



Ministry of Environment,
Climate Change and Technology

REVIEW AND AMEND DESIGN OF MALDIVES METEOROLOGICAL SERVICE GAN OFFICE BUILDING



Promoting Energy Efficient Buildings through
Strengthening Low Carbon Energy
Island Strategies (LCEI) Project





Ministry of Environment, Climate
Change and Technology

Strengthening Low Carbon
Energy Island Strategies (LCEI)
Project



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Ministry of Environment, Climate Change and
Technology

Review and Amend Design of MET Office

Environmental Performance Assessment and Recommendations Report



Promoting Energy Efficient Buildings through
Strengthening Low Carbon Energy
Island Strategies (LCEI) Project



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1. Introduction

1.1. About MET Office

The MET Office building is coming up in Addu island and would house the Meteorological Department. The Ministry of Environment, Climate Change and Technology is inclined to design the building with energy efficient features which would demonstrate the aspects of the draft 'Maldives Building Energy Efficiency Guidelines'. The Guidelines are being developed under the 'Strengthening Low Carbon Energy Island Strategies Project (LCEI)', which is funded by Global Environment Facility (GEF) and is implemented by the Ministry of Environment, Climate Change and Technology. Hence, the proposed office building is being designed, keeping in perspective the recommendations made in the Guidelines. The building would be a benchmark of energy and resource efficiency, thermal and visual comfort and environmental footprint in Maldives.



Figure 1: Perspective view of the MET office

1.2. Project objectives

The aim of this project was to assess and improve the energy efficiency of the MET office. The project objectives were to

- Review the current energy performance of the MET office against the Maldives Building Energy Efficiency Guidelines, and
- Amend the current design with energy conservation and energy efficiency measures to improve its performance beyond the standards set in the Guidelines.

2. Approach and Methodology

2.1. Approach

In order to fulfill the project aim and objectives, the project team followed an iterative and progressive approach as described in the figure 2. The project team evaluated the current design of the MET office based on the design data provided by Riyan Architects and some additional data on equipment provided by the team at MET Office. Using the data collected, the team developed a digital energy model of the MET office to review the performance of the current design and evaluate various energy conservation and energy efficiency measures. Whole building performance method of the Guidelines (section 13) was followed for this exercise. The team tested a total of 56 design interventions including building orientation, solar shading, wall, roof and glass materials, HVAC systems and solar PV, in line with the minimum requirements set under the Maldives Building Energy Efficiency Guidelines (section 6 through 12). The team also suggested various smart building technologies to further reduce the operational energy use. Finally, the team compared the current design against an 'Optimal' case which demonstrates compliance with all the minimum performance requirements of the Guidelines and a 'Best' case which is a combination of the best measures. The team used its data-driven solution 'Sustainability Analytics Hub' to holistically evaluate the energy performance of MET office along with daylighting, thermal comfort, GHG emissions, and cost implications of the various performance improvement measures.

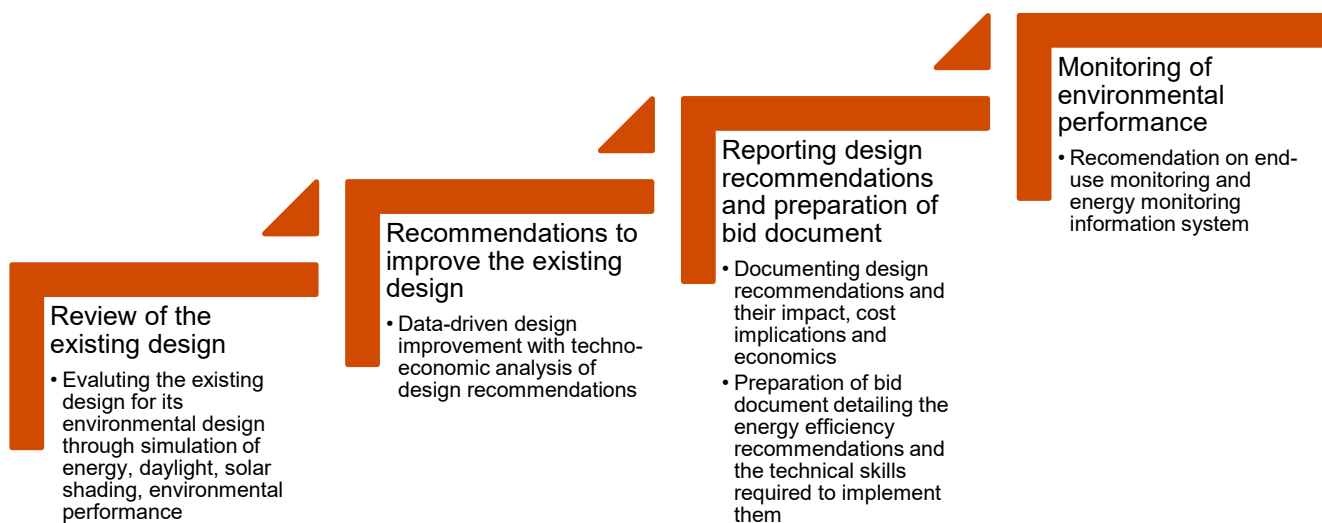


Figure 2: Approach followed to fulfill the project aim and objectives

2.2. Methodology

The project team carried out detailed analysis on the existing design to evaluate its performance against the benchmarks set in the 'Maldives Buildings Energy Efficiency Guidelines'. The team evaluated the MET office design for its:

1. Energy consumption,
2. Cooling load,
3. Availability and quality of daylight,
4. Thermal comfort,
5. Parameters of HVAC system operation

As mentioned in earlier section, the team followed an iterative and progressive approach for this project. As described in figure 3, the team developed the 'baseline' energy model based on the building drawings, building material properties, lighting details and HVAC system shared by Riyan. The equipment density for specific areas was calculated based on the data provided by the team at MET office. Various measures were tested for their impact on the environmental performance. It is to be noted that the lighting design was already optimized by Riyan and hence was recommended to be followed 'as-designed'. Upon analyzing the current design, it was

found that the cooling load of the building is below 50 TR and hence systems such as Air-cooled and water-cooled chillers were ruled-out of the ambit of analysis as these are not feasible for such smaller cooling loads.

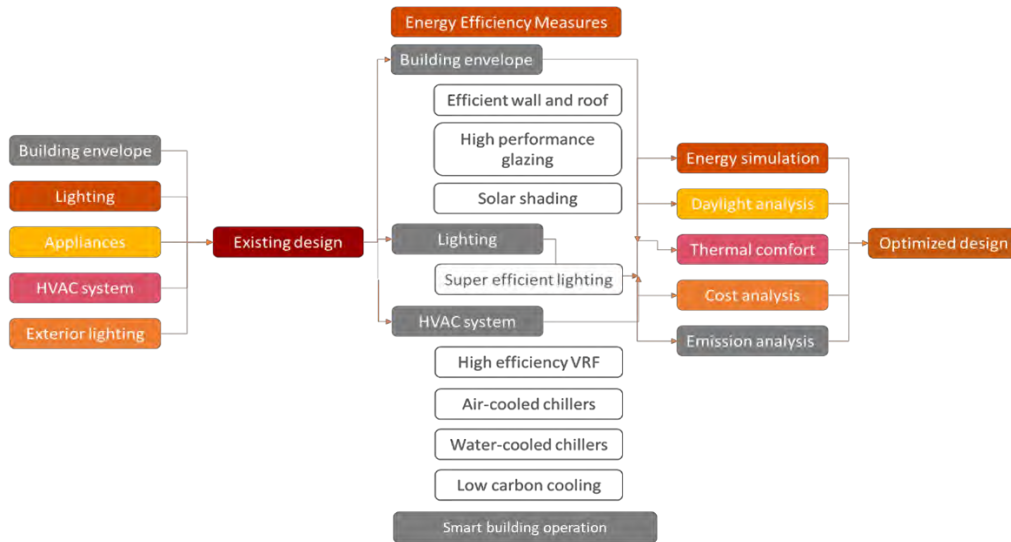


Figure 3: Modelling and analysis workflow

The team conducted simulation studies to evaluate the performance of MET office for its bioclimatic design, building envelope, energy use, thermal comfort, daylight availability and quality and GHG emissions. All the interventions were also evaluated based on the initial investment required, the amount of operational savings generated and payback period.

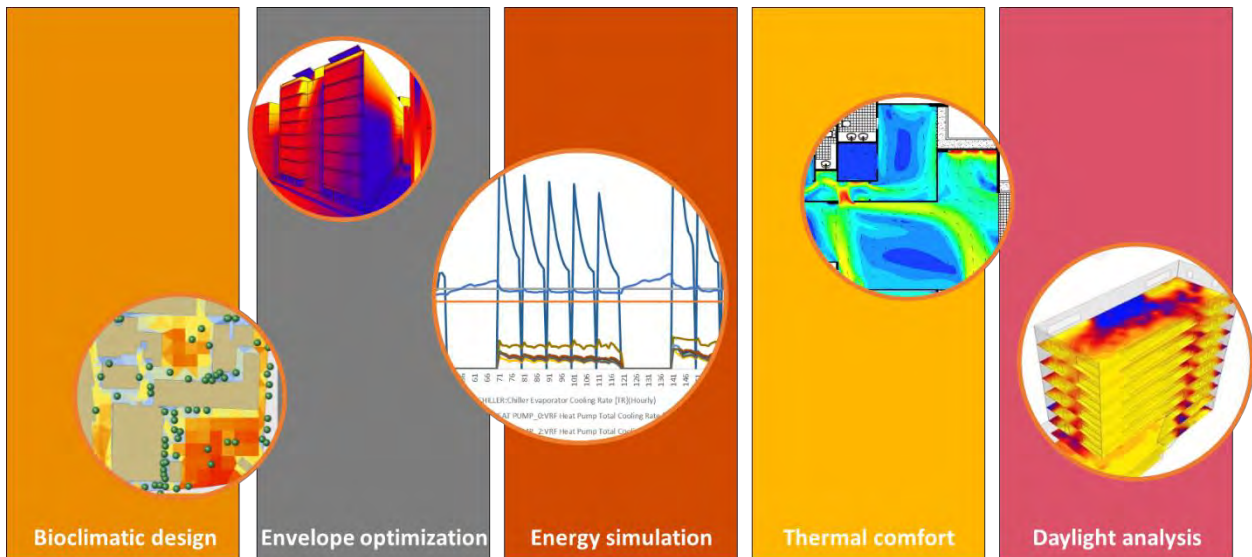


Figure 4: Various analysis carried out by the project team

Detailed Analysis

- **Bioclimatic design**
The existing design was analyzed for its massing, solar shading, orientation, spatial configuration and microclimate. The project team proposed recommendations to improve the bioclimatic aspects of the MET office.
- **Envelope optimization**
The project team reviewed the existing building envelope for its thermal properties and materials and evaluate its impact on the environmental performance. Based on the performance, the project team optimized the building envelope to maximize the performance at optimized cost.

- **Energy Simulation**
The project team generated an energy model of the existing design and review its energy consumption, cooling load, energy profile, HVAC system performance and proposed design changes viz. solar shading, building materials, HVAC system and operation schedule to outperform the KPIs. Cost-benefit analysis was an essential part of this exercise. eQuest version 3.65 was used to carry out this analysis.
- **Thermal comfort**
The existing design was analyzed for the thermal comfort conditions during occupied hours. The analysis focused to maximize thermal comfort at optimized operational cost. Thermal comfort outputs of the energy modelling exercise were used to generate thermal comfort maps.
- **Daylight analysis**
The project team carried out annual daylight simulation and glare studies to evaluate the visual comfort quality of the existing design. The outcomes of the analysis were used in improving the window-wall ratio, glass selection, optimizing solar shading. DaySim was used for annual daylight analysis and EvalGlare was used to analyze possibility of perceivable and disturbing glare.

Based on the analysis, the project team documented the findings of the existing design and the design recommendations to arrive at two design alternatives – optimal and best case. The project team also assisted Riyan Architects in developing the bid document to implement the recommended energy efficiency design interventions, highlighting the technical and material requirements from the contractor.

2.3. About Sustainability Analytics Hub

The project team is having vast experience in delivering similar projects and has developed ‘Sustainability Analytics Hub’-a state-of-the-art, integrated software solution to evaluate sustainability performance of buildings. The project team proposed to deploy this Data-Driven solution which brings together simulation capabilities of different tools to evaluate energy, daylighting, thermal comfort, natural ventilation performance on a single platform and performs cost and environmental impact calculations in real time.

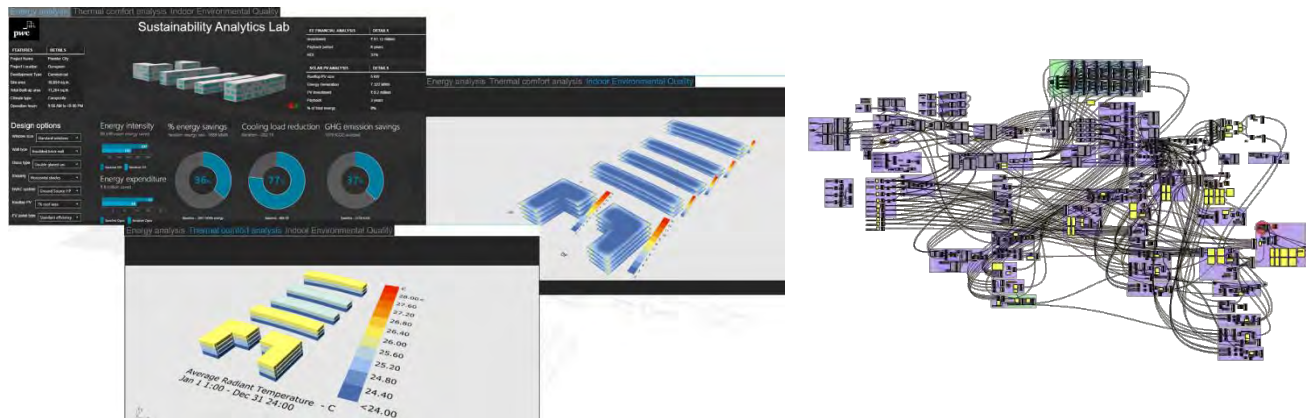


Figure 5: User interface (left) and backend algorithm (right) of the Sustainability Analytics Lab

Sustainability Analytics Hub is powered by industry recognized software tools ‘Rhinoceros’ and its virtual programming and modelling platform ‘Grasshopper’ and its plugins. The energy, thermal comfort and natural ventilation simulations are carried out on ‘EnergyPlus’, and daylight and glare analysis are done on ‘Radiance and Daysim’. Sustainability Analytics Hub is backed by complex, robust algorithm to parametrically model several energy efficient measures and simulate them in real time.

It is an ideal simulation toolkit for the design team to evaluate a broad range of energy efficiency measure and their cost implications in real time. Hence, the project team used this platform to review the existing design of the MET Office and provide design recommendations to enhance its energy and resource efficiency, indoor environmental quality, and reduce its carbon footprint at optimized cost.

2.4. Reference standards

The team followed the draft Maldives Building Energy Efficiency Guidelines as the reference standard to establish the minimum performance criteria. Sections 6 through 12 were followed for different evaluation of different elements of the design and recommend design changes. Section 13 – Whole building performance method as guiding procedure to carry out this study.

2.5. Weather data

Hourly weather data of Gan, Maldives provided by MET office was used to perform the various simulation studies for this project.

The next chapter documents the climate analysis carried out for Gan (Addu atoll) and the qualitative evaluation of the MET office on various principles of passive design.

3. Climate analysis

3.1. Climate of Gan (Addu Island) based on Maldives Meteorological Services data

Maldives Meteorological Service (MMS) is the meteorological department of Maldives. This department provided the climate data comprising of Temperature (min. & max), Relative humidity and Wind speed for the period of last 10 years starting from 2010 - 2020 for Gan, Maldives. External climate components that affect the internal environmental are air temperature, relative humidity, rainfall, wind and solar radiations. The same have been analyzed in the subsequent sections.

3.1.1. Analysis of temperature data

Figure 6 analyses the monthly average temperature along with the minimum and maximum temperatures recorded in Gan, Maldives.

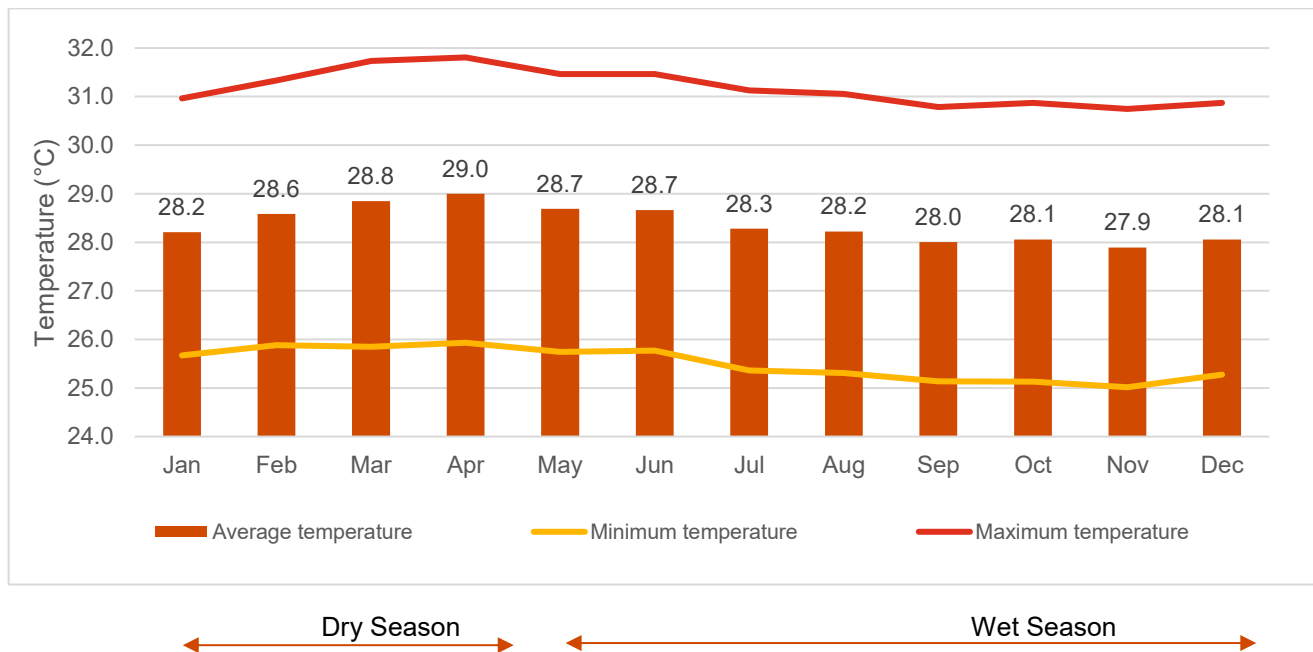


Figure 6: Monthly Average Temperature at Gan, Maldives

It is observed that the temperature is almost constant and above the comfortable range throughout the year. The monthly average temperature increases starting January, and peaks in April and then decreases by August and stays constant for the remaining months of the year. The average temperature for dry season is 28.6 °C with highest average temperature i.e. 31.2 °C in the month of April. The average temperature for wet season is 28.2 °C with and lowest i.e. 25 °C in the months of November. It is observed that the temperature above the comfortable range throughout the year requiring significant energy demand for space cooling.

3.1.2. Analysis of Relative Humidity Data

Relative humidity has substantial impact on thermal comfort level of building occupants along with the ambient air temperature.

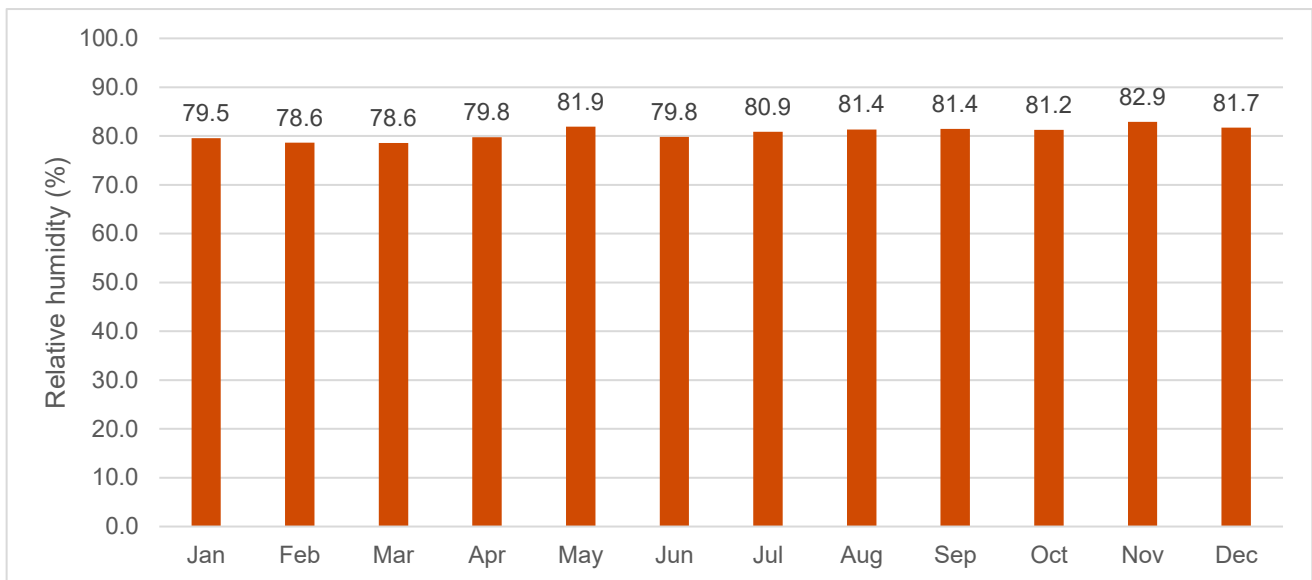


Figure 7: Monthly Average Relative Humidity at Gan, Maldives

Figure 7 shows the monthly relative humidity (in %) of Gan, Maldives from 2010 – 2020. It is observed that the average relative humidity ranges from 75% to 80% throughout the year. It can be concluded from the above graph that relative humidity is high, above 75% throughout the year.

3.1.3. Analysis of Wind Speed

The wind speed in any region plays significant role in building design in order to design windows and its appropriate orientation to bring fresh air inside and to provide accurate ventilation for building occupants. The annual average wind speed wind speed for different months from 2010 to 2020 is presented below.

