><tr><th colspan="2">Value of CSPF (Wh/Wh)</th></tr><tr><td>Size category</td><td>Efficiency level 1 (Mandatory)</td></tr><tr><td>For ACs with cooling capacities < 4.5 kW</td><td>3.30 – 4.60</td></tr><tr><td>For ACs with cooling capacities between 4.5 kW and 7.1 kW</td><td>3.10 – 4.00</td></tr></table></td></tr>
<tr><td>i) Centralized AC systems (Unitary AC system)</td><td>1) For VRV Systems

Variable Refrigerant Flow (VRF) systems shall meet or exceed the efficiency requirements specified in Table below as per the ANSI/AHRI Standard 1230.
<table><tr><th colspan="3">For heating and cooling or both modes</th></tr><tr><td>Size Category (kWr)</td><td>EER (energy efficiency ratio)</td><td>IEER (integrated energy efficiency ratio)</td></tr><tr><td><40 kWr</td><td>3.28</td><td>4.36</td></tr><tr><td>>=40 and < 70 kWr</td><td>3.26</td><td>4.34</td></tr></table></td></tr>
</table>

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for minimum energy efficient building design criteria</th></tr>
<tr><td></td><td></td><td></td><td>
<table>
<tr><td>>=70 kWr</td><td>3.02</td><td>4.07</td></tr>
</table>

2) For Air-cooled Chillers

<table>
<tr><th>Size Category (kWr)</th><th colspan="2">Efficiency level 1 (Mandatory)</th></tr>
<tr><th></th><th>EER</th><th>IPLV</th></tr>
<tr><td><260</td><td>2.8</td><td>3.5</td></tr>
<tr><td>>=260</td><td>3.0</td><td>3.7</td></tr>
</table>

) For Water-cooled Chillers

<table>
<tr><th>Size Category (kWr)</th><th colspan="2">Efficiency level 1 (Mandatory)</th></tr>
<tr><th></th><th>EER</th><th>COP</th></tr>
<tr><td><260</td><td>4.7</td><td>5.8</td></tr>
<tr><td>≥260 & <530</td><td>4.9</td><td>5.9</td></tr>
<tr><td>≥530 &<1,050</td><td>5.4</td><td>6.5</td></tr>
<tr><td>≥1,050 &<1,580</td><td>5.8</td><td>6.8</td></tr>
<tr><td>≥1,580</td><td>6.3</td><td>7.0</td></tr>
</table>
</td></tr>
<tr><td></td><td></td><td>j) Not In-Kind/Innovative Space Cooling Solutions</td><td>

Buildings opting for any above listed not in-kind cooling solution for more than 50% of air conditioning shall be meeting the efficiency level 2 as mentioned in the minimum efficiency levels for the centralized or non-centralized systems as applicable.
Buildings opting for any above listed not in-kind cooling solution for more than 90% of air conditioning shall be meeting the efficiency level 3 as mentioned in the minimum efficiency levels for the centralized or non-centralized systems as applicable.

</td></tr>
<tr><td>4)</td><td>Artificial lighting system and control</td><td>k) Interior Lightings</td><td>
<table>
<tr><th>The lighting power density (LPD) for a space in a building must not exceed the following values in Application Category</th><th>Efficiency level 1 LPD (W/m2)</th></tr>
<tr><td colspan="2">Hotel</td></tr>
<tr><td>Guest room</td><td>9</td></tr>
<tr><td>Lobby</td><td>11</td></tr>
<tr><td>Dining/restaurant</td><td>9</td></tr>
<tr><td colspan="2">Business</td></tr>
</table>
</td></tr>
</table>

S. No	EE Guideline Features	Sub-Sections	Recommendations for minimum energy efficient building design criteria
			(continued LPD table, see below)

Open plan office	10
Enclosed office	10
Sales area	14
Hospital	
Reception	8
Exam/treatment	13
Corridor	9
Educational	
Staff Rooms	11
Classroom/lecture	13
Library	11
Residential	
Family dining	11
Assembly room	10
Food preparation	12
Reading room	10
Common areas of any typology	
Restroom	8
Corridor	7
Parking area	3
Lobby	9
Conference/meeting	11
Staircase	5

1. The LPD shall include all power used by luminaires including lamps, ballasts, regulators, and control devices.
2. Luminaire efficacy for different lighting technology shall be in the range as shown in the table below:

Lighting Technology	Luminous Efficacy (lm/W)
LED	90-120
CFL	50-70
FTL	70-90

Luminaire efficacy is the 'Light output of an entire luminaire divided by the total power consumed by the lamps and ballasts'. It is expressed in lumens per Watt (lm/W).

l) Exterior Lightings

The connected lighting power of exterior lighting applications shall not exceed the lighting power limits as provided in the table below:

