Design Guide for Energy Efficient Buildings

Guidebook 2

Non-Residential buildings of less than 500 sqm

Contents

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Introduction

As Mauritius embarks on its sustainability agenda to foster energy efficiency and a move towards more green practices and renewable technologies, either under the umbrella of the Maurice Ile Durable (MID) initiative or through efforts of individual organisations, a key aspect in moving in the right direction lies in changing the conventional approach of construction projects. This Guidebook was commissioned by the UNDP/Global Environment Facility (UNDP/GEF) and its partners the Ministry of Energy and Public Utilities, the Ministry of Public Infrastructure and the National Development Unit, Land, Transport & Shipping in Mauritius under the programme entitled "Removal of Barriers to Energy Efficiency and Energy Conservation in Buildings".

The Guidebooks and have been prepared by Sarah Wigglesworth Architects in collaboration with Archineers Consulting and Pro-Design Engineering. Through discussions and dialogue with the Mauritius client group and the project's local partners, the design principles and approach embody leading international design and construction practice in the specific area of energy efficiency.

The aim of this document has been to develop a Guide to Energy Efficient Design for modest-sized non-residential buildings less than 500m^2 (below the minimum covered by the Mauritian Building Regulations). The guidelines stated in this document embody leading international design and construction best practice in the specific area of energy efficiency. The building typologies have been identified as follows:

- Schools;
- Community Health Centres;
- Commercial;
- Offices.

The work herein has been developed in the context of projects that consider new approaches to energy generation and revisions to the Building Regulations of Mauritius, documents that will form the framework under which the Energy efficient designs will be procured. The Guidebook includes illustrative examples of design principles that can be adopted to promote energy efficiency and make the most of natural resources, for examply, natural ventilation and daylighting.

The Guidebook has been tailored to compliment the new and existing statutory guidelines as follows:

- Building Control Bill
- Guidelines on Passive Solar Design
- Guidelines on Duct and Piping
- Fire Safety Guidelines of the Fire Department of Mauritius

This Guidebook is one of a series of two Energy Efficient Design Guidebooks for the Mauritian context of smaller buildings (<500m^2) that do not need to demonstrate compliance with building regulations. This Guidebook focuses on the NON-RESIDENTIAL sector; the other book addresses residential buildings – both focusing on buildings with a total floor area less than 500m^2.

The content and scope of the guidance has been discussed extensively both internally with the local project partners – UNDP, Government of Mauritius, stakeholder groups – and directly with the consultant team. The Guidebooks that are now complete represent a united approach that has been garnered throughout the project.

Exclusions

The focus of the Guidebook is on energy efficiency for smaller buildings in the tropical climate of Mauritius. A structural engineer has not checked the work, and the advice should be sought before carrying out any construction work, especially given the extreme weather events that occur on the island. Any recommendations made that relate to structural engineering issues will have to be externally checked and verified to be safe by a suitably qualified structural engineer. The project team does not accept any responsibility or liability for the structural integrity of structures proposed.

Further exclusions relate to capital costing of the construction process for the guidance designs. Planning advice permission should also be considered on a case-by-case basis, however the concept designs contained have been developed within a general understanding and appreciation of local planning bylaws.

1.1 Executive Summary

This Energy Efficient Design Guidebook for Targeted Non-Residential Buildings of total floor area less than 500m^2 is broad ranging: it provides an initial investigation in the first principles of climate and its impact on orientation; and then gets into the detailed considerations required of thermal comfort and energy efficient design.

The purpose of the Guidebook is to define a clear approach that should be followed to deliver a building that is energy efficient for different user groups in the tropical climate of Mauritius. The design principles are listed in a logical approach, so that they are straightforward to follow and implement by school boards, healthcare trusts, developers, builders and statutory authorities.

The Guidebook explains the key principles behind low energy design that are applicable to all buildings. The designs for non-residential buildings are intended to illustrate how these principles can be applied in practice: the principles should not be considered the only solutions to the issues of resource conservation, or used outside of the context of an understanding of the rationale for low energy design.