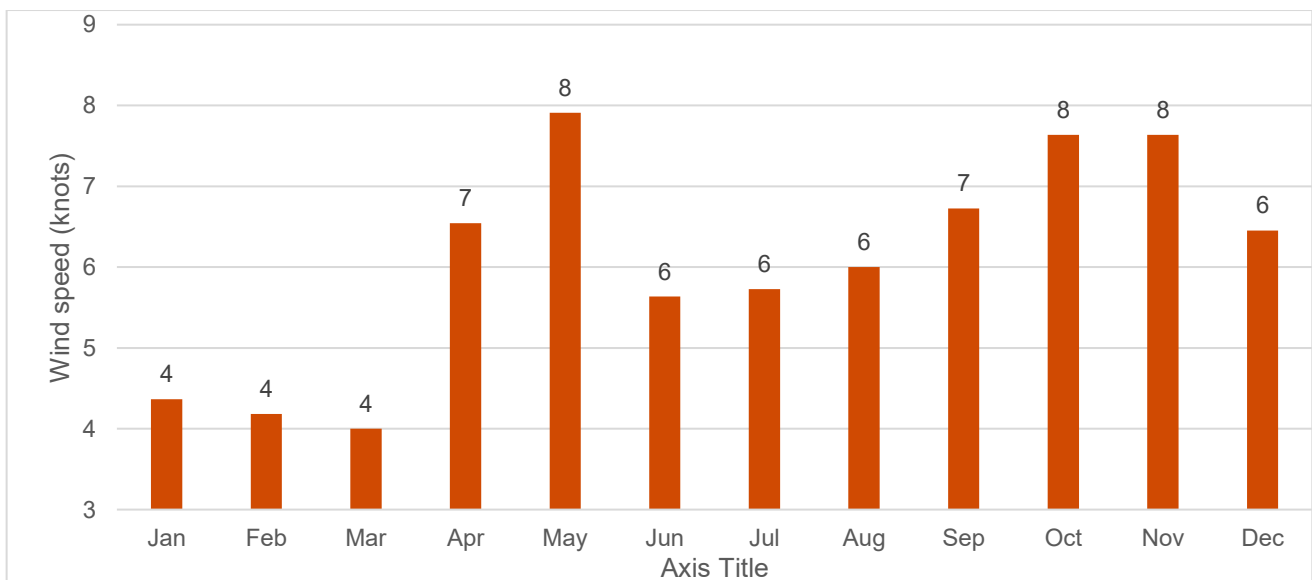


Figure 8: Monthly Average Wind Speed at Gan, Maldives (knots)

Figure 8 shows the monthly average wind speed (in knots) of Gan, Maldives from 2010-2020. It can be concluded from the above graph that wind speed is highest in the month of May and lowest in the month of March. Average wind speed of dry and wet season is 5.0 knots and 7 knots respectively. Detailed analysis of

Wind data indicates that in dry season predominant wind direction is North East (NE) and in wet season wind mainly flows in South West (SW) direction. Throughout the year wind predominantly flows from West direction.

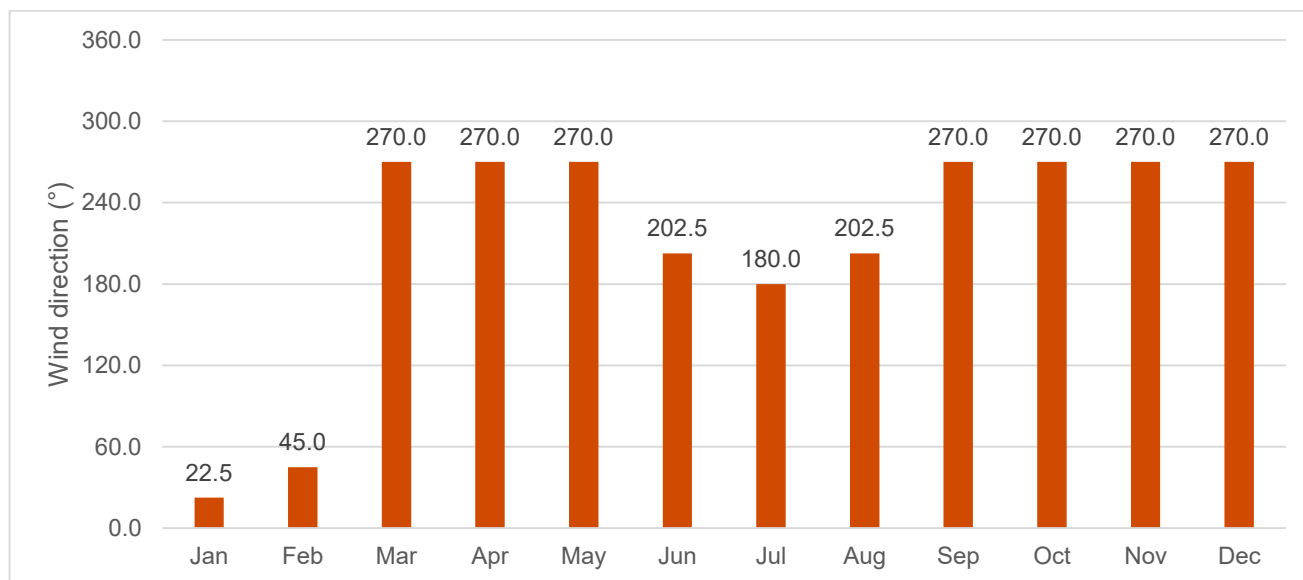


Figure 9: Diagram showing annual wind direction (in degrees) for Gan, Maldives

Figure 9 shows the annual wind direction from January to December. It can be concluded that

- Maximum wind flows from East and West direction in dry season
- Maximum wind flows from South and West direction in wet season
- Predominant wind direction is West for 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 that 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. Site's microclimate can also be improved through vegetation, shaded walkways and seating areas etc.

3.1.4. Analysis of Radiation

The direct solar radiation analysis studies the total amount of direct solar radiation energy falling over different surfaces (Example, building façade, roof etc.) in buildings. It is expressed in kWh/Sqm. The higher this number, 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 subsequent increase in surface temperature. Through building facades, high solar radiation can result in high heat gains into the interiors. The solar radiation analysis also helps in developing solar energy harness strategies for the project.

Figure 10 shows solar radiation analysis for all critical orientations and roof of a building.

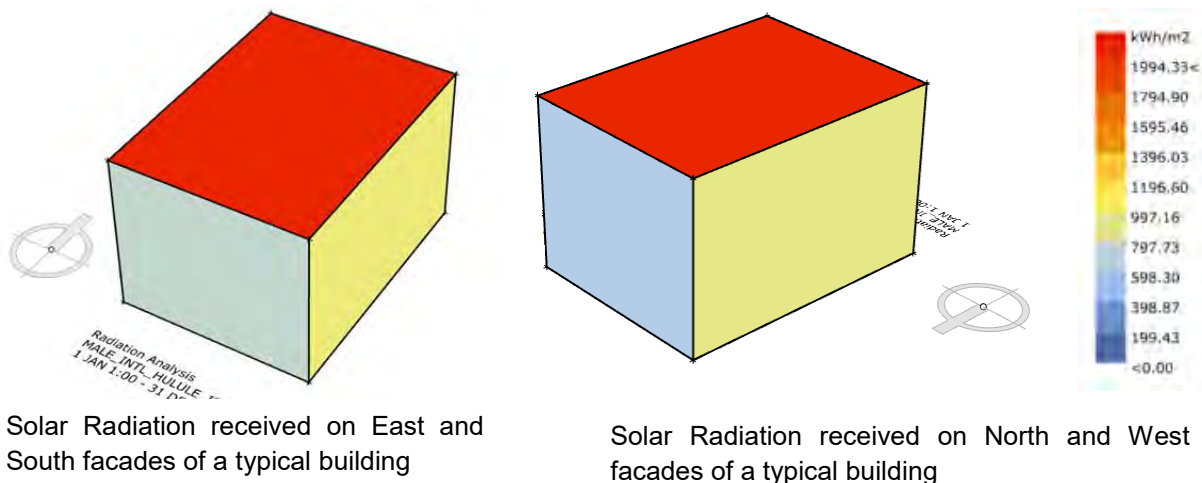
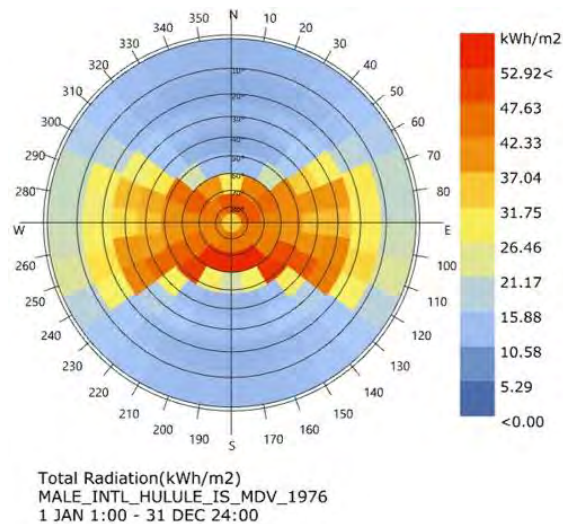


Figure 10: Analysis of Radiation for Maldives

It is observed from figure 10 that North facades receive the least solar radiation (600 kWh/sqm). High solar radiations are observed on the East (1200 kWh/sqm) and West Façade (1200 kWh/sqm) and South facades (1000 kWh/sqm). The roofs receive the highest solar radiation (2000 kWh/sqm).

3.1.5. Psychrometric Analysis and Passive Strategies Evaluation

A psychrometric chart is a graphical representation of the psychrometric processes of the air. Psychrometric processes include physical and thermodynamic properties such as dry bulb temperature, wet bulb temperature, humidity, enthalpy and air density.

It shows dry bulb temperature across the bottom and moisture content of the air up the side. The vertical scale 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 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. Different design strategies are represented by specific zones on this chart. 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 11 analyses the distribution of psychrometric data of Maldives in most effective design Strategy zone in order to create a unique list of design guidelines.

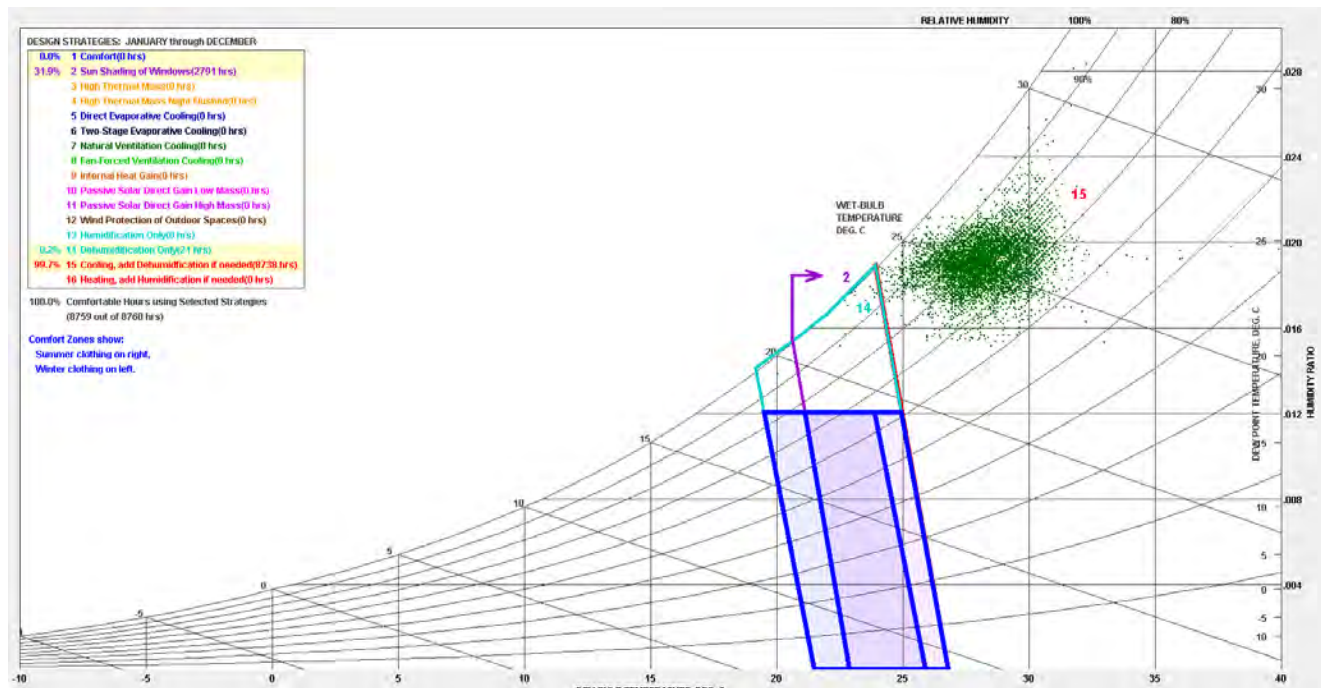


Figure 11: Psychrometric chart analysis for passive design strategies

Comfort criteria have been defined using ASHRAE Standard 55 -2004 Comfort model

It is analyzed through psychrometric chart that for the project site, due to high humidity throughout the year, thermal comfort cannot be achieved naturally. Various passive & low energy strategies shall be effective to achieve better thermal comfort reduce air conditioning load of the building.

1. **Building Form and Orientation-** Building architectural form and orientation in a hot humid climate can greatly affect the indoor climatic conditions, occupant comfort and energy consumption for air conditioning. The orientation of buildings needs to be designed in order 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. *The MET office building is designed taking into consideration these design principles. Longer facades of conditioned spaces are facing north and south, while most unconditioned spaces are oriented due east and west.*
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 summer, monsoon season. Solar shades are recommended in east, West and South facades of all buildings as shown in figure 12. *The MET office building is benefitted from ample mutual shading, with a few surfaces provided with overhangs.*

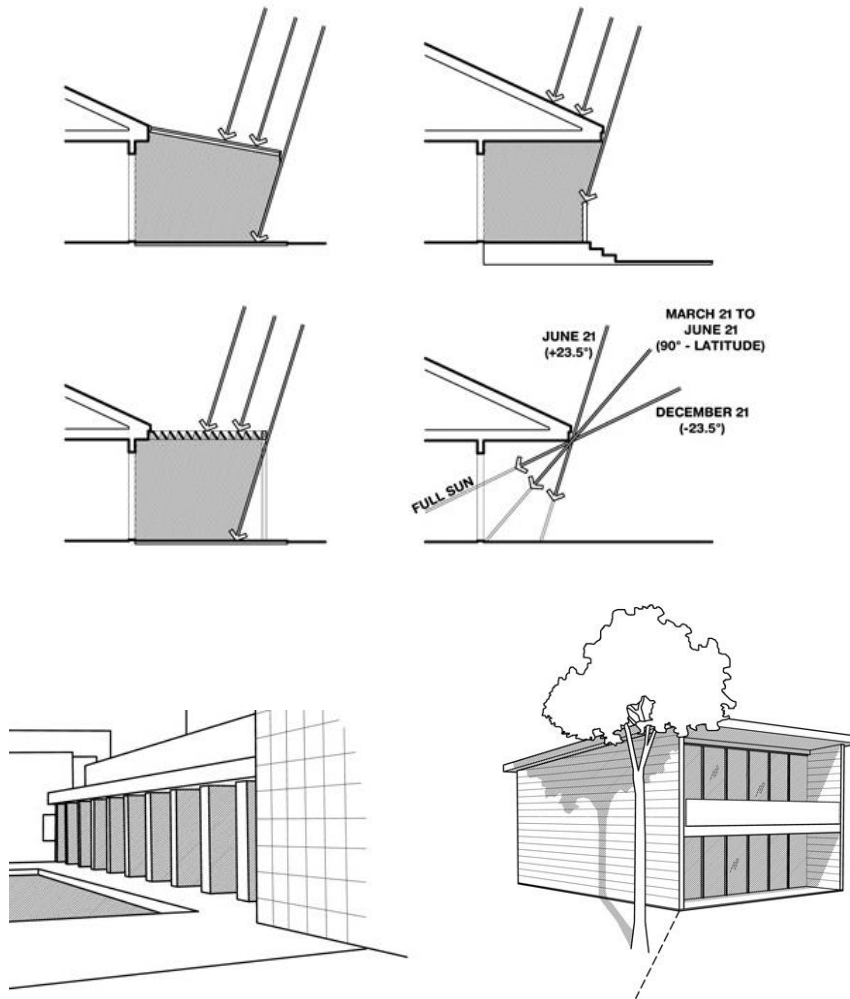


Figure 12: Solar shades are recommended in east, West and South facades of all buildings

3. **Reduce internal heat gains** will be effective during summer and monsoon season. The internal heat gains can be reduced by optimizing occupant density, indoor lighting power and equipment power of the building. Energy efficient LED light fixtures are recommended in the building to achieve optimized LPD (lighting power density) values for the buildings. *The internal loads, especially lighting, in the current MET office design is optimized through selection of LED lighting fixtures which contributed positively to control to the overall internal heat gains.*
4. **Increased Natural ventilation** will help dissipate body heat more effectively during summer and monsoon period. Ventilation on building sites can be improved by raising building on stilts, orientation of building to enhance wind movement, providing cross or mechanical ventilation for indoor spaces. *All the unconditioned spaces in the MET office are having narrow depth and are naturally ventilated through efficient single-sided ventilation which reduces the requirement of mechanical cooling and ventilation and still achieves thermal comfort for the occupants.*

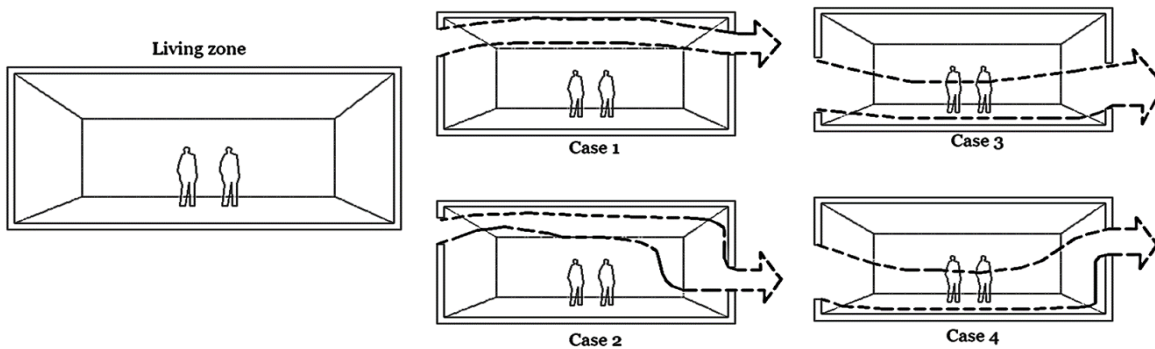


Figure 13: Natural ventilation examples

5. **Window to wall glazing ratios:** The unshaded glazed area should be minimized in south, east & west facades in order to reduce indoor air conditioning load of the building and thermal comfort around building perimeter. Higher glazing ratio can be provided in North East and North West facades. *The current design of the MET office benefits significantly from strategic placement of widows, controlling exposure on south and west façade for conditioned spaces. The overall WWR of the project is 30% which is well below the recommended 40% as per the Guidelines.*
6. **Reduce heat island effect on roof:** The analysis shows that roof shall receive high solar radiation. These solar radiations can be reflected by using light colored finishes, high reflective finishes like white china mosaic tiles & high SRI paints. Terrace gardens can also be designed for accessible terraces to not only reduce heat island effect but also prevent glare discomfort to terrace users. *It has been informed by the team at MET office that around 60% of the roof area would be covered by meteorological recording devices and the rest is to be shaded by solar PV. Thus, the heat island on the roof would be controlled.*



Cool Roof through white Coating



Cool Roof through China Mosaic



Cool Roof using Landscaping

Figure 14: Cool Roof Examples

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. *Rooftop solar PV is proposed for 40% of the roof area.*
8. **Building Envelope**
As observed from the analysis, the exterior walls in south and west direction and the roof receive high solar radiation leading to heat gain into the interiors. To prevent overheating of the building facades, reduce air conditioning load and improve thermal comfort, light colored finishes on facades can be used. Further, insulation is also required to reduce the conductive heat gains inside the building. *This report explored alternatives to optimize the building envelope.*
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. *This report tested various options for air conditioning for the MET office.*

Climate analysis carried out as part of this project helped qualitative evaluation of the current design for its strengths and potential areas of improvement. The next chapter focuses on the analysis of the current design and recommendations to improve the design.

4. Environmental Performance Assessment

4.1. Current Design

The project team developed a digital energy model of the current design of the MET office based on the building drawings, material specifications, lighting and HVAC design provided by Riyan Architects. Equipment power density was calculated based on the data provided by the MET office.

The MET office is a G+1 building with a total built-up area of 1,190 sq.m. and conditioned area of 493 sq.m. It is a C-shaped building and is oriented with longer facades facing south-north. The WWR in the current design is 30%. Office spaces are operated 8AM to 4PM on weekdays, observatory and watch towers are occupied round the clock, conference room is occupied for 2 hours a day and classrooms are occupied in during office hours, once a week. The building envelope consists of conventional 150mm brick walls, 300mm RCC roof and single glazed windows. The lighting power density is calculated to be 2.5 W/m² (on an average for the building). The lighting and equipment power density are based on the design data provided (Table 5 in the Appendix). Split ACs are provided in the current design. In absence of system specifications, these are modelled with 3.1 CSPF (as per section 8.6 of the Guidelines - Minimum mandatory guidelines for HVAC systems). The details of the energy model are provided in appendix.

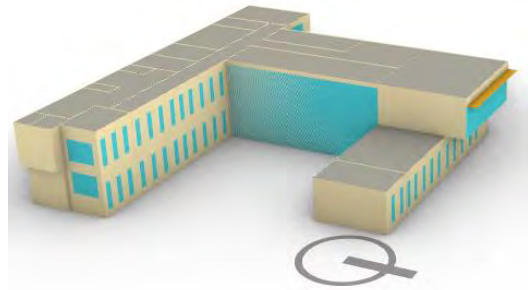


Figure 15: Energy model of the MET office

The energy simulation results of the current design (baseline) estimated the annual energy usage of the MET office to be 149 MWh. This translated to an annual Energy Performance Index (EPI) of 125.5 kWh/m². It is to be noted that this is close to the EPI (120 kWh/m²) for a typical office building in Maldives which is designed in compliance with the Maldives Building Energy Efficiency Guidelines. This can be attributed to the optimized building form, orientation, WWR and window placement.

Figure 16 (left) shows the breakdown of the annual energy use. Due to the equipment-intensive nature of the major activities, the equipment and plug loads account for 72 MWh which is almost 50% of the total annual consumption. Space cooling consume 52 MWh (35%), ventilation 17 MWh (11%) and lighting 8 MWh (5%) of the total energy consumption. Lighting power density as per the current design is 2.6 W/m² which is highly optimized, leading to least consumption due to lighting and significant reduction in space cooling and ventilation requirement.

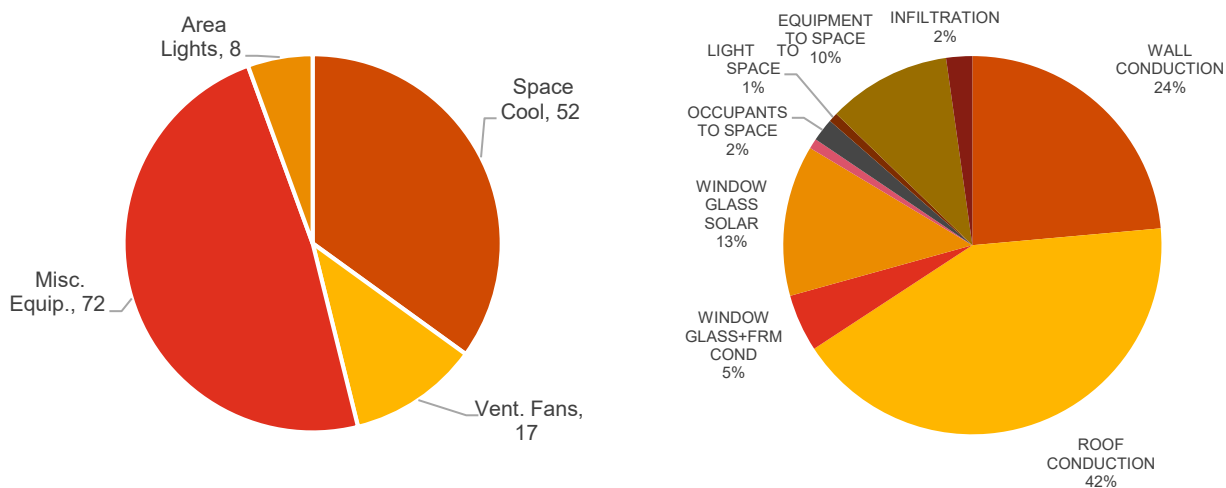


Figure 16: Breakdown of energy use (left) and cooling load (right)

The peak cooling requirements of the current design is simulated at 130 kW (37 TR). Heat gains from the roof are major contributors to the space cooling loads, followed by heat gains through wall and radiation gains through the windows. Equipment is the major internal load contributing to the cooling load.