Application Category	Efficiency level LPD (W/m2)
Building entrance	10 W/m2 of canopied area
Building exit	60 W/lin m of exit door width
Building façade	5.0 W/m2 of vertical façade area

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for minimum energy efficient building design criteria</th></tr>
<tr><td></td><td></td><td></td><td><table>
<tr><td>Emergency signs</td><td>1</td></tr>
<tr><td>Walkways, pathways</td><td>2</td></tr>
<tr><td>Landscaping</td><td>0.5</td></tr>
</table></td></tr>
<tr><td rowspan="2">5)</td><td rowspan="2">Plumbing Systems</td><td>m) Plumbing fixtures</td><td><table>
<tr><th>For all the building typologies, water-efficient plumbing fixtures shall be installed with the following flowrate values: Fixture Type</th><th>Maximum Flow Rate/Consumption</th><th>Duration</th><th>Estimated daily uses per person</th></tr>
<tr><td rowspan="2">Water Closets</td><td>6 LPF (Full-flush)</td><td>1 flush</td><td>1</td></tr>
<tr><td>3 LPF (Half-flush)</td><td>1 flush</td><td>4</td></tr>
<tr><td>Urinals</td><td>4 LPF</td><td>1 flush</td><td>2</td></tr>
<tr><td>Faucets/Taps</td><td>6 LPM</td><td>15 seconds</td><td>4</td></tr>
<tr><td>Showerhead/Rain Showers/Handheld Spray</td><td>10 LPM</td><td>8 minutes</td><td>1</td></tr>
</table></td></tr>
<tr><td>n) Rainwater harvesting</td><td>In all the building typologies, a rainwater harvesting system that captures at least 25% of run-off volumes from the roof area for collection and reuse shall be provided to reduce dependence on piped water supply.

The rainwater harvesting system should cater to at least average rainfall data for the wet season of 9.5 mm per day.</td></tr>
<tr><td>6)</td><td>Renewable Energy Systems</td><td></td><td>In all the building typologies, renewable energy systems should constitute 2.5 % of the total electricity consumption of the building.

However, the user can design for higher renewable energy utilization levels to reduce the dependency on electricity from the utilities. But the maximum amount of electricity generated from the renewable energy systems in a month should not be higher than the monthly electricity requirement of the location/building. Also, the load-bearing structure (in case of solar PV) should be in line with the local structural requirements to ensure the capability of the building to withstand the installed RE system.</td></tr>
<tr><td>7)</td><td>Building Operations</td><td></td><td>a) Ensure operating temperature of air conditioning systems to be 25°C ± 1°C
b) Perform periodical checks of equipment performances:

• Once in a year for chillers, cooling towers, AHUs, pumps and motors etc.
• Bi-yearly for unitary air conditioning products</td></tr>
</table>

S. No	EE Guideline Features	Sub-Sections	Recommendations for minimum energy efficient building design criteria
			c) Create awareness (like signages) and training modules for occupants to disseminate knowledge for energy efficiency. Create building level promotional programs to support energy efficiency.

2. Recommendations for Higher Efficiency Level of Building Design under Prescriptive Method

Table 18: Recommendations for Higher Efficiency Level of Building Design under Prescriptive Method

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for Higher Efficiency Level of Building Design</th></tr>
<tr><td>1)</td><td>Bio-Climatic Design</td><td>a) Ventilation</td><td>The energy performance or service value which is measured in terms of air delivery in cubic metres per minute/input power in watts of the ceiling fans can be Efficiency level 4 and Energy Level 5 as prescribed in the Indian Standards IS 374:2019.
<table><tr><th>EE level</th><th>Ceiling fan with Blade sweep<1,200mm</th><th>Ceiling fan with Blade sweep>=1,200mm</th></tr><tr><td>Efficiency Level 4</td><td>>=4.6 - <5.1</td><td>>=5.5 - <6.0</td></tr><tr><td>Efficiency Level 5</td><td>>=5.1</td><td>>=6.0</td></tr></table></td></tr>
<tr><td rowspan="2">2)</td><td rowspan="2">Building Envelope</td><td>a) U-value for wall material</td><td>The user can design for higher efficiency levels by reducing the U-value of the wall assembly to 0.9 W/m²K</td></tr>
<tr><td>b) U-value for roof material</td><td>The user can design for higher efficiency levels by reducing the U-value of the roof assembly to 0.6 W/m²K</td></tr>
<tr><td rowspan="2">3)</td><td rowspan="2">Thermal Comfort/ Building Operation</td><td>c) Non-centralized (Unitary AC system)</td><td><table><tr><th colspan="3">Value of CSPF (Wh/Wh)</th></tr><tr><td>Size category</td><td>Efficiency level 2</td><td>Efficiency level 3</td></tr><tr><td>For ACs with cooling capacities < 4.5 kW</td><td>4.60 – 5.30</td><td>≥5.30</td></tr><tr><td>For ACs with cooling capacities between 4.5 kW and 7.1 kW</td><td>4.00 - 5.10</td><td>≥5.10</td></tr></table></td></tr>
<tr><td>d) Centralized AC systems</td><td>1) For Air-cooled Chillers
<table><tr><th>Efficiency level 2</th></tr></table></td></tr>
</table>