4.2. Design Recommendations

This sub-section documents the impact of various design alternatives tested to improve the performance of the current design. It follows the requirements set under various sections and sub-sections of the Guidelines.

4.2.1. Bio-climatic building design

This sub-section mentions the performance of the current design against the requirements and recommendations of section 6 of the Guidelines.

4.2.1.1. Building form and orientation

Bio-climatically, the current building is C-shaped which offers enough self-shading throughout the day. The orientation in the current design is well designed for. It could be supported from the results of 90 and 270-degree rotation which resulted an increase in the energy use. A 180-degree rotation would result in 1% energy savings as shown in figure 18.

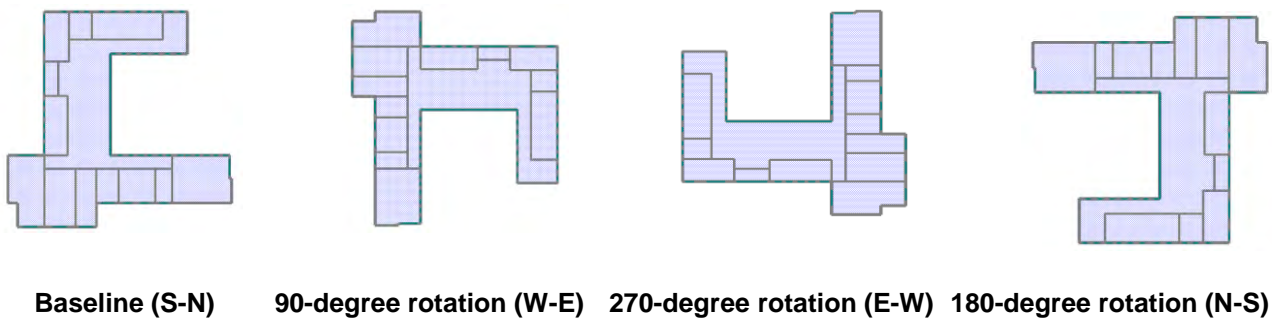


Figure 17: Various alternatives for building orientation

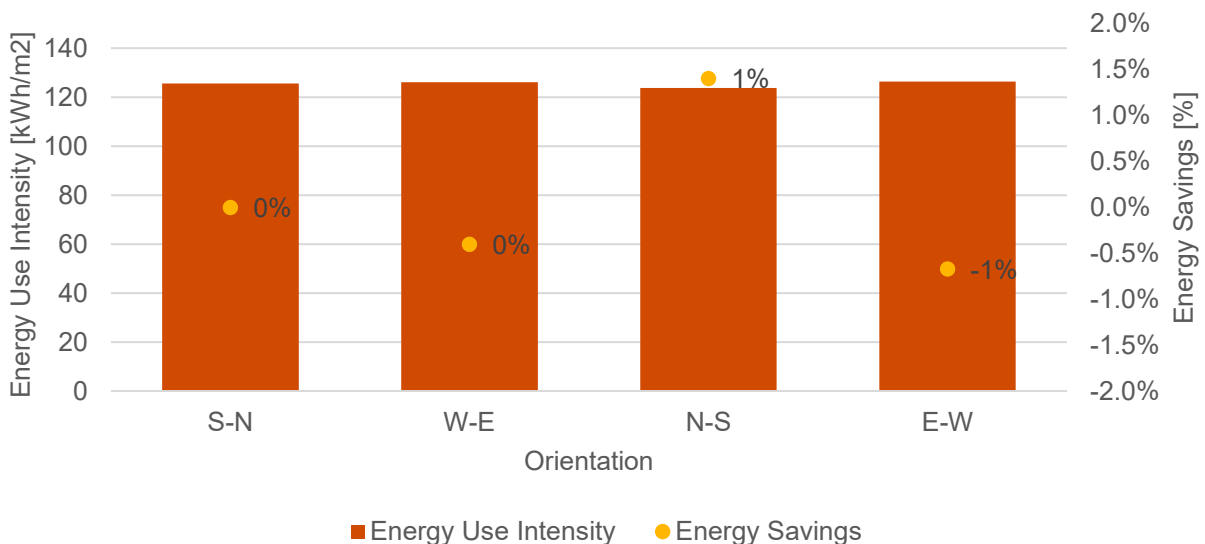


Figure 18: Impact of rotation on EPI of the current design

4.2.1.2. Window-Wall Ratio

WWR is an important driver of energy use and space cooling load. Typical office buildings surveyed by the project team as part of other assignment in Maldives show that the WWR in a typical design could be as high as 70%. The Guidelines recommend a maximum WWR of 40% for office buildings. The current design of the MET office has achieved a WWR of 30%, which is lower than 40% as recommended. Thus, the current design is accepted in terms of WWR.

4.2.1.3. Shading

As mentioned in section 3.1.5, solar shading is an important strategy of passive design, especially for buildings in Maldives. Owing to the building form, lower window-wall ratio and placement of windows, the current design has reduced the solar radiant and conduction gains from windows. Simulations estimate that 200mm overhangs and 200mm fins on all facades could further reduce the energy use by 1% and 2%, respectively. The potential for energy use reduction through a combination of overhangs and fins is 3%, as showed in figure 19. Figure 20 shows various design alternatives to provide horizontal and vertical shading to windows. Although solar shading offers potential to reduce energy use and cooling load, high capital investment makes them cost-ineffective and hence are not included in the final recommendations.

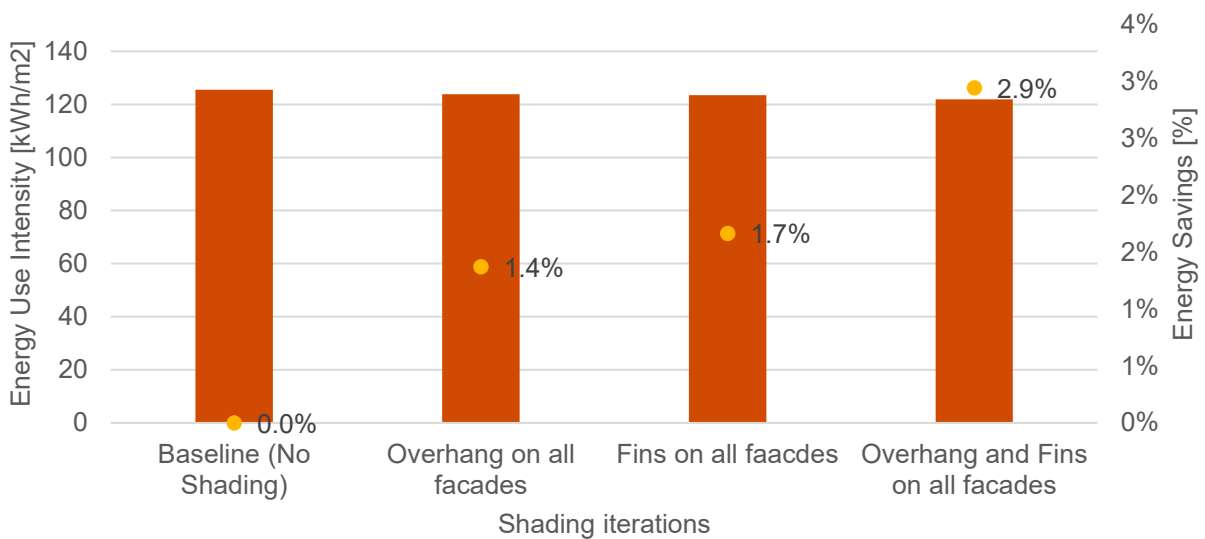


Figure 19: Impact of solar shading on energy use

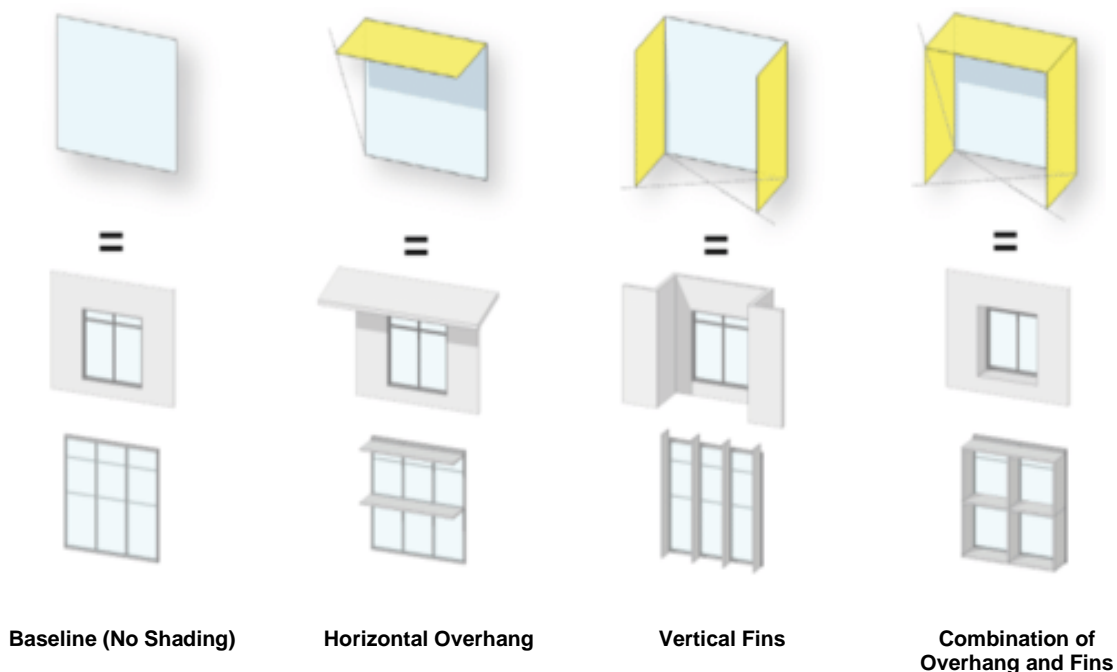


Figure 20: Design alternatives for solar shading

4.2.1.4. Daylighting

The project team evaluated the current design for its daylighting performance using dynamic simulation. Section 6.3.4.2 of the Guidelines recommends achieving a minimum of useful daylight for a minimum of 70% of the area for a target illuminance (below which the floor area would be deemed to be underlit) of 500 lux on the working plane which is 800 mm above the floor level. The glaring illuminance (beyond which the occupants could experience visual discomfort) is set at 2,000 lux. The objective of the daylight analysis is to ascertain the amount of floor area receiving daylight in the range of 500-2,000 lux, which is the useful daylight. The glass visible light transmittance (VLT) is assumed to be 80%, which corresponds to a clear, single pane glass.

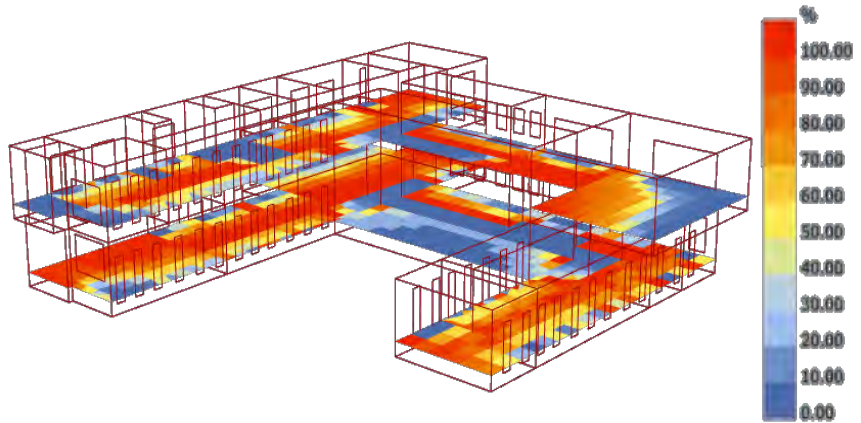


Figure 21: Daylight analysis for the current design

The current design receives useful daylight for 79% of the floor area (figure 21), which demonstrates compliance with the requirements of the Guidelines. The project team has carried out several simulations for different options of glass VLT (40% to 70%). The outcome of the analysis suggests that the glass to be selected for MET office should have a minimum VLT of 50% to meet the performance requirement set in the Guidelines, as shown in figure 22.

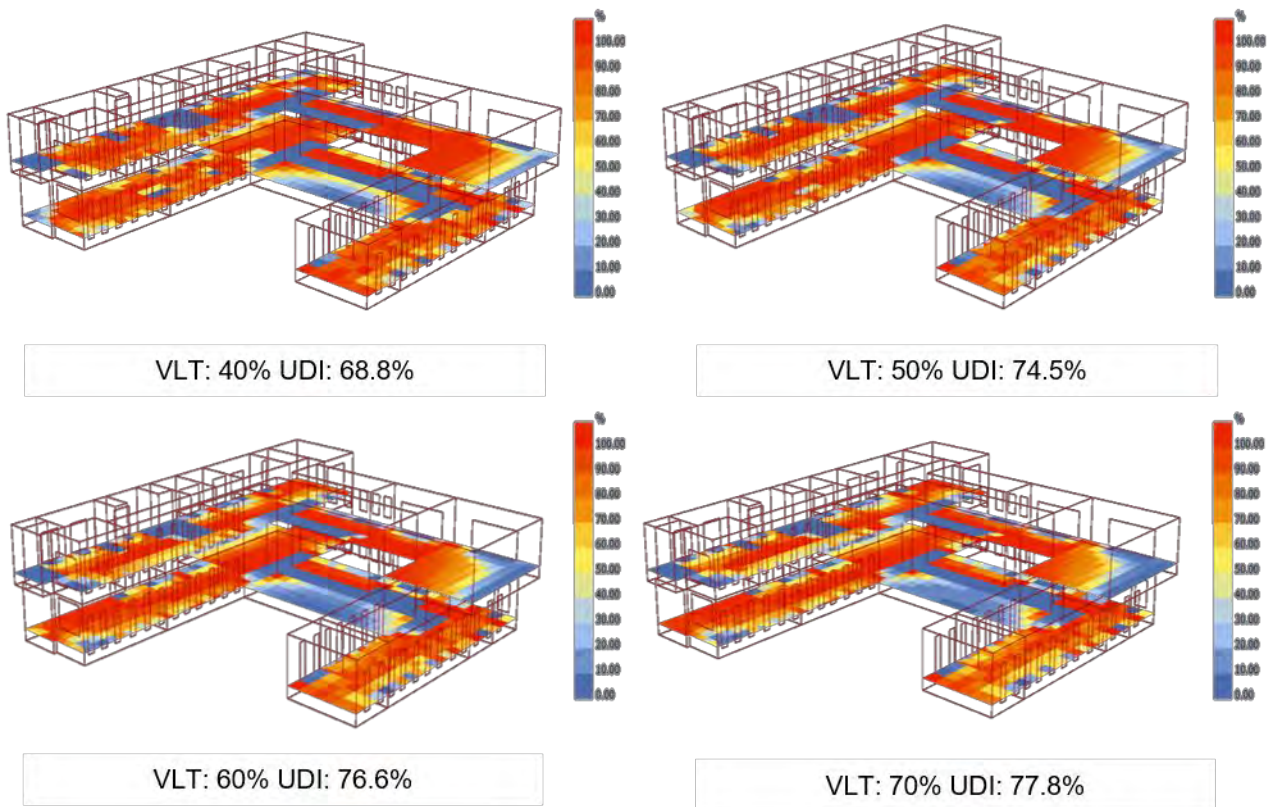


Figure 22: UDI analysis for various options of glass VLT

4.2.2. Building envelope

This sub-section details the analysis done to evaluate the performance of the building envelope of the current design and the recommendations made to improve its efficiency.

4.2.2.1. Walls

Walls constitute 70% of the vertical envelope area of the MET office. Thus, these offer good potential to reduce energy use through improving their thermal conductance. The current design has 150 mm brick wall assembly. Improving the U-value reduces the conduction heat gains through the walls. This can be done by using a thermally high performing materials such as AAC blocks or by adding insulation internally or externally on the wall. U-value of 0.9 W/m². K and 0.3 W/m².K could reduce energy use by 4% and 5%, respectively, as shown in figure 23.

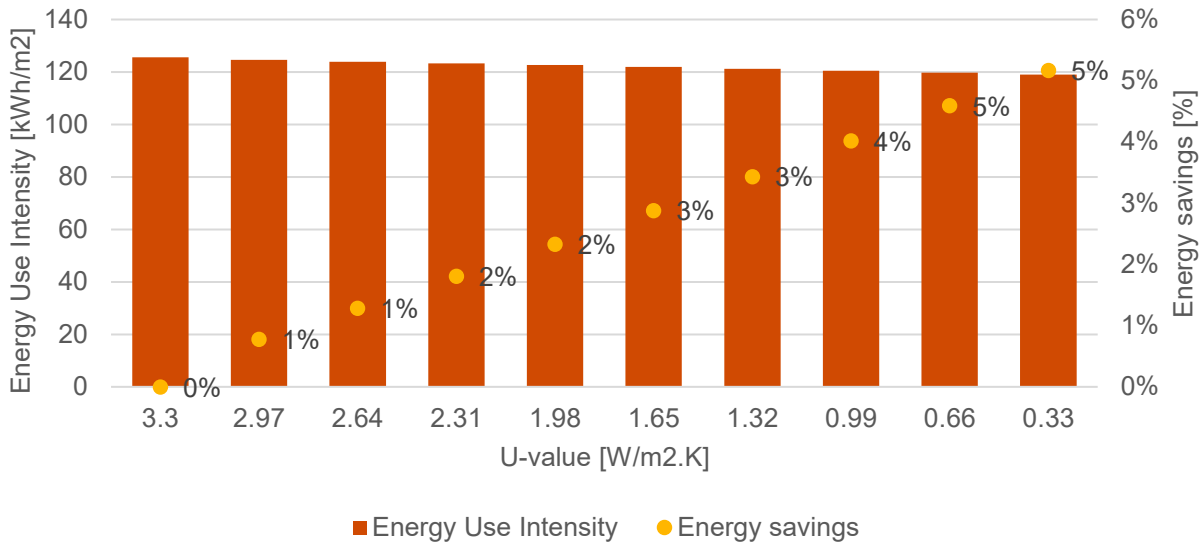


Figure 23: Impact of improving wall u-value on energy use

4.2.2.2. Roof

As mentioned in section 4.1, conduction heat gains through roof significantly contribute to the space cooling load of the current design of MET office. Thus, lowering U-value of the roof would result in reduction in space cooling requirements and the corresponding energy use. U-value of 0.6 W/m².K and 0.3 W/m².K could reduce energy use by 5.1% and 6.3%, respectively.

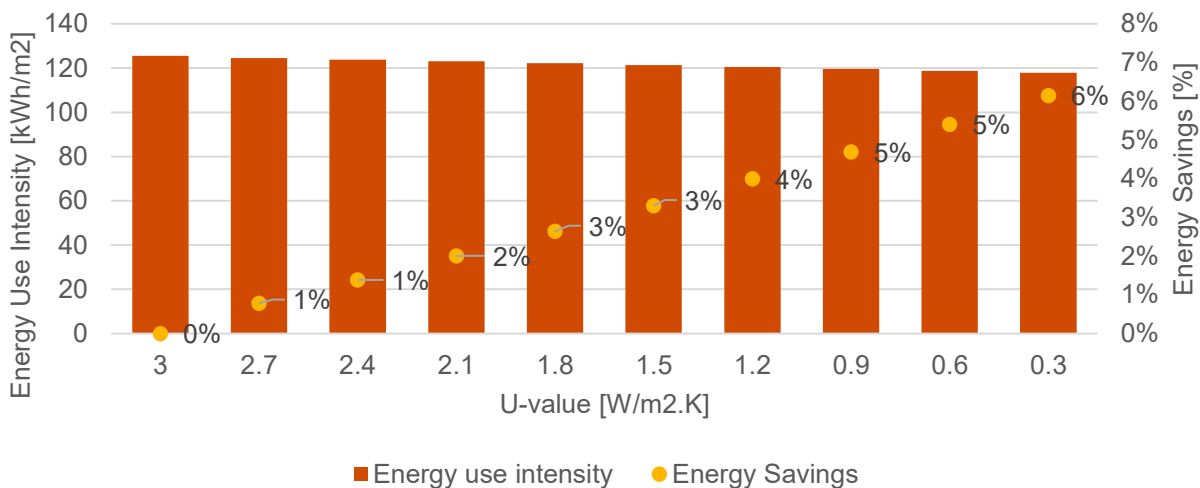


Figure 24: Impact of lowering roof u-value on energy use

The recommended U-values for walls and roof could be achieved through a combination of various types of insulation, brick and RCC layer. A few combinations are provided in appendix in Tables 10 through 13.

4.2.2.3. Glass

Solar radiation gains through widows are a major component of building peak load in Maldives. However, good bio-climatic design of the MET Office with lower WWR means the solar radiation heat gains are lower than typical design. Section 7.2.3 of the Guidelines recommends an SHGC value of 0.4 or lower. Simulation results for single pane glass with an SHGC of 0.4 suggests reduction in energy use by 2% and 0.25 by 3.3%, as shown in figure 25.

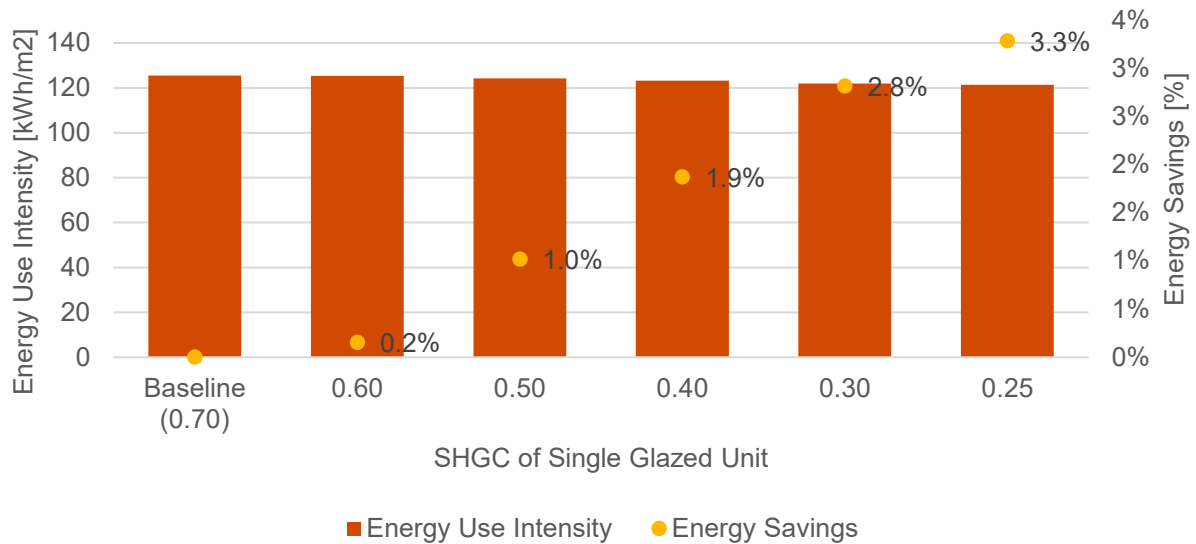


Figure 25: Impact of lowering SHGC of single glazing on energy use

As mentioned in the guidelines and in earlier analysis, conduction heat gains through windows in Maldives have lower contribution to the building's cooling load, compared to the radiation heat gains. Thus, the MET office would not benefit significantly by double glazed units. On the contrary, the building would be penalized due to short-wave radiation being trapped inside the building, not able to escape to the outdoors in the night-time due to low diurnal temperature difference. Double glazed unit (U-value-1.8 W/m².K) with an SHGC of 0.4 would result in 2% and 0.25 in 3.2% energy savings, as shown in figure 26.

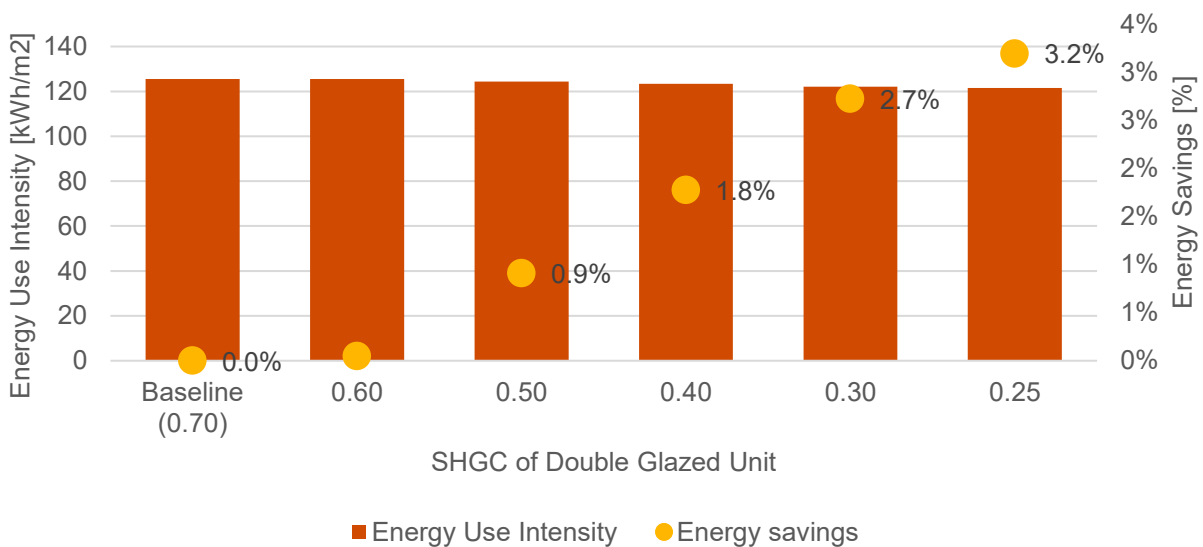


Figure 26: Impact of lowering SHGC of Double-glazed Units on energy use

4.2.3. Thermal comfort systems and controls

This sub-section covers the analysis of the current design with respect to section 8 of the Guidelines and the impact of design changes from the HVAC perspective on energy use.

4.2.3.1. Cooling setpoint

Improving the building envelope has a positive impact on the thermal comfort of the occupants. It means that the same level of thermal comfort could be achieved at lower cooling requirement. It also means that the cooling setpoint could be increased by a reasonable measure which could lead to reduction in capital investment on the cooling system and their operational expenditure. Section 8.5 of the Guidelines allows for 1 °C increase in cooling setpoint. Increasing the cooling setpoint for MET office to 25 °C could result in 1.2% energy savings, as shown in figure 27.

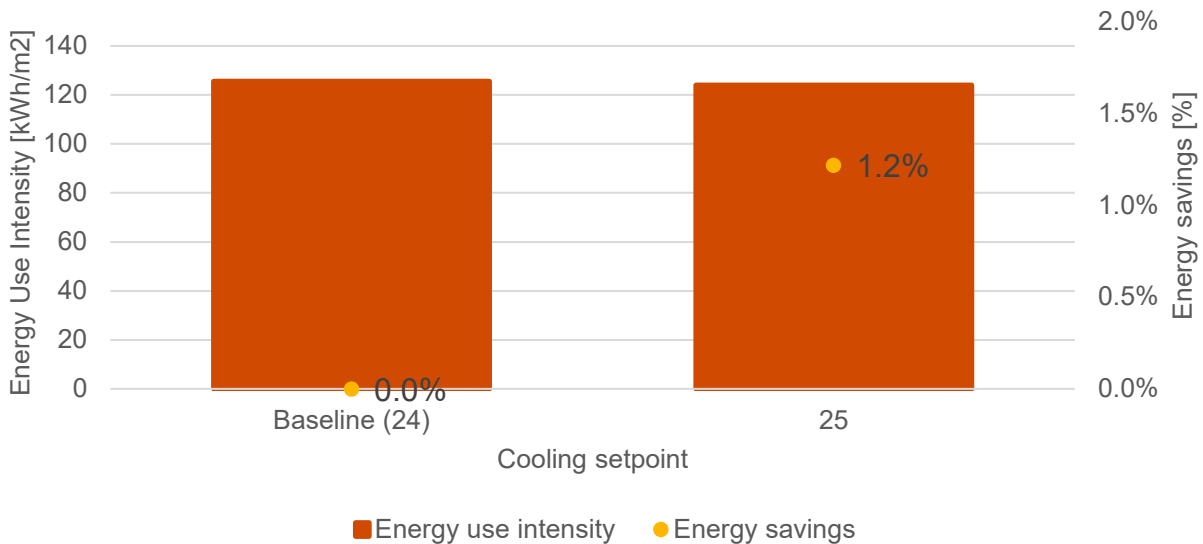


Figure 27: Impact of increasing cooling setpoint on energy use

4.2.3.2. Split ACs with higher CSPF

The current design is optimized for its form, orientation, WWR. Thus, the potential for major efficiency gains lie in improving the building envelope and the performance of the HVAC system. Improving the efficiency of split ACs could result in notable energy savings. CSPF of 4 (4-star) and 5.1 (5-star) could yield 4% and 10% energy savings, as shown in figure 28.

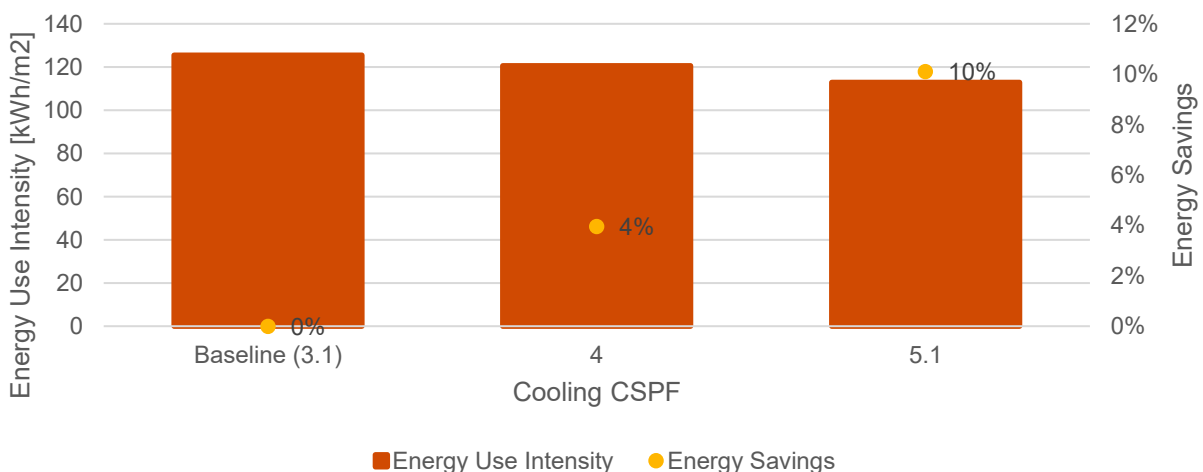


Figure 28: Impact of improving CSPF of split ACs on energy use

4.2.3.3. VRF systems

VRF systems are proven technology and are more efficient compared to split ACs, offering better performance at part load conditions. For cooling loads such as the MET office, these systems have provided better operational performance compared to Split ACs. In this case, VRF system of COP 4 and 5.1 could generate 10% and 15% energy savings, respectively, as shown in figure 29. The recommended COP is compliant with the requirements of section 8.5 of the Guidelines.

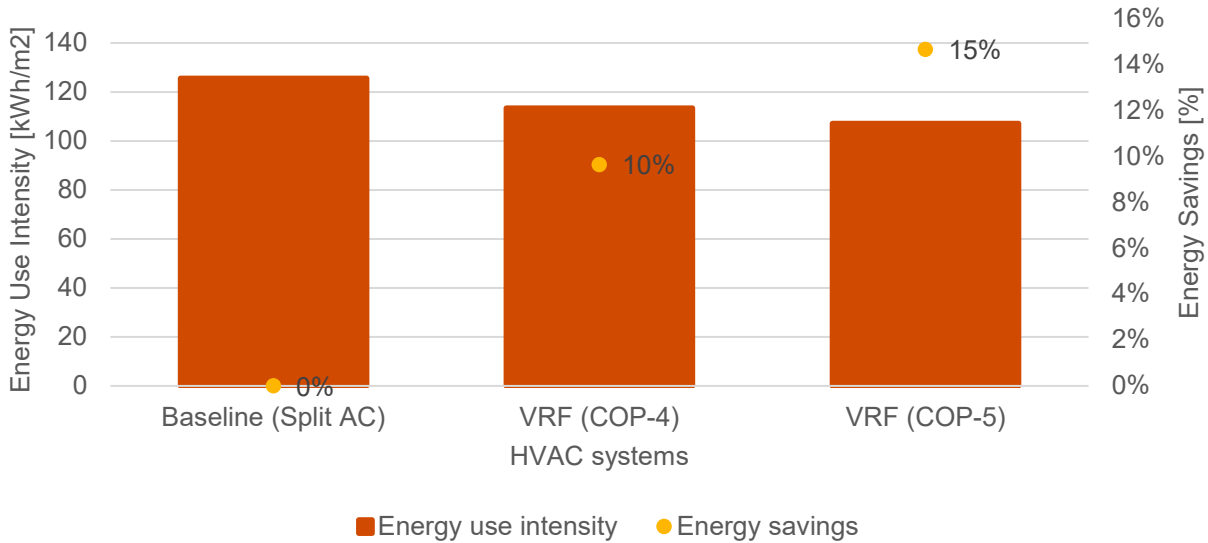


Figure 29: Impact of VRF systems on energy use

4.2.4. Smart building systems

4.2.4.1. Lighting controls

Lighting control can be defined as hardware - and software - systems that regulate the intensity level of the light output in response to a command or action. Efficient lighting controls can reduce lighting energy by an average of 24% to 38%. Today's lighting controls fit into four main categories, according to their size and function:

1. Distributed networked systems offering total lighting control management.
2. Scalable panel systems using low-voltage, mechanically held, single- and double-pole latching relays.
3. Architectural/commercial control systems handling a variety of control applications and using input devices that vary from keypads to touchscreen controllers
4. Networked devices and wall box dimmers.

In aggregate, the lighting controls in smart building systems are responsible for occupancy/vacancy control, daylight harvesting, time scheduling, task level tuning, lumen maintenance, and personal control within a workspace.

4.2.4.2. Smart BMS

BMS is basically a solution which is integrated into a facility to ensure an environment that is safe, secure, comfortable and energy efficient. In order to be efficient, the BMS must be properly integrated into the facilities.

Monitoring of the environmental performance in operational phase

It was essential that the building achieved the environmental performance and yielded the savings on operational cost, as projected during the design stage. We assisted the design team to incorporate environmental monitoring system during the design stage and assisted in the selection of:

- Smart environmental sensors
- Sub-meter for end-use monitoring

- Smart building energy monitoring system

Smart environmental Sensors

Smart environmental sensors are becoming essential for the modern, connected, energy efficient buildings. These sensors collect real-time data on temperature, humidity, lighting, occupancy, indoor air quality and electrical current. The data is then sent to the central building automation system controls and regulates the building operation to optimize resource allocation and operational cost.

Examples of some companies which manufacture such sensors for the use in smart buildings are Texas Instruments, ST Microelectronics, Analog Devices, Infineon Technologies etc.



Figure 30: Smart environmental sensors and the data collected

Sub-meter for end-use monitoring

End-use monitoring is important for energy efficient operation of a facility to ensure that each end-use is catered in an efficient manner and at optimal energy expenditure. Sub-meters can be attached for each electrical end-use viz. lighting, appliances, HVAC and the data can be used to monitor and explore the scope of further improvement.



Figure 31: Submeters for different end uses in a building

Smart building energy monitoring system

Smart building energy monitoring systems have the potential to generate significant savings in the operational stage. An IoT-enabled and machine learning capable building energy monitoring system could

- optimize cost and comfort,
- enhance energy efficiency,
- ensure sustainability targets are met,
- detect abnormal usage patterns and appliance operations,
- use big data to continuously improve operations

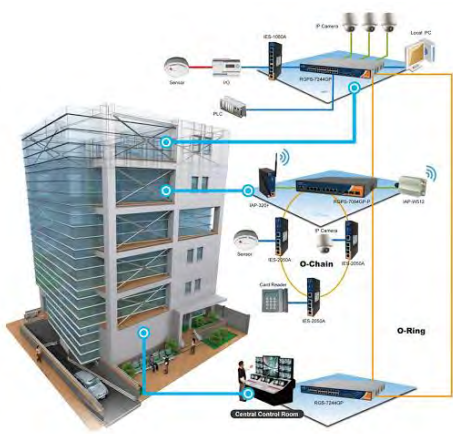


Figure 32: Smart sensors network and centralized smart building energy management system

Some top vendors for smart BMS are: Metasys, Cisco, Siemens, Honeywell, Schneider Electric, ABB, Johnson Controls etc. who can be consulted for integrating the buildings with smart technologies. A table (Table 14) consisting of some buildings integrated with these smart technologies and their environmental, economic and social impact has been provided in the appendix.

4.2.5. Renewable energy

The MET office is aimed to set an example of energy efficiency and energy security for office buildings in Maldives. As part of this exercise, rooftop solar PV was analyzed for on-site renewable energy generation.

Based on the brief from the team at MET office, the project team evaluated the potential of energy generation considering that 40% of the roof area would be allocated for solar PV. The PV panels are modeled of polycrystalline type with 15% efficiency. PV panels of higher efficiency up to 19% are also available for selection, provided its availability in the Maldivian market.



The modeled PV system is a 22 kWp capacity system covering 216.6 sq.m area. It has an energy generation potential of 34,531 kWh/year. For the current design, this PV system could offset 23% of the annual energy consumption. Section 11 of the Guidelines require at least 2.5% of the building's total electricity consumption to be met by renewable energy systems. The proposed PV system satisfies this requirement.

4.2.6. Water efficiency

Reducing indoor water use in offices can be accomplished through water-efficient plumbing fixtures. The EE guidelines impose a maximum on the amount of water used per flush by toilets and urinals and per minute by faucets and showerheads. Water efficient plumbing fixtures are recommended in the building with the following flow rate values:

Table 1: Water fixtures and recommended flow rates

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

Rainwater harvesting system

The climate analysis indicates that overall rainfall has increased from 2008 to 2018 by 57% in Male. Therefore, Rainwater harvesting system are recommended in the building to capture at least 25% of run-off volumes from roof area for collection and reuse in flushing and horticulture to reduce dependence on piped water supply.

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

Table 2: Rainwater harvesting calculations

	Description	Result	Unit
1	Roof area	659.30	m ²
2	Rain fall	2360.00	mm/year
3	Rain water from roofs	1555.95	m ³ /year
4	Mean rain water supply	1555.95	m ³ /year
5	Mean rain water available for harvest	4.26	m ³ /year
6	Mean rain water to be used for treatment	4.26	m ³ /day
7	Monthly rain water treatment	127.89	m ³ /day
8	Dry season period (months)	2.00	m ³ /month
9	Total rain water requirement for dry period	255.77	months
10	Rain water collected during dry period	168.12	m ³
11	Total storage capacity needed for dry season	87.65	m ³
12	Design rain water holding tank capacity	88.00	m ³
13	Proposed rain water holding tank capacity	96.20	m ³

5. Building Envelope Design Proposal

After thorough analysis, it was highlighted that the building was designed to shade itself to most part of the day and adding shading fins will not have any major impact on energy consumption savings. In addition to this, no other change to the building form is suggested from the analysis. Building orientation, sun shading or introducing windows to improve natural lighting is not recommended with this analysis. Hence no new proposal is required for building design. The existing design itself suffices to meet the best-case scenario.



Figure 33: Building envelope remains same for best case scenario

6. Summary of Design Recommendations and Costing

The previous section focused on the impact of improving performance of individual parameter on the annual energy use of the MET office. This section provides two design alternatives – ‘Optimum case’ and ‘Best case’. The optimum case demonstrates compliance with minimum requirements set by the Guidelines. The best case is a combination of best possible values of the design parameters discussed in the previous section. A summary of the details of these cases and design recommendations is provided in the table below.

Table 3: Summary of design recommendations for Optimum and Best case

S. No.	Parameter	Current design	Optimum case	Best case
1	Orientation	S-N	Same as current design (S-N)	Same as current design (S-N)
2	Shading	No shading	Same as current design (No shading)	Same as current design (No shading)
3	WWR	30%	Same as current design (30%)	Same as current design (30%)
4	Wall U-value	3 W/m ² . K	0.9 W/m ² . K	0.6 W/m ² . K
5	Roof U-value	3.5 W/m ² . K	0.6 W/m ² . K	0.3 W/m ² . K
6	Glazing U value	5.8 W/m ² . K (VLT – 80%)	5.8 W/m ² . K (VLT – 50%)	5.8 W/m ² . K (VLT – 50%)
7	Glazing SHGC	0.70	0.40	0.25
8	Lighting Power Density	2.5 W/m ²	Same as current design (2.5 W/m ²)	Same as current design (2.5 W/m ²)
9	HVAC system	Split AC units (CSPF – 2.7), Set point 24 degC	Split AC units (CSPF – 4), Set point 25 degC	VRF units (CSPF – 5.1), Set point 25 degC
10	Smart building	None	Smart lighting controls, Smart BMS, End-use sub-metering	Smart lighting controls, Smart BMS, End-use sub-metering
11	Rooftop Solar PV	None	22 kWp rooftop solar PV	

12	Plumbing design		As per EE guidelines
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Table 4: Summary of optimal and best case and design recommendations

S. No	Parameter	Design recommendations	Optimum case				Best case			
			Cost implication (MVR)		Energy Savings (%)	Payback period (Years)	Cost implication (MVR)		Energy Savings (%)	Payback period (Years)
			Capital cost	Miscellaneous costs			Capital cost	Miscellaneous costs		
1	Orientation	Orientation is already optimized	-	-	-	-	-	-	-	-
2	Shading	Spaces on East and West facades are unconditioned and mutually shaded; Conditioned spaces are oriented due North-South and have controlled WWR. Thus, additional shading is not recommended	-	-	-	-	-	-	-	-
3	WWR	WWR is already optimized	-	-	-	-	-	-	-	-
4	Wall U-value	Add insulation on walls externally	255,640.46	-	4.6	8.6	409,327.68	-	5.2	12.2
5	Roof U-value	Add insulation on roof externally	315,028.50	-	5.4	9.0	587,315.60	-	6.1	14.7

6	Glazing U value	Select Single glazed unit	-	-	-	-	-	-	-	-
7	Glazing SHGC	Select glass with recommended SHGC and selectivity ratio more than 1.5	47,939.08	-	1.9	3.9	230,107.58	-	3.3	10.8
8	Lighting Power Density	Lighting is already optimized	-	-	-	-	-	-	-	-
9	HVAC system	Select HVAC equipment with recommended CSPF	84,598	-	4.0	3.3	110,055	-	14.7	1.2
10	Smart building	Select smart BMS, smart lighting, temperature and occupancy sensors, sub-metering	-	-	-	-	1,005,545.14	-	15	15.5
11	Rooftop Solar PV	Install Rooftop Solar PV	610,632	-	28	4.1	610,632	-	37	4.1
12	Plumbing design	Select dual flush fixtures and faucets which are low flow, rainwater harvesting system	136,600.88	1,236.38		-	136,600.88	1,236.38	-	-
13	Total		1,450,438.92	1,236.38	16 (44 including Solar PV)	5.7	3,089,583.88	1,236.38	37 (74 including Solar PV)	10

Note: All prices include estimated labor, material and transportation cost, except plumbing design for which miscellaneous cost is reported separately. With a profit % depending on the item. Payback period is calculated based on the capital cost.

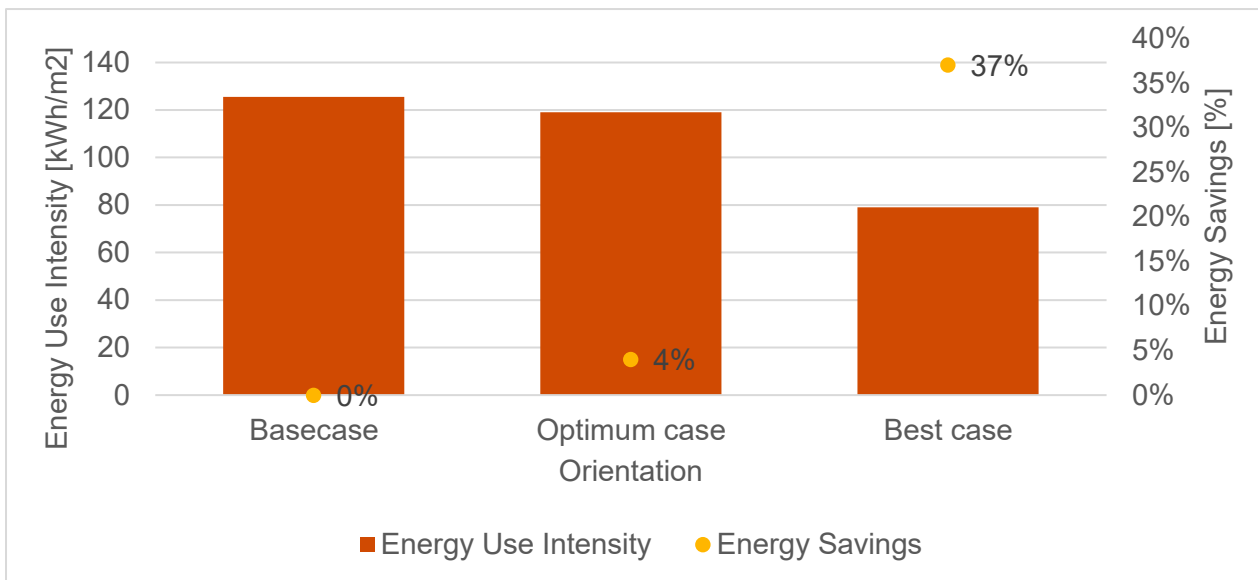


Figure 34: Comparison of baseline case with optimum and best case

Figure 35 shows the comparison of baseline case against the optimum and base case. The optimum case would consume 4% less energy than the baseline case, owing to better envelope properties and efficient HVAC system. It is to be noted that this case has an LPD of 6 W/m², complying with the Guidelines. Since the LPD in the baseline case is much less (2.5 W/m²) than this, adopting all the other design parameters from the optimum case could result in 16% energy savings and an EPI of 105 kWh/m². Thus, for the purpose of techno-economic analysis, it is assumed that the project team will keep the current lighting design, yielding 16% (44% savings including contribution from solar PV) energy savings and an **EPI of 105.4 kWh/m²**. In terms of cooling demand, the optimum case could result to 35 TR. The overall cost of implementing the Optimum case would be **MVR 1,450,438.92** with a payback period of **5.7 years**. The cost would be **MVR 1,451,675.30 including miscellaneous costs**.