<table>
<tr><th>S. No</th><th>EE Guideline Features</th><th>Sub-Sections</th><th>Recommendations for Higher Efficiency Level of Building Design</th></tr>
<tr><td></td><td></td><td>(Unitary AC system)</td><td>
<table>
<tr><th>Size Category (kWr)</th><th>EER</th><th>IPLV</th></tr>
<tr><td><260</td><td>3.0</td><td>4.0</td></tr>
<tr><td>>=260</td><td>3.2</td><td>5.0</td></tr>
</table>
2) For Water-cooled Chillers
<table>
<tr><th></th><th colspan="2">Efficiency level 2</th><th colspan="2">Efficiency level 3</th></tr>
<tr><td>Size Category (kWr)</td><td>EER</td><td>COP</td><td>EER</td><td>COP</td></tr>
<tr><td><260</td><td>5.2</td><td>6.9</td><td>5.8</td><td>7.1</td></tr>
<tr><td>≥260 & <530</td><td>5.8</td><td>7.1</td><td>6.0</td><td>7.9</td></tr>
<tr><td>≥530 &<1,050</td><td>5.8</td><td>7.5</td><td>6.3</td><td>8.4</td></tr>
<tr><td>≥1,050 &<1,580</td><td>6.2</td><td>8.1</td><td>6.5</td><td>8.8</td></tr>
<tr><td>≥1,580</td><td>6.5</td><td>8.9</td><td>6.7</td><td>9.1</td></tr>
</table>
</td></tr>
<tr><td>4)</td><td>Artificial lighting system and control</td><td>e) Interior Lightings</td><td>
The lighting power density (LPD) for a space in a building must not exceed the following values:
<table>
<tr><th>Application Category</th><th>Efficiency level 2
LPD (W/m2)</th><th>Efficiency level 3
LPD (W/m2)</th></tr>
<tr><td colspan="3">Hotel</td></tr>
<tr><td>Guest room</td><td>7.5</td><td>4.5</td></tr>
<tr><td>Lobby</td><td>9</td><td>5.5</td></tr>
<tr><td>Dining/restaurant</td><td>7</td><td>4.5</td></tr>
<tr><td colspan="3">Business</td></tr>
<tr><td>Open plan office</td><td>8.5</td><td>6</td></tr>
<tr><td>Enclosed office</td><td>8.5</td><td>6</td></tr>
<tr><td>Sales area</td><td>11</td><td>9</td></tr>
<tr><td colspan="3">Hospital</td></tr>
<tr><td>Reception</td><td>6.5</td><td>5</td></tr>
<tr><td>Exam/treatment</td><td>10.5</td><td>7</td></tr>
<tr><td>Corridor</td><td>7.5</td><td>5</td></tr>
<tr><td colspan="3">Educational</td></tr>
<tr><td>Staff Rooms</td><td>9</td><td>7</td></tr>
<tr><td>Classroom/lecture</td><td>11</td><td>9</td></tr>
<tr><td>Library</td><td>10</td><td>9</td></tr>
<tr><td colspan="3">Residential</td></tr>
</table>
</td></tr>
</table>

S. No	EE Guideline Features	Sub-Sections	Recommendations for Higher Efficiency Level of Building Design

Family dining	10	9
Assembly room	9	8
Food preparation	11	10
Reading room	9	8
Common areas of any typology		
Restroom	6	4
Corridor	4.5	2.5
Parking area	2	1.5
Lobby	7.5	4.5
Conference/meeting	9	6
Staircase	4.5	3.5

3. Recommendations for minimum energy efficient building design criteria under Whole Building Performance Method

Maximum allowable EPI ratios for different building typologies

Table 19: Recommendations for minimum energy efficient building design criteria under Whole Building Performance Method

Typology	Compliant
Government Buildings	1.00
Commercial Buildings	1.00
Hotels and Guesthouses	1.00
Residential Buildings	1.00

4. Recommendations for Higher Efficiency Level of Building Design under Whole Building Performance Method

Maximum allowable EPI ratios for different building typologies

Table 20: Recommendations for Higher Efficiency Level of Building Design under Whole Building Performance Method

Typology	Efficiency Level 1	Efficiency Level 2
Government Buildings	0.85	0.65
Commercial Buildings	0.85	0.65
Hotels and Guesthouses	0.85	0.65
Residential Buildings	0.75	0.55

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