The best case yields 37% (74% energy savings including contribution from solar PV) energy savings over the baseline case and an **EPI of 79 kWh/m²**, owing to superior values of all the design parameters mentioned in table 3. These also include the smart building features, which have a potential to generate 15% energy savings. The reduced cooling demand for the best case would be 29 TR. Implementing the Best-case scenario would come at a cost of **MVR 3,089,583.88** at a payback period of **10 years**. The cost would be **MVR 3,090,820.26 including miscellaneous cost**. It should be noted that the cost of implementing the best case includes the cost of efficient plumbing fixtures which do not contribute to any energy savings but is added to highlight the cost of high-performance design.

The 22 kWp of solar PV system could offset additional 28% of the total energy consumption of the optimum case and 37% of the total energy consumption for the best case. The proposed solar PV system satisfies the requirement of section 11 of the Guidelines to offset at least 2.5% of the building's total electricity consumption using renewable energy.

7. Conclusion

The project aimed at assessing the environmental performance of the current design of the MET office against the requirements set in the EE Guidelines. The project also aimed at improving the current design with energy conservation and energy efficiency measures to improve its performance beyond the standards set in the Guidelines. The current design is well-optimized for building form, optimization, window-wall ratio, window placement and mutual shading, due to which the EPI was simulated at 125.5 kWh/m². Through various building envelope improvement measures, efficient HVAC systems and controls, smart technologies and rooftop Solar PV described in section 4 and 5, there is a potential to reduce the cooling load by 22% and annual energy consumption by 37%, resulting to an EPI of 79 kWh/m². Implementing the features of the best case scenario would implicate a capital expenditure of MVR 3,089,583.88 with a payback period of 10 years. Total cost including miscellaneous cost would be MVR 3,090,820.26.

Table 5: Summary of cost implication and energy savings

S. No.	Case	Cost implication (MVR)	Energy savings (%)	Energy Performance Index (in kWh/m ² /year)	Payback period (in years)
1	Optimum	1,450,438.92	16 (44 with Solar PV)	105	5.7
2	Best	3,089,583.88	37 (74 with Solar PV)	79	10

SUMMARY OF BILLS OF QUANTITIES

DESCRIPTION	PHASE 1			PHASE 2			PHASE 3			AIR SHED			ALL PHASES		
	Original	optimal	Best	Original	optimal	Best	Original	optimal	Best	Original	optimal	Best	Original	optimal	Best
	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT
PRELIMINARIES	975,635.00	975,635.00	975,635.00	193,826.25	193,826.25	193,826.25	332,206.25	332,206.25	332,206.25	69,263.50	69,263.50	69,263.50	1,570,931.00	1,570,931.00	1,570,931.00
EXCAVATION AND FILLING	291,980.00	291,980.00	291,980.00	109,060.00	109,060.00	109,060.00	94,005.00	94,005.00	95,241.38	26,147.30	26,147.30	26,147.30	521,192.30	522,428.68	522,428.68
INSITU CONCRETE WORKS	3,439,120.00	3,439,120.00	3,439,120.00	756,590.00	756,590.00	756,590.00	1,207,350.00	1,207,350.00	1,207,350.00	198,645.00	198,645.00	198,645.00	5,001,705.00	5,001,705.00	5,001,705.00
MASONRY	549,729.05	715,872.54	798,623.30	64,018.15	95,848.06	111,719.85	250,186.95	336,002.80	378,753.00	42,618.75	67,314.18	79,628.25	906,552.90	1,215,037.58	1,366,724.80
WINDOWS, SCREENS & LIGHTS	382,378.44	403,621.69	484,340.02	64,806.00	68,400.00	82,080.00	197,250.00	208,208.33	249,850.00	26,325.00	27,787.50	33,345.00	670,753.44	708,017.52	849,611.02
DOORS, SHUTTERS & HATCHES	433,260.00	442,630.00	478,236.00	27,720.00	27,720.00	27,720.00	198,955.58	200,260.58	205,219.50	59,962.41	59,962.41	59,962.41	719,897.97	730,572.97	771,427.97
FLOOR, WALL, CEILING, AND ROOF FINISHINGS	1,468,496.28	1,414,577.10	1,414,577.10	213,629.95	203,310.55	203,310.55	593,552.42	603,978.78	603,978.78	71,351.15	72,319.09	72,319.09	2,347,029.80	2,294,185.58	2,294,185.58
SUSPENDED CEILING	310,862.00	333,604.00	420,311.00	18,866.00	21,850.00	33,212.00	69,741.00	77,937.50	109,064.20				399,463.00	433,451.50	582,607.80
STRUCTURAL METAL WORKS										175,783.00	175,783.00	175,783.00	175,783.00	175,783.00	175,783.00
PAINTING & DECORATIONS	1,113,833.28	1,301,963.28	1,396,780.88	98,870.18	131,888.08	149,055.18	258,589.40	318,486.90	349,033.00	36,149.80	36,149.80	36,149.80	1,507,448.00	1,788,488.00	1,931,619.88
STAIRS, WALKWAYS AND BALUSTRADES	355,324.00	355,324.00	355,324.00	6,840.00	6,840.00	6,840.00	18,900.00	18,900.00	18,900.00				381,004.00	381,004.00	381,004.00
ROOFING										104,494.50	104,494.50	104,494.50	104,494.50	104,494.50	104,494.50
MECHANICAL & ELECTRICAL SERVICES	914,220.00	914,220.00	914,220.00	118,916.50	118,916.50	118,916.50	316,000.00	316,000.00	316,000.00	56,295.00	56,295.00	56,295.00	1,405,431.50	1,405,431.50	1,405,431.50
FIRE SYSTEM	105,170.00	105,170.00	105,170.00	16,678.00	16,678.00	16,678.00	78,323.00	78,323.00	78,323.00	9,252.00	9,252.00	9,252.00	209,423.00	209,423.00	209,423.00
PLUMBING	274,910.00	274,910.00	274,910.00	26,210.00	26,210.00	26,210.00	96,085.00	96,085.00	151,435.00				397,205.00	452,555.00	452,555.00
AIRCONDITION SYSTEM	353,140.00	353,140.00	419,892.00	49,220.00	49,220.00	61,491.00	51,180.00	51,180.00	82,212.00				453,540.00	538,138.00	581,595.00
LIFT	600,000.00	600,000.00	600,000.00										600,000.00	600,000.00	600,000.00
ADDITIONS AND OMISSIONS															
PLUMBING DESIGN AS PER EE GUIDELINES			81,250.88											81,250.88	81,250.88
ROOF TOP SOLAR PV														810,832.00	810,832.00
SMART LIGHTING CONTROLS, SMART BMS, ENDUSE SUB METERING									1,005,545.14						1,005,545.14
TOTAL AMOUNT	11,508,058.05	11,921,827.67	12,369,125.96	1,765,245.03	1,826,358.04	1,896,709.13	3,762,324.58	3,938,924.12	4,178,187.36	876,287.41	903,413.28	921,284.85	17,971,915.00	19,423,580.36	21,062,735.32

Table 6: Summary of BoQ for all phases

Appendix

Table 7: Basic information of the MET office

Building Characteristics	
Floors	G+1 Office building
Total built-up area	1,190 sq. m
Total Conditioned area	493 sq. m
Operating schedule	Offices: 8AM to 4PM; Observatory/Watch: 24x7 Classroom: 8AM to 4PM once a week Meeting: 2 hours a day

Table 8: Inputs to the development of baseline energy model of the MET office

S. NO	Parameter	BASECASE
1	Orientation	S-N
2	Shading	Partially shaded
3	WWR	30%

4	Wall U-value	3.0 W/m ² .K (15 mm Plaster + 150mm Brick + 15 mm plaster)
5	Roof U-value	3.5 W/m ² .K (50 mm screed + 300 mm RCC + 50 mm finish)
6	Glazing U value	5.8 (Single Pane)
7	Glazing SHGC	0.7
8	Lighting Power Density	As per design
9	Equipment Power Density	As per details provided by MET
10	HVAC system	Split AC units (CSPF – 2.7), Set point 24 deg
11	Fresh Air	Air-conditioned spaces-no fresh air; Non air-conditioned spaces-Naturally ventilated

Table 9: Calculated Lighting power density for each spaces of the MET office (as per Lighting design)

Space (Ground floor)	LPD (W/sqft)	Space (First Floor)	LPD (W/sqft)
Watch office	0.20	Record	0.35
Observatory	0.20	Server	0.30
Observatory ext	0.20	Classroom	0.40

Prayer hall	0.30	Consultant office	0.15
Changing room	0.36	Dry and laundry	0.15
Repair	0.10	WC 1	0.33
Garage	0.10	WC 2	0.33
WC	0.36	WC 3	0.33
Admin	0.23	Bed	0.18
Dining Kitchen	0.28	Lobby	0.20
Data archive	0.20	WC	0.36
Offices	0.20	Atrium	0.10
Reception lobby	0.10	Living	0.60
Store	0.15	Conference	0.50

Possible construction assembly for walls

U-value: 0.9 W/m². K

Table 10: Construction assembly option for Wall U-value: 0.9 W/m².K

Materials (Outside to Inside)
Expanded Polyurethane, 20mm
Brick, 200mm

U-value: 0.6 W/m². K

Table 11: Construction assembly option for Wall U-value: 0.6 W/m².K

Materials (Outside to Inside)
Expanded Polystyrene, 32mm
Brick, 200mm

Possible construction assembly for roof

U-value: 0.6 W/m². K

Table 12: Construction assembly option for Roof U-value: 0.6 W/m².K

Materials (Outside to Inside)
Expanded Polyurethane, 76mm
Brick, 200mm

U-value: 0.3 W/m². K

Table 13: Construction assembly option for Roof U-value: 0.3 W/m².K

Materials (Outside to Inside)
Expanded Polystyrene, 110mm
Brick, 200mm

Table 14: Case studies on impact of smart building technologies

Case Study	Technologies used	Environmental	Economic	Social
Herman Miller International Headquarters, UK	<ul style="list-style-type: none"> · Computerized ventilation system · Motorized fanlight opening for windows · Automatic night-cooling strategy · Sensors in the floor slabs · Water meters · Sensor controlled lighting strategy · Photographic identity cards · CCTV surveillance · Electronic document management system · Sub-metering 	Office space with intelligent lighting strategy uses almost 4 times less energy than retail space of smaller floor area, with conventional lighting. Water wastage is prevented	Intelligent lighting strategy and a computerized ventilation system helped increase operational savings.	Staff safety, efficiency and productivity improved

<p>The U.S. Green Building Council (USGBC) Headquarters, USA</p>	<ul style="list-style-type: none"> · Lighting system controlled off an IT backbone · Motorized window shades · Occupancy sensors for lighting and plugs · Automated temperature modulation · Integrated lighting and HVAC system · Ventilation system with two-position diffuser · Sub-metering 	<p>60% less energy and 40% water savings than a typical code-compliant office. Integration of intelligent lighting controls and automated temperature modulation resulted in a 15% drop in energy usage.</p>	<p>US\$96,000-per-year savings and a low payback period.</p>	<p>Increased staff productivity</p>
<p>Genzyme Centre, USA</p>	<ul style="list-style-type: none"> · Automated curtainwall glazing system · Automated blind system · Natural light enhancement system · Ventilation system with CO2 sensors · Automated faucets · Soil sensors for irrigation · Building-commissioning plan 	<p>The daylight dimming system reduces lighting energy use by 45%. The building uses 32% less water than a comparable office building and saves 753,297 litres of water a year.</p>	<p>The building management system has reduced the overall energy cost by 41%.</p>	<p>The high performance curtain wall glazing system and the natural light enhancement system maximise natural daylight exposure to 75% and bring in fresh air.</p>
<p>Asia Square Tower 1, Singapore</p>	<ul style="list-style-type: none"> · Integrated Intelligent Building Management System · CO2 sensor system · Photo sensors · Air Handling Units with ultra-violet emitters · Zoned HVAC system · Property management system · Smart card access system with proximity card readers · Automated destination- 	<p>The Intelligent Building Management System (IBMS) improved energy efficiency.</p>	<p>Reduction in operating costs by 20%.</p>	<p>State-of-art security, fire protection and property management systems ensured greater business efficiency</p>

	<ul style="list-style-type: none"> controlled lift system · CCTV surveillance · Guard Tour System · Fire Protection System · Multiple communications and information risers 			
Taipei 101 Tower, Taiwan	<ul style="list-style-type: none"> · Energy Management and Control System · Water management system · Integrated electronic security systems · CCTV surveillance · Computerized smartcard access control system · Visitor Access Kiosk System · Optically controlled gates · Automated destination-controlled lift system · Fire Protection system · Smoke exhaust system · Multiple communications and information risers 	The Energy Management and Control System (EMCS) reduces energy consumption by 33.41 million kWh per year and potable water usage by 30%, saving 28 million litres of water a year.	The Energy Management and Control System (EMCS) saves more than US\$2 million per year.	The integrated security system comprising of surveillance, smartcard access control, visitor access kiosk and fire protection systems provide the tenants with advanced safety features.
Conclusion	Use of intelligent systems has reported benefits on the environmental, economic and social fronts.	Communication between various building systems through a centralized system can lead to increased energy savings as opposed to a stand-alone system.	The return on investment due to the energy and operational cost savings have reduced the payback period for most of the intelligent building equipments.	Smart features of an intelligent system can enhance the overall well-being of people which translates to improved efficiency and productivity in the workplace.



Ministry of Environment, Climate Change and
Technology

Review and Amend Design of MET Office

Sustainability Assessment Report



**Promoting Energy Efficient Buildings through
Strengthening Low Carbon Energy
Island Strategies (LCEI) Project**



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1. Introduction

1.1. About MET Office

The MET Office building is coming up in Addu island and would house the Meteorological Department. The Ministry of Environment, Climate Change and Technology is inclined to design the building with energy efficient features which would demonstrate the aspects of the draft 'Maldives Building Energy Efficiency Guidelines'. The Guidelines are being developed under the 'Strengthening Low Carbon Energy Island Strategies Project (LCEI)', which is funded by Global Environment Facility (GEF) and is implemented by the Ministry of Environment Ministry of Environment, Climate Change and Technology. Hence, the proposed office building is being designed, keeping in perspective the recommendations made in the Guidelines. The building would be a benchmark of energy and resource efficiency, thermal and visual comfort and environmental footprint in Maldives.



Figure 1: Perspective view of the MET office

1.2. Project objectives

The aim of this project was to assess and improve the energy efficiency of the MET office. The project objectives were to

- Review the current energy performance of the MET office against the Maldives Building Energy Efficiency Guidelines, and
- Amend the current design with energy conservation and energy efficiency measures to improve its performance beyond the standards set in the Guidelines.

2. Approach and Methodology

2.1. Approach

In order to fulfill the project aim and objectives, the project team followed an iterative and progressive approach as described in the figure 2. The project team evaluated the current design of the MET office based on the design data provided by Riyan Architects and some additional data on equipment provided by the team at MET Office. Using the data collected, the team developed a digital energy model of the MET office to review the performance of the current design and evaluate various energy conservation and energy efficiency measures. Whole building performance method of the Guidelines (section 13) was followed for this exercise. The team tested a total of 56 design interventions including building orientation, solar shading, wall, roof and glass materials, HVAC systems and solar PV, in line with the minimum requirements set under the Maldives Building Energy Efficiency Guidelines (section 6 through 12). The team also suggested various smart building technologies to further reduce the operational energy use. Finally, the team compared the current design against an 'Optimal' case which demonstrates compliance with all the minimum performance requirements of the Guidelines and a 'Best' case which is a combination of the best measures as per Internal best practices. The Best case is presented in this report as the recommended design. The team used its data-driven solution 'Sustainability Analytics Hub' to holistically evaluate the energy performance of MET office along with daylighting, thermal comfort, GHG emissions, and cost implications of the various performance improvement measures.

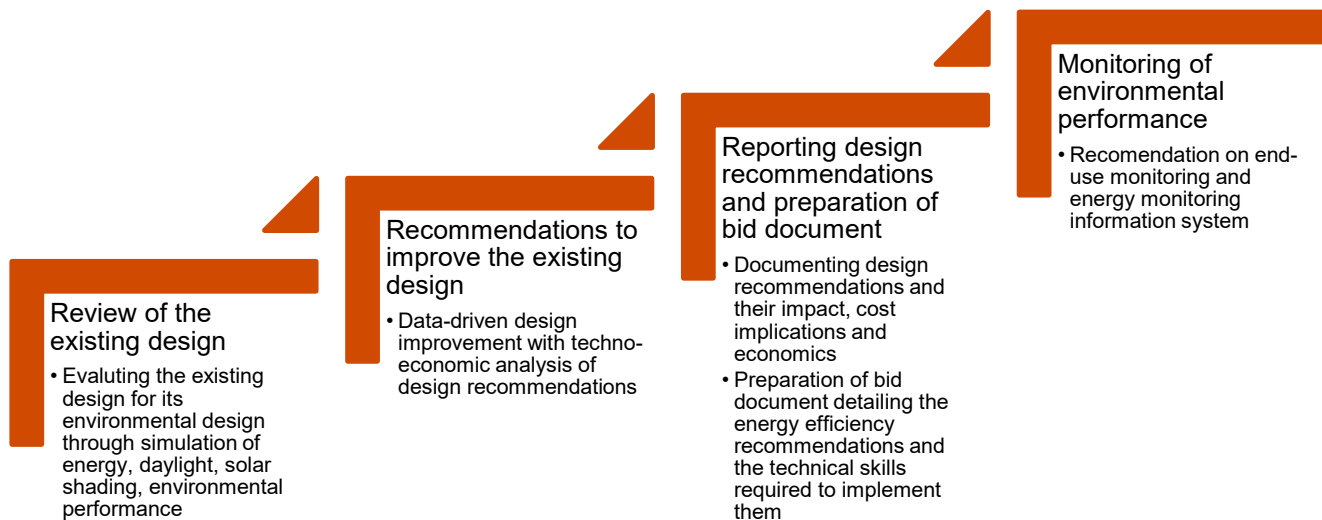


Figure 2: Approach followed to fulfill the project aim and objectives

2.2. Methodology

The project team carried out detailed analysis on the existing design to evaluate its performance against the benchmarks set in the 'Maldives Buildings Energy Efficiency Guidelines'. The team evaluated the MET office design for its:

1. Energy consumption,
2. Cooling load,
3. Availability and quality of daylight,
4. Thermal comfort,
5. Parameters of HVAC system operation

As mentioned in earlier section, the team followed an iterative and progressive approach for this project. As described in figure 3, the team developed the 'baseline' energy model based on the building drawings, building material properties, lighting details and HVAC system shared by Riyan. The equipment density for specific areas was calculated based on the data provided by the team at MET office. Various measures were tested for their impact on the environmental performance. It is to be noted that the lighting design was already optimized by

Riyan and hence was recommended to be followed 'as-designed'. Upon analyzing the current design, it was found that the cooling load of the building is below 50 TR and hence systems such as Air-cooled and water-cooled chillers were ruled-out of the ambit of analysis as these are not feasible for such smaller cooling loads.

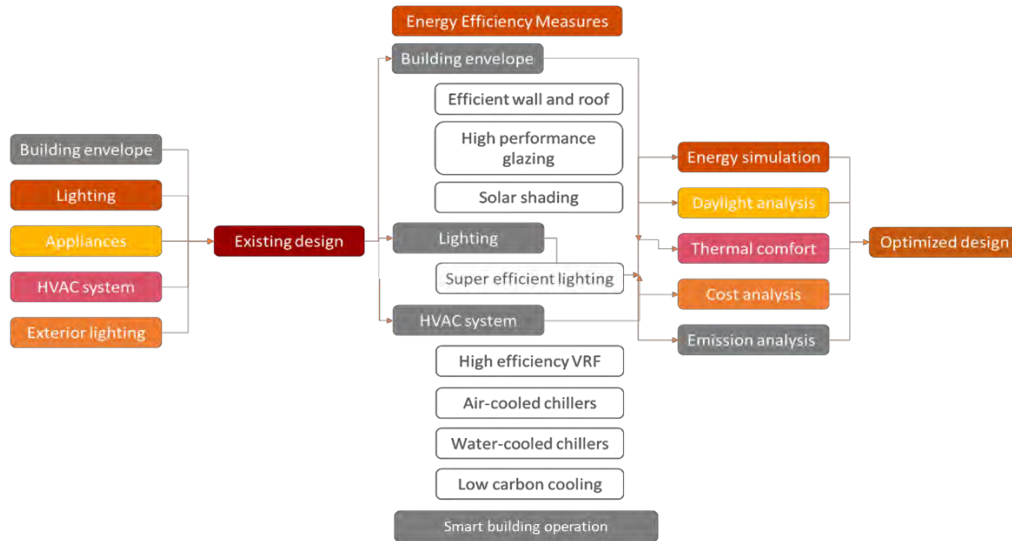


Figure 3: Modelling and analysis workflow

The team conducted simulation studies to evaluate the performance of MET office for its bioclimatic design, building envelope, energy use, thermal comfort, daylight availability and quality and GHG emissions. All the interventions were also evaluated based on the initial investment required, the amount of operational savings generated and payback period.

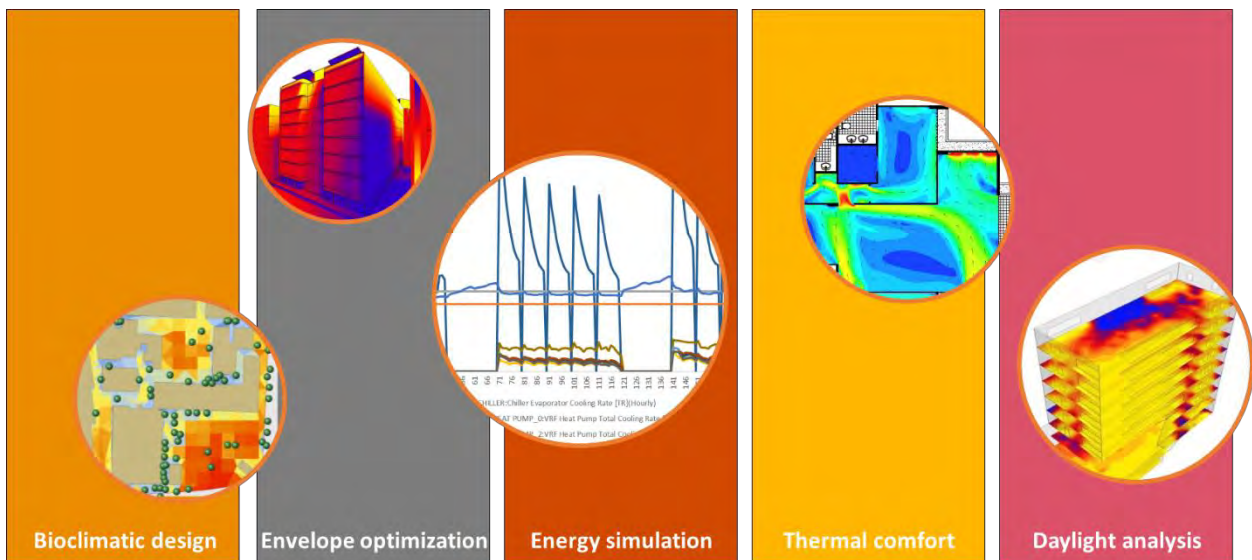


Figure 4: Various analysis carried out by the project team

Detailed Analysis

- **Bioclimatic design**
The existing design was analyzed for its massing, solar shading, orientation, spatial configuration and microclimate. The project team proposed recommendations to improve the bioclimatic aspects of the MET office.
- **Envelope optimization**
The project team reviewed the existing building envelope for its thermal properties and materials and evaluate its impact on the environmental performance. Based on the performance, the project team optimized the building envelope to maximize the performance at optimized cost.

- **Energy Simulation**
The project team generated an energy model of the existing design and review its energy consumption, cooling load, energy profile, HVAC system performance and proposed design changes viz. solar shading, building materials, HVAC system and operation schedule to outperform the KPIs. Cost-benefit analysis was an essential part of this exercise. eQuest version 3.65 was used to carry out this analysis.
- **Thermal comfort**
The existing design was analyzed for the thermal comfort conditions during occupied hours. The analysis focused to maximize thermal comfort at optimized operational cost. Thermal comfort outputs of the energy modelling exercise were used to generate thermal comfort maps.
- **Daylight analysis**
The project team carried out annual daylight simulation and glare studies to evaluate the visual comfort quality of the existing design. The outcomes of the analysis were used in improving the window-wall ratio, glass selection, optimizing solar shading. DaySim was used for annual daylight analysis and EvalGlare was used to analyze possibility of perceivable and disturbing glare.

Based on the analysis, the project team documented the findings of the existing design and the design recommendations to arrive at two design alternatives – optimal and best case. The project team also assisted Riyan Architects in developing the bid document to implement the recommended energy efficiency design interventions, highlighting the technical and material requirements from the contractor.

2.3. About Sustainability Analytics Hub

The project team is having vast experience in delivering similar projects and has developed ‘Sustainability Analytics Hub’-a state-of-the-art, integrated software solution to evaluate sustainability performance of buildings. The project team proposed to deploy this Data-Driven solution which brings together simulation capabilities of different tools to evaluate energy, daylighting, thermal comfort, natural ventilation performance on a single platform and performs cost and environmental impact calculations in real time.

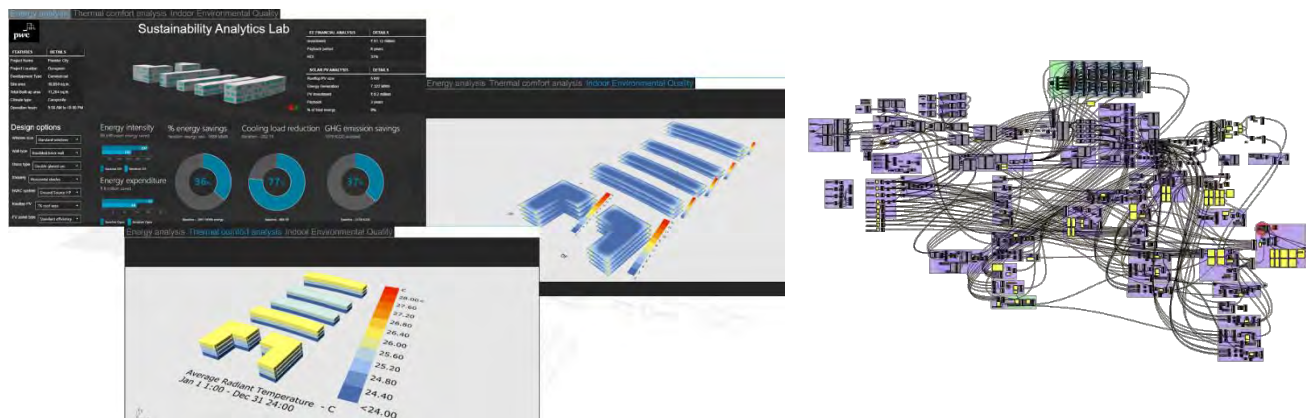


Figure 5: User interface (left) and backend algorithm (right) of the Sustainability Analytics Lab

Sustainability Analytics Hub is powered by industry recognized software tools ‘Rhinceros’ and its virtual programming and modelling platform ‘Grasshopper’ and its plugins. The energy, thermal comfort and natural ventilation simulations are carried out on ‘EnergyPlus’, and daylight and glare analysis are done on ‘Radiance and Daysim’. Sustainability Analytics Hub is backed by complex, robust algorithm to parametrically model several energy efficient measures and simulate them in real time.

It is an ideal simulation toolkit for the design team to evaluate a broad range of energy efficiency measure and their cost implications in real time. Hence, the project team used this platform to review the existing design of the MET Office and provide design recommendations to enhance its energy and resource efficiency, indoor environmental quality, and reduce its carbon footprint at optimized cost.

2.4. Reference standards

The team followed the draft Maldives Building Energy Efficiency Guidelines as the reference standard to establish the minimum performance criteria. Sections 6 through 12 were followed for different evaluation of different elements of the design and recommend design changes. Section 13 – Whole building performance method as guiding procedure to carry out this study.

2.5. Weather data

Hourly weather data of Gan, Maldives provided by MET office was used to perform the various simulation studies for this project.

The next chapter documents the environmental performance assessment of the MET office building and the qualitative evaluation of proposed energy efficiency measures in the building.

3. Environmental Performance Assessment

3.1. Current Design

The project team developed a digital energy model of the current design of the MET office based on the building drawings, material specifications, lighting and HVAC design provided by Riyan Architects. Equipment power density was calculated based on the data provided by the MET office.

The MET office is a G+1 building with a total built-up area of 1,190 sq.m. and conditioned area of 493 sq.m. It is a C-shaped building and is oriented with longer facades facing south-north. The WWR in the current design is 30%. Office spaces are operated 8AM to 4PM on weekdays, observatory and watch towers are occupied round the clock, conference room is occupied for 2 hours a day and classrooms are occupied in during office hours, once a week. The building envelope consists of conventional 150mm brick walls, 300mm RCC roof and single glazed windows. The lighting power density is calculated to be 2.5 W/m² (on an average for the building). The lighting and equipment power density are based on the design data provided (Table 5 in the Appendix). Split ACs are provided in the current design. In absence of system specifications, these are modelled with 3.1 CSPF (as per section 8.6 of the Guidelines - Minimum mandatory guidelines for HVAC systems). The details of the energy model are provided in appendix.

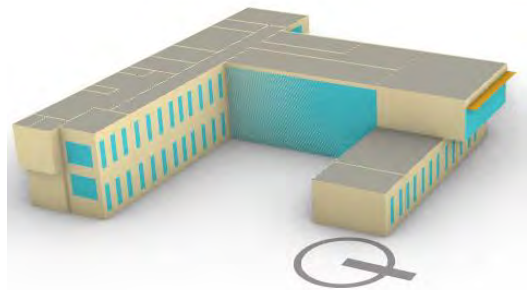


Figure 6: Energy model of the MET office

The energy simulation results of the current design (baseline) estimated the annual energy usage of the MET office to be 149 MWh. This translated to an annual Energy Performance Index (EPI) of 125.5 kWh/m². It is to be noted that this is close to the EPI (120 kWh/m²) for a typical office building in Maldives which is designed in compliance with the Maldives Building Energy Efficiency Guidelines. This can be attributed to the optimized building form, orientation, WWR and window placement.

Figure 16 (left) shows the breakdown of the annual energy use. Due to the equipment-intensive nature of the major activities, the equipment and plug loads account for 72 MWh which is almost 50% of the total annual consumption. Space cooling consume 52 MWh (35%), ventilation 17 MWh (11%) and lighting 8 MWh (5%) of the total energy consumption. Lighting power density as per the current design is 2.6 W/m² which is highly optimized, leading to least consumption due to lighting and significant reduction in space cooling and ventilation requirement.

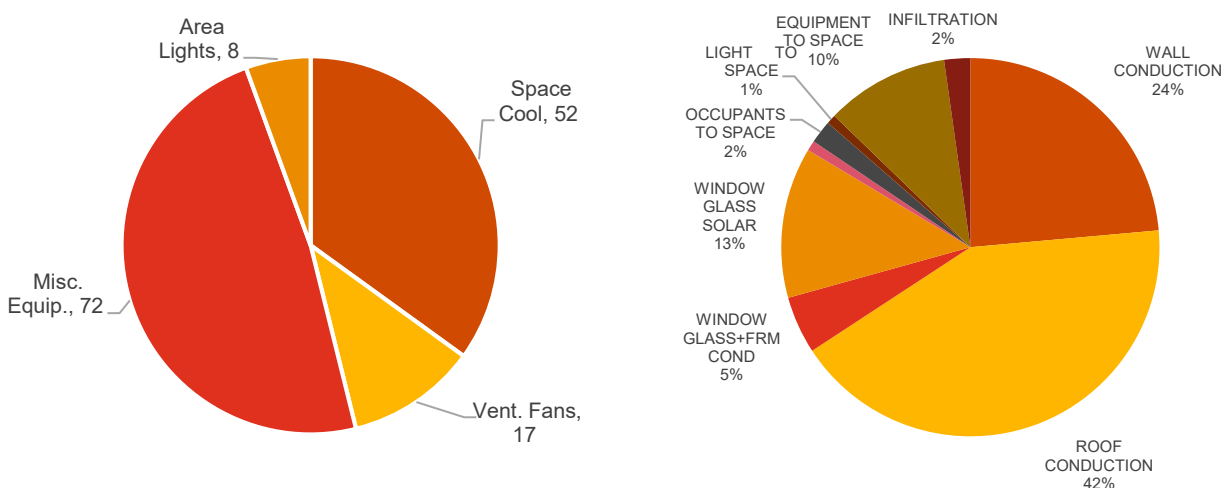


Figure 7: Breakdown of energy use (left) and cooling load (right)

The peak cooling requirements of the current design is simulated at 130 kW (37 TR). Heat gains from the roof are major contributors to the space cooling loads, followed by heat gains through wall and radiation gains through the windows. Equipment is the major internal load contributing to the cooling load.

3.2. Design Recommendations

This sub-section documents the impact of various design alternatives tested to improve the performance of the current design. It follows the requirements set under various sections and sub-sections of the Guidelines.

3.2.1. Bio-climatic building design

This sub-section mentions the performance of the current design against the requirements and recommendations of section 6 of the Guidelines.

3.2.1.1. Building form and orientation

Bio-climatically, the current building is C-shaped which offers enough self-shading throughout the day. The orientation in the current design is well designed for. It could be supported from the results of 90 and 270-degree rotation which resulted an increase in the energy use. A 180-degree rotation would result in 1% energy savings as shown in figure 18.

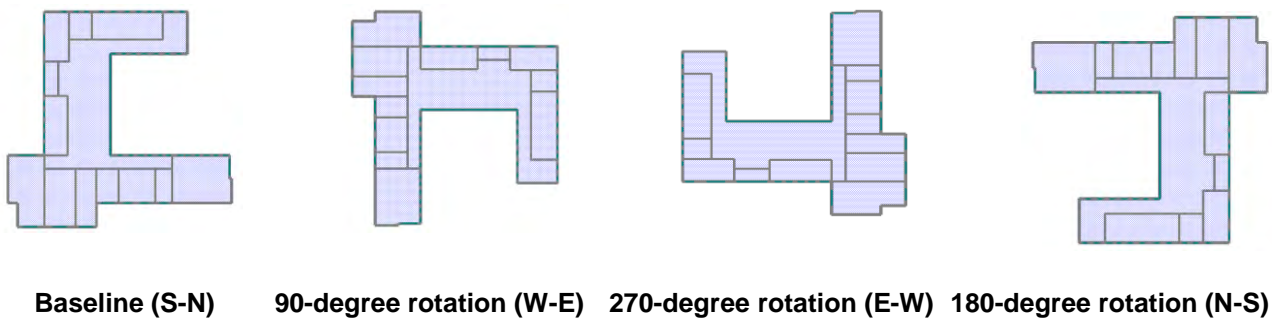


Figure 8: Various alternatives for building orientation

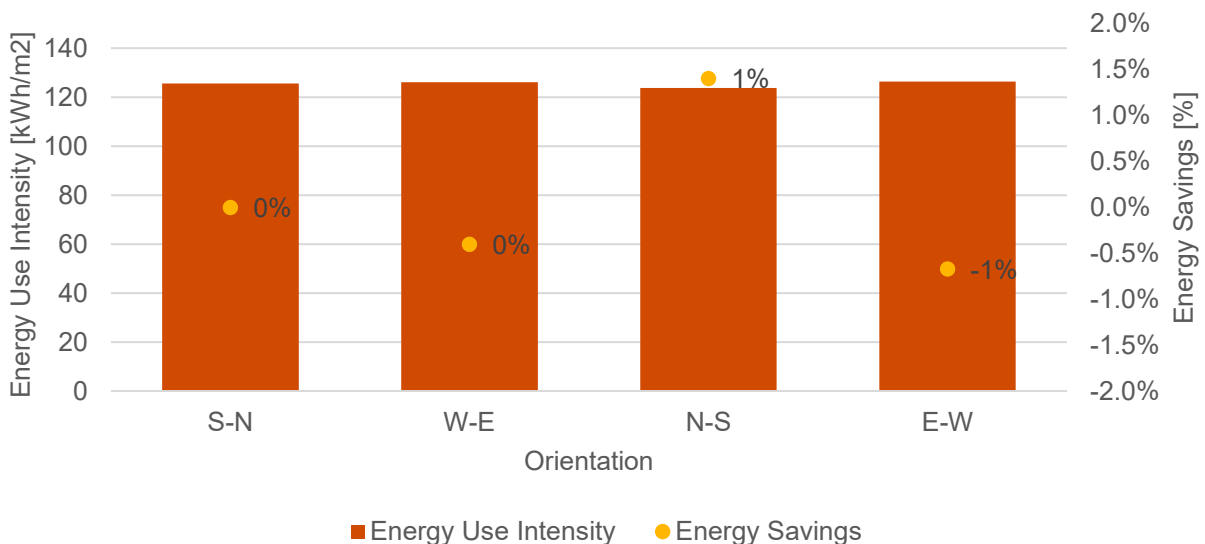


Figure 9: Impact of rotation on EPI of the current design

3.2.1.2. Window-Wall Ratio

WWR is an important driver of energy use and space cooling load. Typical office buildings surveyed by the project team as part of other assignment in Maldives show that the WWR in a typical design could be as high as 70%. The Guidelines recommend a maximum WWR of 40% for office buildings. The current design of the MET office has achieved a WWR of 30%, which is lower than 40% as recommended. Thus, the current design is accepted in terms of WWR.

3.2.1.3. Shading

As mentioned in section 3.1.5, solar shading is an important strategy of passive design, especially for buildings in Maldives. Owing to the building form, lower window-wall ratio and placement of windows, the current design has reduced the solar radiant and conduction gains from windows. Simulations estimate that 200mm overhangs and 200mm fins on all facades could further reduce the energy use by 1% and 2%, respectively. The potential for energy use reduction through a combination of overhangs and fins is 3%, as showed in figure 19. Figure 20 shows various design alternatives to provide horizontal and vertical shading to windows. Although solar shading offers potential to reduce energy use and cooling load, high capital investment makes them cost-ineffective and hence are not included in the final recommendations.

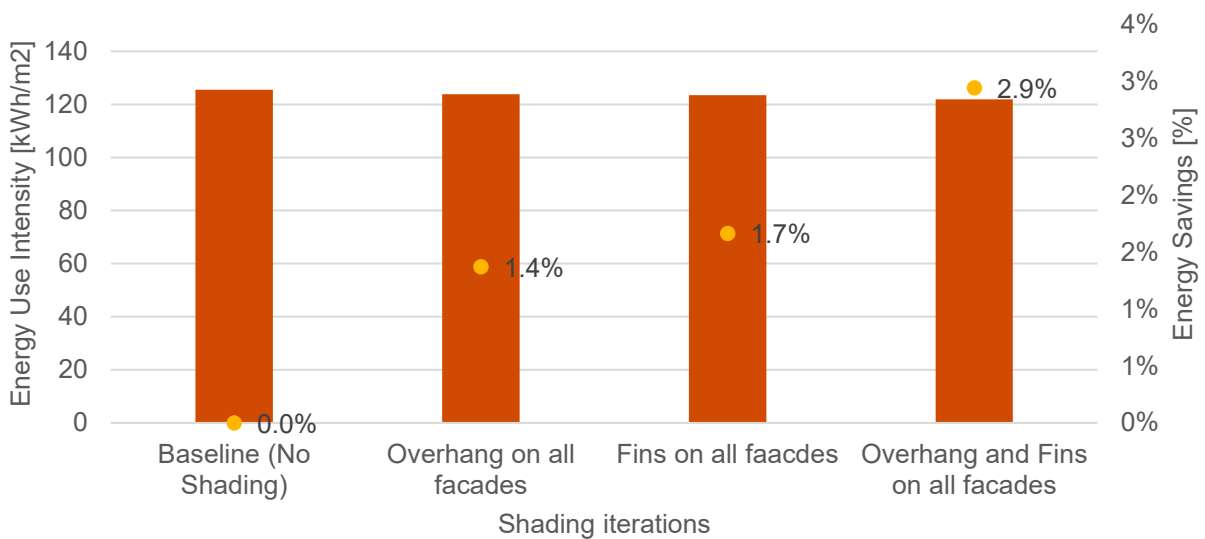


Figure 10: Impact of solar shading on energy use

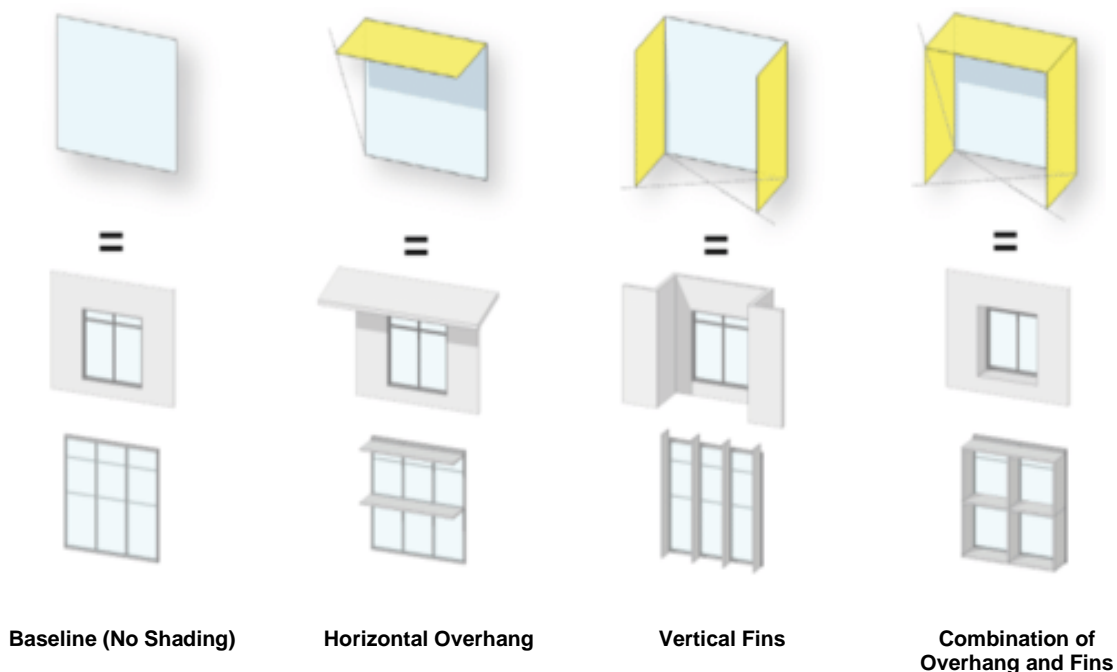


Figure 11: Design alternatives for solar shading

3.2.1.4. Daylighting

The project team evaluated the current design for its daylighting performance using dynamic simulation. Section 6.3.4.2 of the Guidelines recommends achieving a minimum of useful daylight for a minimum of 70% of the area for a target illuminance (below which the floor area would be deemed to be underlit) of 500 lux on the working plane which is 800 mm above the floor level. The glaring illuminance (beyond which the occupants could experience visual discomfort) is set at 2,000 lux. The objective of the daylight analysis is to ascertain the amount of floor area receiving daylight in the range of 500-2,000 lux, which is the useful daylight. The glass visible light transmittance (VLT) is assumed to be 80%, which corresponds to a clear, single pane glass.

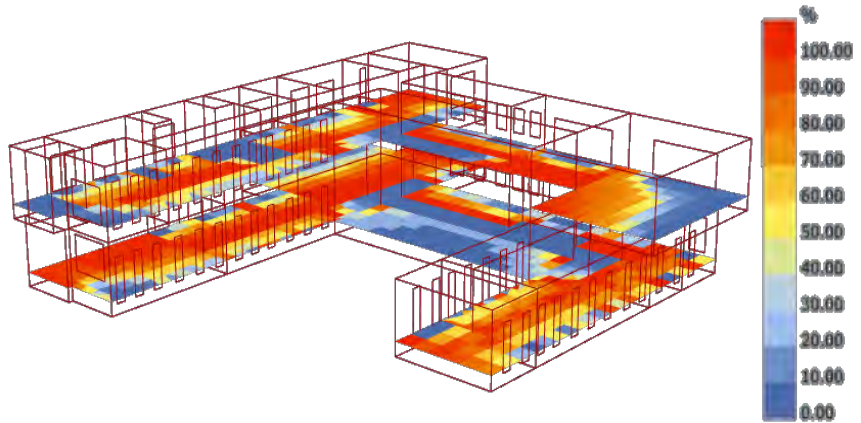


Figure 12: Daylight analysis for the current design

The current design receives useful daylight for 79% of the floor area (figure 21), which demonstrates compliance with the requirements of the Guidelines. The project team has carried out several simulations for different options of glass VLT (40% to 70%). The outcome of the analysis suggests that the glass to be selected for MET office should have a minimum VLT of 50% to meet the performance requirement set in the Guidelines, as shown in figure 22.

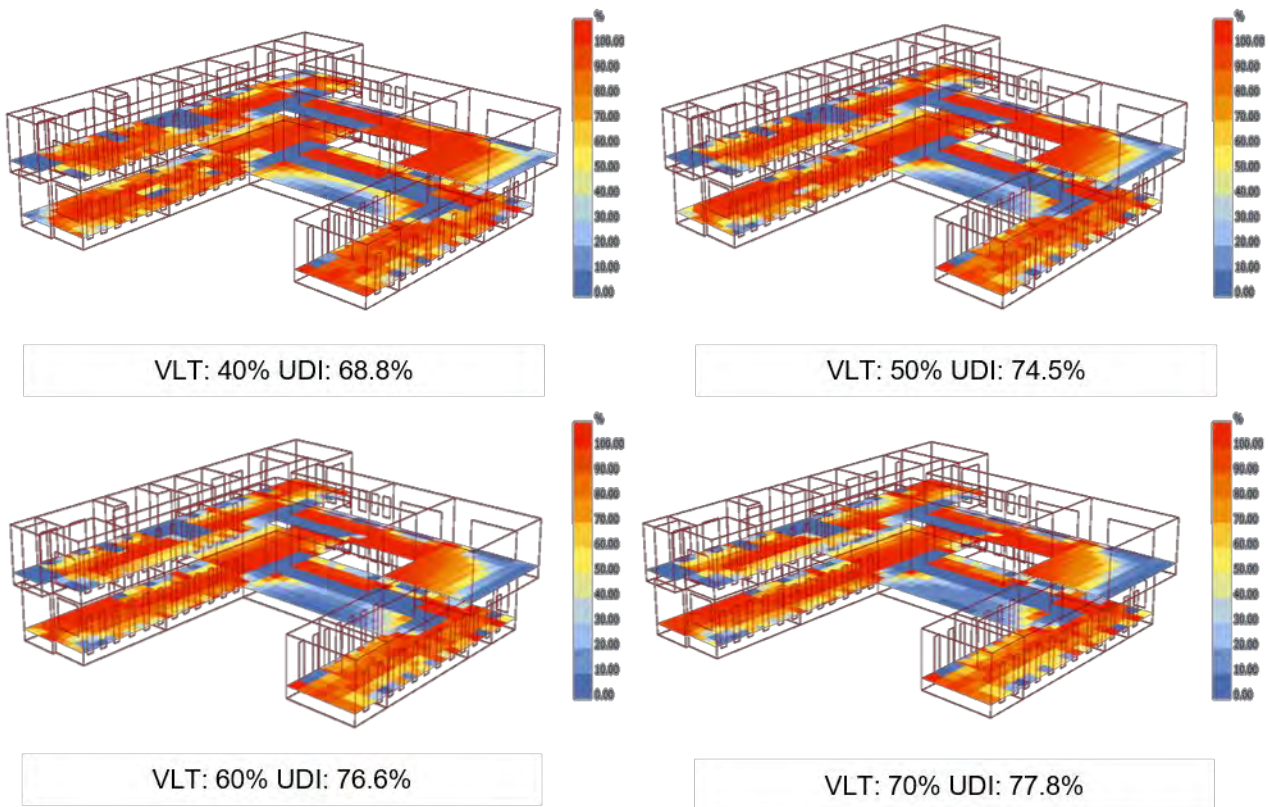


Figure 13: UDI analysis for various options of glass VLT

3.2.2. Building envelope

This sub-section details the analysis done to evaluate the performance of the building envelope of the current design and the recommendations made to improve its efficiency.

3.2.2.1. Walls

Walls constitute 70% of the vertical envelope area of the MET office. Thus, these offer good potential to reduce energy use through improving their thermal conductance. The current design has 150 mm brick wall assembly. Improving the U-value reduces the conduction heat gains through the walls. This can be done by using a thermally high performing materials such as AAC blocks or by adding insulation internally or externally on the wall. U-value of 0.9 W/m². K and 0.3 W/m².K could reduce energy use by 4% and 5%, respectively, as shown in figure 23.

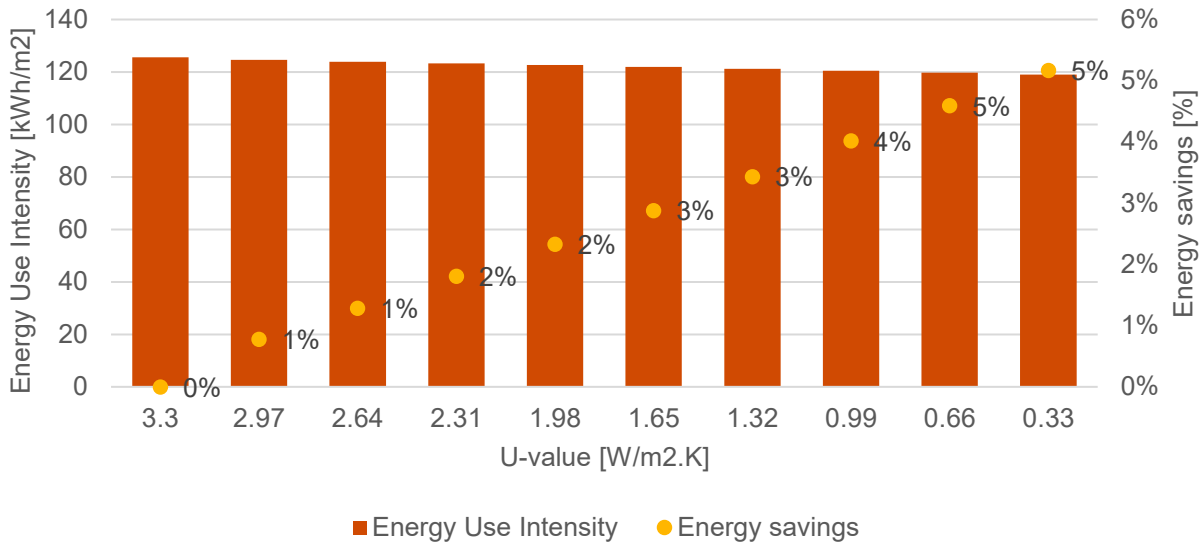


Figure 14: Impact of improving wall u-value on energy use

3.2.2.2. Roof

As mentioned in section 4.1, conduction heat gains through roof significantly contribute to the space cooling load of the current design of MET office. Thus, lowering U-value of the roof would result in reduction in space cooling requirements and the corresponding energy use. U-value of 0.6 W/m².K and 0.3 W/m².K could reduce energy use by 5.1% and 6.3%, respectively.

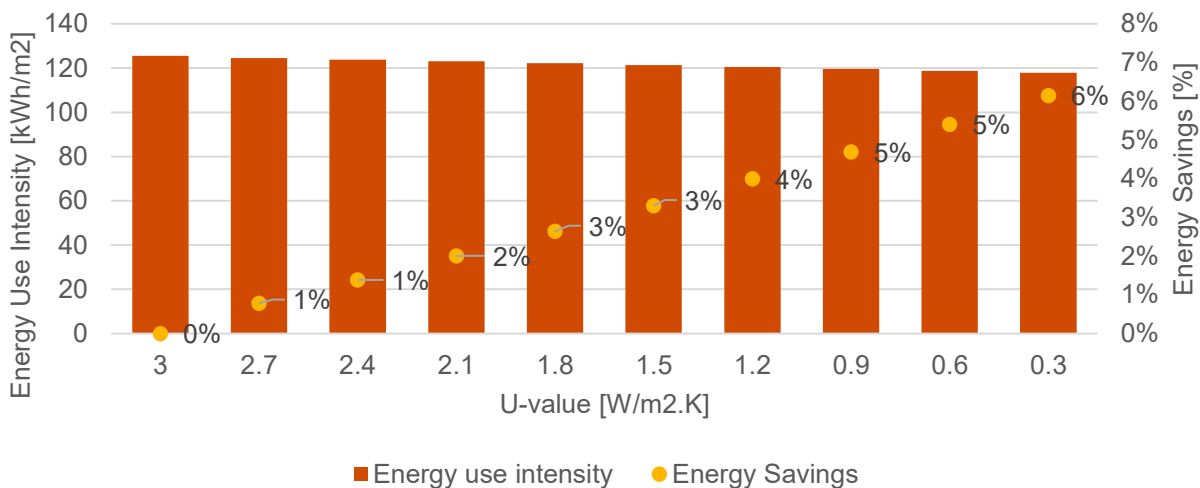


Figure 15: Impact of lowering roof u-value on energy use

The recommended U-values for walls and roof could be achieved through a combination of various types of insulation, brick and RCC layer. A few combinations are provided in appendix in Tables 10 through 13.

3.2.2.3. Glass

Solar radiation gains through widows are a major component of building peak load in Maldives. However, good bio-climatic design of the MET Office with lower WWR means the solar radiation heat gains are lower than typical design. Section 7.2.3 of the Guidelines recommends an SHGC value of 0.4 or lower. Simulation results for single pane glass with an SHGC of 0.4 suggests reduction in energy use by 2% and 0.25 by 3.3%, as shown in figure 25.

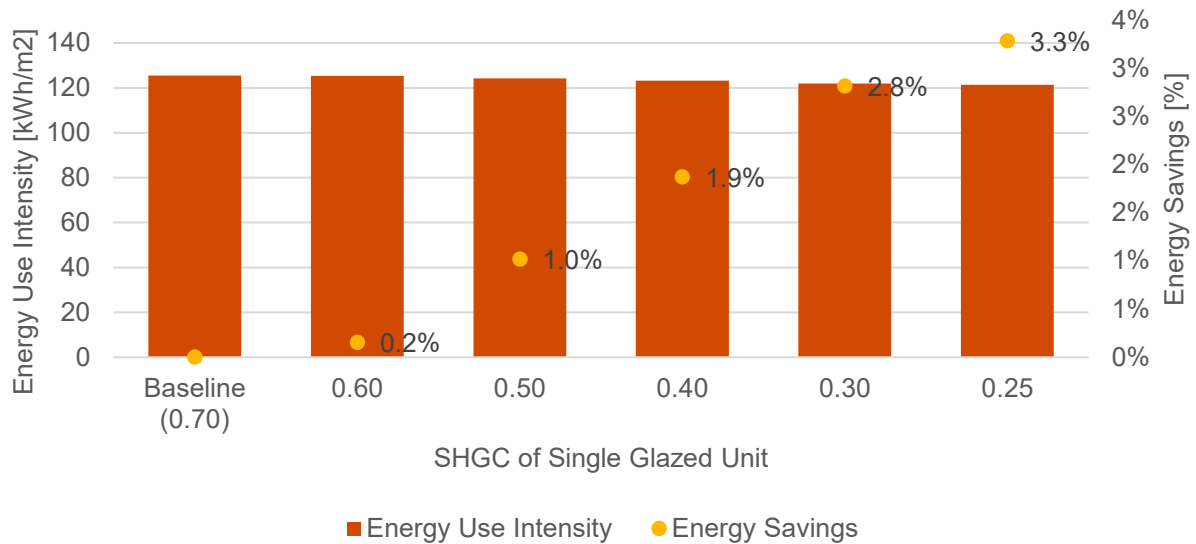


Figure 16: Impact of lowering SHGC of single glazing on energy use

As mentioned in the guidelines and in earlier analysis, conduction heat gains through windows in Maldives have lower contribution to the building’s cooling load, compared to the radiation heat gains. Thus, the MET office would not benefit significantly by double glazed units. On the contrary, the building would be penalized due to short-wave radiation being trapped inside the building, not able to escape to the outdoors in the night-time due to low diurnal temperature difference. Double glazed unit (U-value-1.8 W/m².K) with an SHGC of 0.4 would result in 2% and 0.25 in 3.2% energy savings, as shown in figure 26.

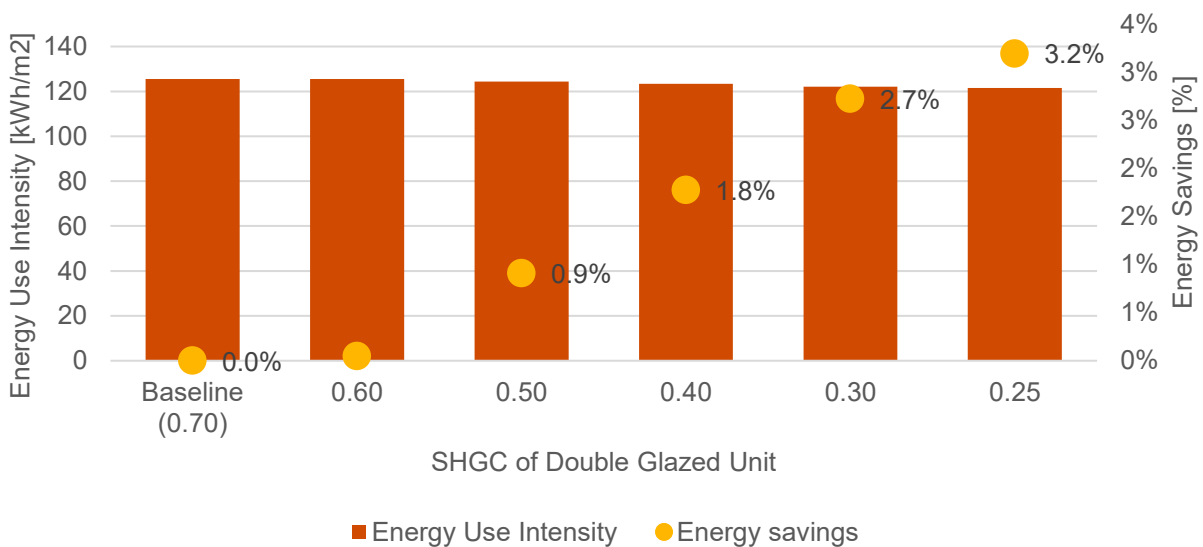


Figure 17: Impact of lowering SHGC of Double-glazed Units on energy use

3.2.3. Thermal comfort systems and controls

This sub-section covers the analysis of the current design with respect to section 8 of the Guidelines and the impact of design changes from the HVAC perspective on energy use.

3.2.3.1. Cooling setpoint

Improving the building envelope has a positive impact on the thermal comfort of the occupants. It means that the same level of thermal comfort could be achieved at lower cooling requirement. It also means that the cooling setpoint could be increased by a reasonable measure which could lead to reduction in capital investment on the cooling system and their operational expenditure. Section 8.5 of the Guidelines allows for 1 °C increase in cooling setpoint. Increasing the cooling setpoint for MET office to 25 °C could result in 1.2% energy savings, as shown in figure 27.

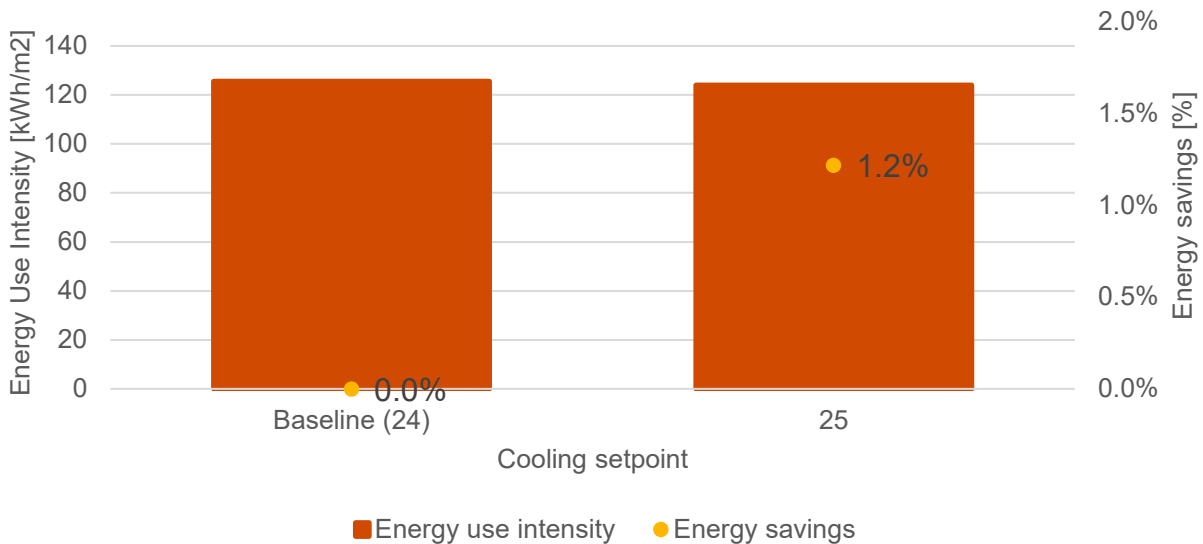


Figure 18: Impact of increasing cooling setpoint on energy use

3.2.3.2. Split ACs with higher CSPF

The current design is optimized for its form, orientation, WWR. Thus, the potential for major efficiency gains lie in improving the building envelope and the performance of the HVAC system. Improving the efficiency of split ACs could result in notable energy savings. CSPF of 4 (4-star) and 5.1 (5-star) could yield 4% and 10% energy savings, as shown in figure 28.

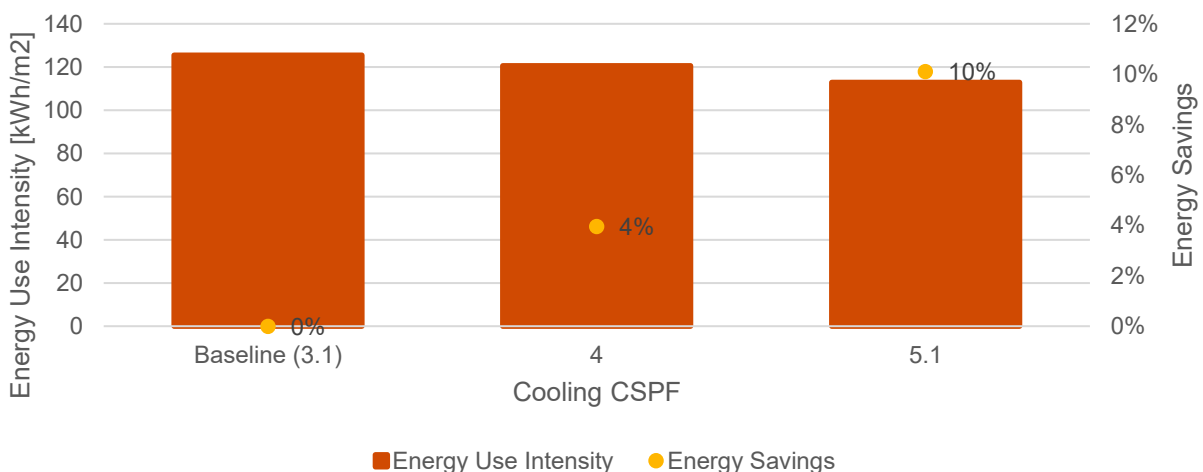


Figure 19: Impact of improving CSPF of split ACs on energy use

3.2.3.3. VRF systems

VRF systems are proven technology and are more efficient compared to split ACs, offering better performance at part load conditions. For cooling loads such as the MET office, these systems have provided better operational performance compared to Split ACs. In this case, VRF system of COP 4 and 5.1 could generate 10% and 15% energy savings, respectively, as shown in figure 29. The recommended COP is compliant with the requirements of section 8.5 of the Guidelines.

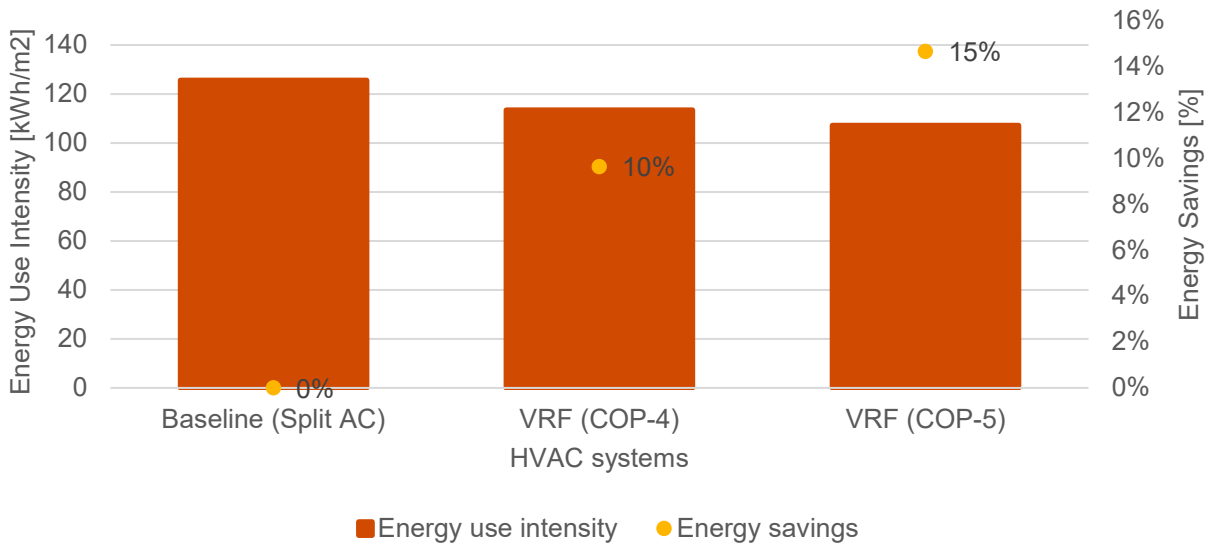


Figure 20: Impact of VRF systems on energy use

3.2.4. Smart building systems

3.2.4.1. Lighting controls

Lighting control can be defined as hardware - and software - systems that regulate the intensity level of the light output in response to a command or action. Efficient lighting controls can reduce lighting energy by an average of 24% to 38%. Today's lighting controls fit into four main categories, according to their size and function:

1. Distributed networked systems offering total lighting control management.
2. Scalable panel systems using low-voltage, mechanically held, single- and double-pole latching relays.
3. Architectural/commercial control systems handling a variety of control applications and using input devices that vary from keypads to touchscreen controllers
4. Networked devices and wall box dimmers.

In aggregate, the lighting controls in smart building systems are responsible for occupancy/vacancy control, daylight harvesting, time scheduling, task level tuning, lumen maintenance, and personal control within a workspace.

3.2.4.2. Smart BMS

BMS is basically a solution which is integrated into a facility to ensure an environment that is safe, secure, comfortable and energy efficient. In order to be efficient, the BMS must be properly integrated into the facilities.

Monitoring of the environmental performance in operational phase

It was essential that the building achieved the environmental performance and yielded the savings on operational cost, as projected during the design stage. We assisted the design team to incorporate environmental monitoring system during the design stage and assisted in the selection of:

- Smart environmental sensors
- Sub-meter for end-use monitoring

- Smart building energy monitoring system

Smart environmental Sensors

Smart environmental sensors are becoming essential for the modern, connected, energy efficient buildings. These sensors collect real-time data on temperature, humidity, lighting, occupancy, indoor air quality and electrical current. The data is then sent to the central building automation system controls and regulates the building operation to optimize resource allocation and operational cost.

Examples of some companies which manufacture such sensors for the use in smart buildings are Texas Instruments, ST Microelectronics, Analog Devices, Infineon Technologies etc.



Figure 21: Smart environmental sensors and the data collected

Sub-meter for end-use monitoring

End-use monitoring is important for energy efficient operation of a facility to ensure that each end-use is catered in an efficient manner and at optimal energy expenditure. Sub-meters can be attached for each electrical end-use viz. lighting, appliances, HVAC and the data can be used to monitor and explore the scope of further improvement.



Figure 22: Submeters for different end uses in a building

Smart building energy monitoring system

Smart building energy monitoring systems have the potential to generate significant savings in the operational stage. An IoT-enabled and machine learning capable building energy monitoring system could

- optimize cost and comfort,
- enhance energy efficiency,
- ensure sustainability targets are met,
- detect abnormal usage patterns and appliance operations,
- use big data to continuously improve operations



Figure 23: Smart sensors network and centralized smart building energy management system

Some top vendors for smart BMS are: Metasys, Cisco, Siemens, Honeywell, Schneider Electric, ABB, Johnson Controls etc. who can be consulted for integrating the buildings with smart technologies. A table (Table 14) consisting of some buildings integrated with these smart technologies and their environmental, economic and social impact has been provided in the appendix.

3.2.5. Renewable energy

The MET office is aimed to set an example of energy efficiency and energy security for office buildings in Maldives. As part of this exercise, rooftop solar PV was analyzed for on-site renewable energy generation.

Based on the brief from the team at MET office, the project team evaluated the potential of energy generation considering that 40% of the roof area would be allocated for solar PV. The PV panels are modeled of polycrystalline type with 15% efficiency. PV panels of higher efficiency up to 19% are also available for selection, provided its availability in the Maldivian market.



The modeled PV system is a 22 kWp capacity system covering 216.6 sq.m area. It has an energy generation potential of 34,531 kWh/year. For the current design, this PV system could offset 23% of the annual energy consumption. Section 11 of the Guidelines require at least 2.5% of the building's total electricity consumption to be met by renewable energy systems. The proposed PV system satisfies this requirement.

3.2.6. Water efficiency

Reducing indoor water use in offices can be accomplished through water-efficient plumbing fixtures. The EE guidelines impose a maximum on the amount of water used per flush by toilets and urinals and per minute by faucets and showerheads. Water efficient plumbing fixtures are recommended in the building with the following flow rate values:

Table 1: Water fixtures and recommended flow rates

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

Rainwater harvesting system

The climate analysis indicates that overall rainfall has increased from 2008 to 2018 by 57% in Male. Therefore, Rainwater harvesting system are recommended in the building to capture at least 25% of run-off volumes from roof area for collection and reuse in flushing and horticulture to reduce dependence on piped water supply.

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

Table 2: Rainwater harvesting calculations

Description	Result	Unit
1 Roof area	659.30	m ²
2 Rain fall	2360.00	mm/year
3 Rain water from roofs	1555.95	m ³ /year
4 Mean rain water supply	1555.95	m ³ /year
5 Mean rain water available for harvest	4.26	m ³ /year
6 Mean rain water to be used for treatment	4.26	m ³ /day
7 Monthly rain water treatment	127.89	m ³ /day
8 Dry season period (months)	2.00	m ³ /month
9 Total rain water requirement for dry period	255.77	months
10 Rain water collected during dry period	168.12	m ³
11 Total storage capacity needed for dry season	87.65	m ³
12 Design rain water holding tank capacity	88.00	m ³
13 Proposed rain water holding tank capacity	96.20	m ³

4. Summary of Design Recommendations and Costing

The previous section focused on the impact of improving performance of individual parameter on the annual energy use of the MET office. This section provides information on the proposed design. The proposed case is a combination of best possible values of the design parameters discussed in the previous section. A summary of the details and design recommendations is provided in the table below.

Table 3: Summary of design recommendations for the proposed design

S. No.	Parameter	Current design	Proposed design
1	Orientation	S-N	Same as current design (S-N)
2	Shading	No shading	Same as current design (No shading)
3	WWR	30%	Same as current design (30%)
4	Wall U-value	3 W/m ² . K	0.6 W/m ² . K
5	Roof U-value	3.5 W/m ² . K	0.3 W/m ² . K
6	Glazing U value	5.8 W/m ² . K (VLT – 80%)	5.8 W/m ² . K (VLT – 50%)
7	Glazing SHGC	0.70	0.25
8	Lighting Power Density	2.5 W/m ²	Same as current design (2.5 W/m ²)
9	HVAC system	Split AC units (CSPF – 2.7), Set point 24 degC	VRF units (CSPF – 5.1), Set point 25 degC
10	Smart building	None	Smart lighting controls, Smart BMS, End-use sub-metering
11	Rooftop Solar PV	None	22kWp rooftop solar PV system
12	Plumbing design		As per EE guidelines

Table 4: Summary of techno-economic analysis for the proposed design

Proposed design						
S. No.	Parameter	Design recommendations	Cost implication (MVR)		Energy Savings (%)	Payback period (Years)
			Capital cost	Miscellaneous costs		
1	Orientation	Orientation is already optimized	-	-	-	-
2	Shading	Spaces on East and West facades are un-conditioned and mutually shaded; Conditioned spaces are oriented due North-South and have controlled WWR. Thus, additional shading is not recommended	-	-	-	-
3	WWR	WWR is already optimized	-	-	-	-
4	Wall U-value	Add insulation on walls externally	409,327.68	-	5.2	12.2
5	Roof U-value	Add insulation on roof externally	587,315.60	-	6.1	14.7
6	Glazing U value	Select Single glazed unit	-	-	-	-
7	Glazing SHGC	Select glass with recommended SHGC and selectivity ratio more than 1.5	230,107.58	-	3.3	10.8
8	Lighting Power Density	Lighting is already optimized	-	-	-	-
9	HVAC system	Select HVAC equipment with recommended CSPF	110,055	-	14.7	1.2

10	Smart building	Select smart BMS, smart lighting, temperature and occupancy sensors, sub-metering	1,005,545.14	-	15	15.5
11	Rooftop Solar PV	Install Rooftop Solar PV	610,632	-	37	4.1
12	Plumbing design	Select dual flush fixtures and faucets which are low flow, rainwater harvesting system	136,600.88	1,236.38	-	-
13	Total		3,089,583.88	1,236.38	37 (74 including Solar PV)	10

Note: All prices include estimated labor, material and transportation cost, except plumbing design for which miscellaneous cost is reported separately. With a profit % depending on the item. Payback period is calculated based on the capital cost.

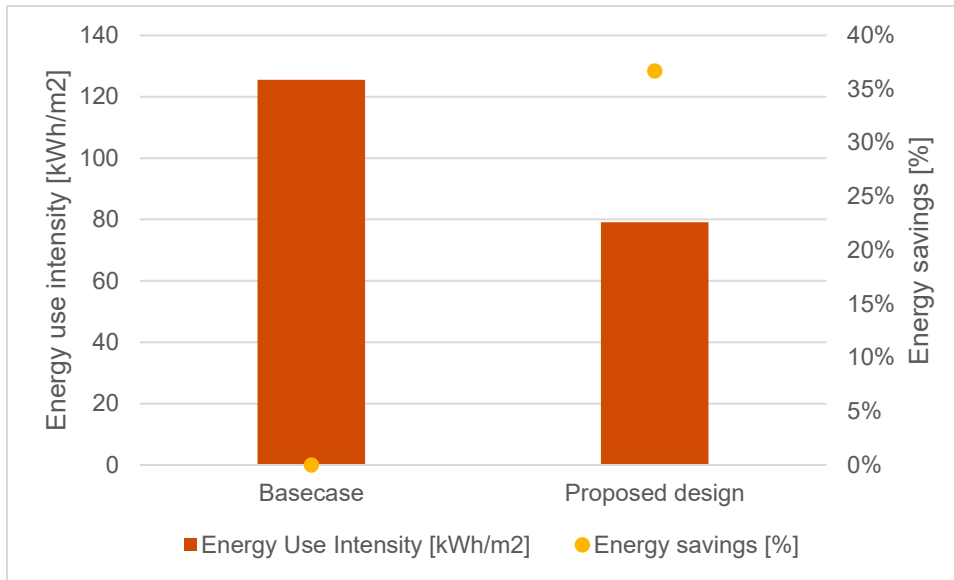


Figure 24: Comparison of baseline case with proposed design

Figure 35 shows the comparison of baseline case against the proposed design.

The proposed design yields **37% (74% energy savings including contribution from solar PV)** energy savings over the baseline case and an **EPI of 79 kWh/m²**, owing to superior values of all the design parameters mentioned in table 3. These also include the smart building features, which have a potential to generate 15% energy savings. Annual and lifetime energy savings (over a period of 50 years) would be 55 MWh and 2,764 MWh, respectively. The reduced cooling demand for the best case would be 29 TR. Implementing the proposed design would come at an additional cost of **MVR 3,089,583.88** at a payback period of **10 years**. The total additional cost would be **MVR 3,090,820.26 including miscellaneous cost**. It should be noted that the cost of implementing the best case includes the cost of efficient plumbing fixtures which do not contribute to any energy savings but is added to highlight the cost of high-performance design.

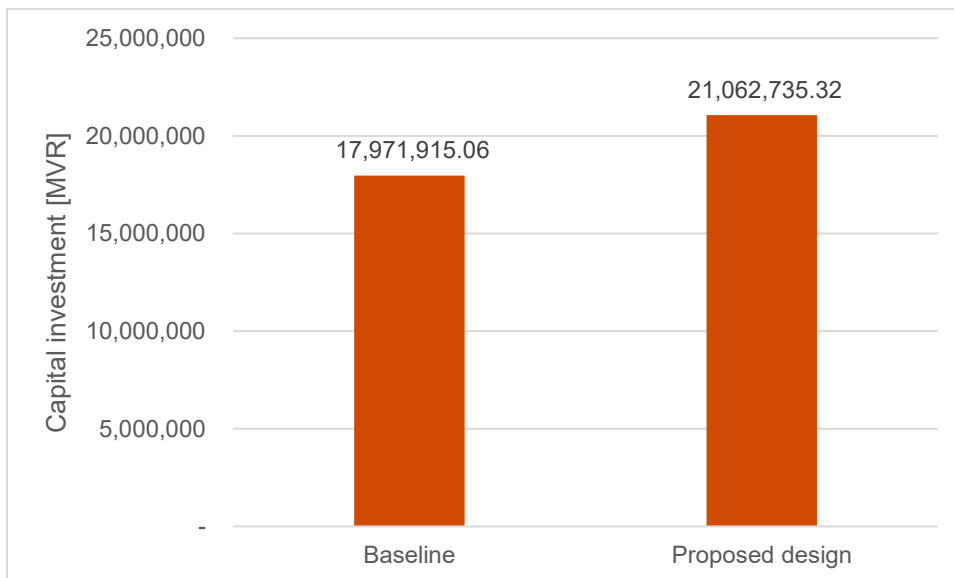


Figure 25: Comparison of capital investment for Baseline and Proposed design

The 22 kWp of solar PV system could offset additional **37%** of the total energy consumption for the proposed case. The proposed solar PV system satisfies the requirement of section 11 of the Guidelines to offset at least 2.5% of the building's total electricity consumption using renewable energy.

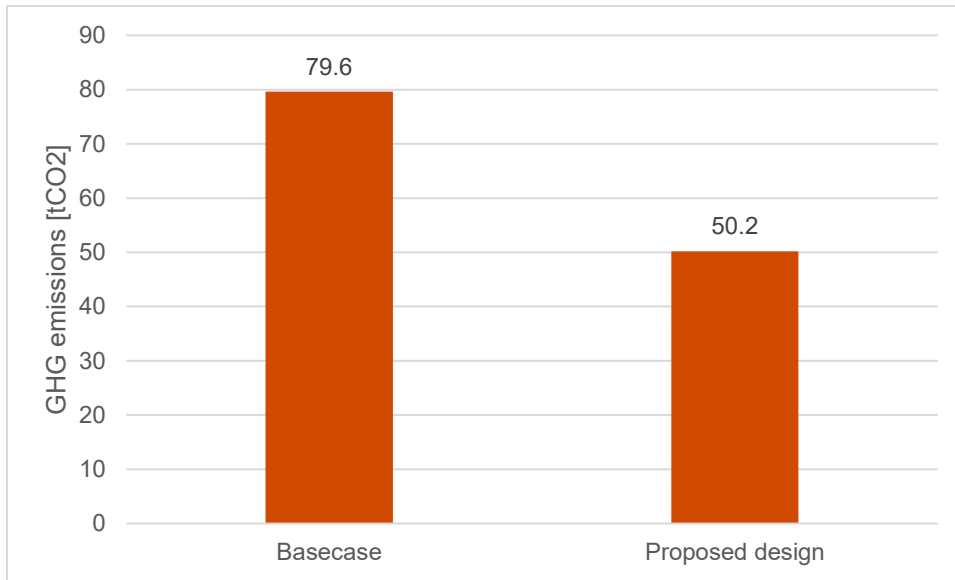


Figure 26: GHG emissions for Baseline and Proposed design

Improving energy efficiency would also reflect in the environmental footprint of the building. Due to implementation of the proposed design, MET Office would save almost 30 tCO₂ annually and 1,500 tCO₂ in its lifetime.

5. Conclusion

The project aimed at assessing the environmental performance of the current design of the MET office against the requirements set in the EE Guidelines. The project also aimed at improving the current design with energy conservation and energy efficiency measures to improve its performance beyond the standards set in the Guidelines. The current design is well-optimized for building form, optimization, window-wall ratio, window placement and mutual shading, due to which the EPI was simulated at 125.5 kWh/m². Through various building envelope improvement measures, efficient HVAC systems and controls, smart technologies and rooftop Solar PV described in section 4 and 5, there is a potential to reduce the cooling load by 22% and annual energy consumption by 37%, resulting to an EPI of 79 kWh/m². Implementing the features of the proposed design would implicate a capital expenditure of MVR 3,089,583.88 with a payback period of 10 years. Total cost including miscellaneous cost would be MVR 3,090,820.26.

Table 5: Summary of cost implication and energy savings

S. No.	Case	Cost implication (MVR)	Energy savings (%)	GHG emissions averted (tCO ₂)	Energy Performance Index (in kWh/m ² /year)	Payback period (in years)
1	Recommended design	3,089,583.88	37 (74 with Solar PV)	30	79	10

SUMMARY OF BILLS OF QUANTITIES										
	<i>Original</i>	<i>Best</i>	<i>Original</i>	<i>Best</i>	<i>Original</i>	<i>Best</i>	<i>Original</i>	<i>Best</i>	<i>Original</i>	<i>Best</i>
DESCRIPTION	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT	AMOUNT
PRELIMINARIES	975,635.00	975,635.00	193,826.25	193,826.25	332,206.25	332,206.25	69,263.50	69,263.50	1,570,931.00	1,570,931.00
EXCAVATION AND FILLING	291,980.00	291,980.00	109,060.00	109,060.00	94,005.00	95,241.38	26,147.30	26,147.30	521,192.30	522,428.68
INSITU CONCRETE WORKS	3,439,120.00	3,439,120.00	756,590.00	756,590.00	1,207,350.00	1,207,350.00	198,645.00	198,645.00	5,601,705.00	5,601,705.00
MASONRY	549,729.05	798,623.30	64,018.15	111,719.65	250,186.95	378,753.60	42,618.75	79,628.25	906,552.90	1,368,724.80
WINDOWS, SCREENS & LIGHTS	382,378.44	484,346.02	64,800.00	82,080.00	197,250.00	249,850.00	26,325.00	33,345.00	670,753.44	849,621.02
DOORS, SHUTTERS & HATCHES	433,260.00	478,236.00	27,720.00	27,720.00	198,955.56	205,219.56	59,962.41	59,962.41	719,897.97	771,137.97
FLOOR, WALL, CEILING, AND ROOF FINISHINGS	1,468,496.28	1,414,577.16	213,629.95	203,310.55	593,552.42	603,978.78	71,351.15	72,319.09	2,347,029.80	2,294,185.58
SUSPENDED CEILING	310,862.00	420,311.60	18,860.00	33,212.00	69,741.00	109,084.20			399,463.00	562,607.80
STRUCTURAL METAL WORKS							175,783.00	175,783.00	175,783.00	175,783.00
PAINTING & DECORATIONS	1,113,833.28	1,396,780.88	98,876.18	149,055.18	258,589.40	349,633.60	36,149.80	36,149.80	1,507,448.66	1,931,619.46
STAIRS, WALKWAYS AND BALUSTRADES	355,324.00	355,324.00	6,840.00	6,840.00	18,900.00	18,900.00			381,064.00	381,064.00
ROOFING							104,494.50	104,494.50	104,494.50	104,494.50
MECHANICAL & ELECTRICAL SERVICES	914,220.00	914,220.00	118,916.50	118,916.50	316,000.00	316,000.00	56,295.00	56,295.00	1,405,431.50	1,405,431.50
FIRE SYSTEM	105,170.00	105,170.00	16,678.00	16,678.00	78,323.00	78,323.00	9,252.00	9,252.00	209,423.00	209,423.00
PLUMBING	274,910.00	274,910.00	26,210.00	26,210.00	96,085.00	151,435.00			397,205.00	452,555.00
AIRCONDITION SYSTEM	353,140.00	419,892.00	49,220.00	61,491.00	51,180.00	82,212.00			453,540.00	563,595.00
LIFT	600,000.00	600,000.00							600,000.00	600,000.00
ADDITIONS AND OMMISIONS									-	-
PLUMBING DESIGN AS PER EE GUIDELINES		81,250.88								81,250.88
ROOF TOP SOLAR PV									-	610,632.00
SMART LIGHTING CONTROLS, SMART BMS, ENDUSE SUB METERING						1,005,545.14				1,005,545.14
TOTAL AMOUNT	11,568,058.05	12,369,125.96	1,765,245.03	1,896,709.13	3,762,324.58	4,178,187.36	876,287.41	921,284.85	17,971,915.06	21,062,735.32

Table 6: Summary of BoQ for all phases

Appendix

Table 7: Basic information of the MET office

Building Characteristics	
Floors	G+1 Office building
Total built-up area	1,190 sq. m
Total Conditioned area	493 sq. m
Operating schedule	Offices: 8AM to 4PM; Observatory/Watch: 24x7 Classroom: 8AM to 4PM once a week Meeting: 2 hours a day

Table 8: Inputs to the development of baseline energy model of the MET office

S. NO	Parameter	BASECASE
1	Orientation	S-N
2	Shading	Partially shaded
3	WWR	30%

4	Wall U-value	3.0 W/m ² .K (15 mm Plaster + 150mm Brick + 15 mm plaster)
5	Roof U-value	3.5 W/m ² .K (50 mm screed + 300 mm RCC + 50 mm finish)
6	Glazing U value	5.8 (Single Pane)
7	Glazing SHGC	0.7
8	Lighting Power Density	As per design
9	Equipment Power Density	As per details provided by MET
10	HVAC system	Split AC units (CSPF – 2.7), Set point 24 deg
11	Fresh Air	Air-conditioned spaces-no fresh air; Non air-conditioned spaces-Naturally ventilated

Table 9: Calculated Lighting power density for each spaces of the MET office (as per Lighting design)

Space (Ground floor)	LPD (W/sqft)	Space (First Floor)	LPD (W/sqft)
Watch office	0.20	Record	0.35
Observatory	0.20	Server	0.30
Observatory ext	0.20	Classroom	0.40

Prayer hall	0.30	Consultant office	0.15
Changing room	0.36	Dry and laundry	0.15
Repair	0.10	WC 1	0.33
Garage	0.10	WC 2	0.33
WC	0.36	WC 3	0.33
Admin	0.23	Bed	0.18
Dining Kitchen	0.28	Lobby	0.20
Data archive	0.20	WC	0.36
Offices	0.20	Atrium	0.10
Reception lobby	0.10	Living	0.60
Store	0.15	Conference	0.50

Possible construction assembly for walls

U-value: 0.9 W/m². K

Table 10: Construction assembly option for Wall U-value: 0.9 W/m².K

Materials (Outside to Inside)
Expanded Polyurethane, 20mm
Brick, 200mm

U-value: 0.6 W/m². K

Table 11: Construction assembly option for Wall U-value: 0.6 W/m².K

Materials (Outside to Inside)
Expanded Polystyrene, 32mm
Brick, 200mm

Possible construction assembly for roof

U-value: 0.6 W/m². K

Table 12: Construction assembly option for Roof U-value: 0.6 W/m².K

Materials (Outside to Inside)
Expanded Polyurethane, 76mm
Brick, 200mm

U-value: 0.3 W/m². K

Table 13: Construction assembly option for Roof U-value: 0.3 W/m².K

Materials (Outside to Inside)
Expanded Polystyrene, 110mm
Brick, 200mm

Table 14: Case studies on impact of smart building technologies

Case Study	Technologies used	Environmental	Economic	Social
Herman Miller International Headquarters, UK	<ul style="list-style-type: none"> · Computerized ventilation system · Motorized fanlight opening for windows · Automatic night-cooling strategy · Sensors in the floor slabs · Water meters · Sensor controlled lighting strategy · Photographic identity cards · CCTV surveillance · Electronic document management system · Sub-metering 	Office space with intelligent lighting strategy uses almost 4 times less energy than retail space of smaller floor area, with conventional lighting. Water wastage is prevented	Intelligent lighting strategy and a computerized ventilation system helped increase operational savings.	Staff safety, efficiency and productivity improved

<p>The U.S. Green Building Council (USGBC) Headquarters, USA</p>	<ul style="list-style-type: none"> · Lighting system controlled off an IT backbone · Motorized window shades · Occupancy sensors for lighting and plugs · Automated temperature modulation · Integrated lighting and HVAC system · Ventilation system with two-position diffuser · Sub-metering 	<p>60% less energy and 40% water savings than a typical code-compliant office. Integration of intelligent lighting controls and automated temperature modulation resulted in a 15% drop in energy usage.</p>	<p>US\$96,000-per-year savings and a low payback period.</p>	<p>Increased staff productivity</p>
<p>Genzyme Centre, USA</p>	<ul style="list-style-type: none"> · Automated curtainwall glazing system · Automated blind system · Natural light enhancement system · Ventilation system with CO2 sensors · Automated faucets · Soil sensors for irrigation · Building-commissioning plan 	<p>The daylight dimming system reduces lighting energy use by 45%. The building uses 32% less water than a comparable office building and saves 753,297 litres of water a year.</p>	<p>The building management system has reduced the overall energy cost by 41%.</p>	<p>The high performance curtain wall glazing system and the natural light enhancement system maximise natural daylight exposure to 75% and bring in fresh air.</p>
<p>Asia Square Tower 1, Singapore</p>	<ul style="list-style-type: none"> · Integrated Intelligent Building Management System · CO2 sensor system · Photo sensors · Air Handling Units with ultra-violet emitters · Zoned HVAC system · Property management system · Smart card access system with proximity card readers · Automated destination- 	<p>The Intelligent Building Management System (IBMS) improved energy efficiency.</p>	<p>Reduction in operating costs by 20%.</p>	<p>State-of-art security, fire protection and property management systems ensured greater business efficiency</p>

	<ul style="list-style-type: none"> controlled lift system · CCTV surveillance · Guard Tour System · Fire Protection System · Multiple communications and information risers 			
Taipei 101 Tower, Taiwan	<ul style="list-style-type: none"> · Energy Management and Control System · Water management system · Integrated electronic security systems · CCTV surveillance · Computerized smartcard access control system · Visitor Access Kiosk System · Optically controlled gates · Automated destination-controlled lift system · Fire Protection system · Smoke exhaust system · Multiple communications and information risers 	The Energy Management and Control System (EMCS) reduces energy consumption by 33.41 million kWh per year and potable water usage by 30%, saving 28 million litres of water a year.	The Energy Management and Control System (EMCS) saves more than US\$2 million per year.	The integrated security system comprising of surveillance, smartcard access control, visitor access kiosk and fire protection systems provide the tenants with advanced safety features.
Conclusion	Use of intelligent systems has reported benefits on the environmental, economic and social fronts.	Communication between various building systems through a centralized system can lead to increased energy savings as opposed to a stand-alone system.	The return on investment due to the energy and operational cost savings have reduced the payback period for most of the intelligent building equipments.	Smart features of an intelligent system can enhance the overall well-being of people which translates to improved efficiency and productivity in the workplace.