The design principles have been gathered through direct experience of Mauritian life, academic research, professional and industrial feedback from local experts, detailed review of international best practice from tropical regions and directly from Mauritian Government officials and steering groups throughout each stage of the project.

The main factors that inform this approach has been to demonstrate how energy efficient buildings can work within the tropical Mauritian climate with clear replicable methods that provide shelter from excessive overheating associated with the solar gains, whilst capturing the prevailing Trade winds to drive natural ventilation and cooling.

The goal of the project is to develop clear guidance to enable non-residential buildings to operate without the need for mechanical systems – such as ventilation and air conditioning – to improve energy efficiency. The guidance is intended to provide comfortable, secure accommodation that can operate in passive mode as much as possible, where no electrical powered, complex building systems are required – saving both operational and capital cost.

The project team has focused effort on ensuring that the proposals within the Guidebook are easily constructed from materials readily available in Mauritius. This is primarily concrete block and reinforced concrete – however further investigations have been carried out into the use of other more sustainable materials, such as 'American Blocks', timber and rammed earth.

Each principle highlights a distinct, focused factor to improve energy efficiency and improve well-being in the most economical manner. From a practical perspective, it is envisaged that in some cases, not all principles will be integrated at the same time. In cases such as this, the builders, end-users and developers will be able to select the most appropriate option for any given building project.

In most cases, the design principles can be achieved through a variety of solutions, and it is hoped that this feedback will continue through the construction and occupation of the new non-residential buildings in the forthcoming years. Each solution has its own merits, be it in terms of lowest capital cost, lowest maintenance, most effective or most durable. Informative feedback from the Mauritian Government and practitioners has been helpful in the review of these solutions.

1.2 Integrated Design Process

The key to achieving a sustainable design is to adopt a holistic mindset so that elements of the building are made to work for each other rather than against each other. This holistic approach is commonly termed an integrated design process (IDP), which has been the basis of the work presented in this Guidebook. The IDP is one where the client, architect, engineer and local advisor have worked together to explain and understand what is needed to produce energy efficient buildings in Mauritius.

Based on this approach, the reader is encouraged to apply the principles outlined in this Guidebook through customising and adapting the design drivers for their specific project. This can be achieved once one becomes familiar with these principles and develops a clear understanding of their underlying basis. So the goal of this Guidebook is two-fold: (1) to present the principles that can be used to achieve a comfortable, low energy and sustainable environment, and (2) to raise awareness in the public that energy efficiency is cost effective and the preferred solution.

1.3 Low Energy Design Principles

In addressing the Terms of Reference for this Project this team has taken as their starting point the following issues:

- Climatic factors pertaining to Mauritius;
- Expectations and requirements of clients in the non-residential sectors;
- Availability of low cost materials
- Relative expense and unavailability of technologies such as insulation, timber, double glazed windows and low energy technology
- Prevalence of a culture of self-build.

Our key aims in developing design principles that keep costs to a minimum whilst offering a comfortable environment for occupants, have been to use:

- Low-tech, simple, self-build technologies wherever possible.
- Available climatic conditions to reduce reliance on energy

1.4 Design Principles in Mauritius

Through understanding of the tropical climate, the buildings will be designed and constructed to suit their local context. In Mauritius the key drivers are high temperatures and high humidity, and designs need to aim at reducing both in the most cost-effective way. Additional hazards that need accounting for include occasional cyclones and the prevalence of insects.

2

Site-Specific Design

2.1 Bio-Climatic Design

Climate Parameter	Element of building design
Humidity	*Building architecture (fabric and glazing), ventilation and air-conditioning strategy*
Rainfall	*Plumbing and ventilation*
Solar Path	*Building architecture (layout, form, orientation, external and internal shading), lighting/daylighting design*
Solar Radiation	*Building architecture (fabric and glazing), ventilation and air-conditioning design*
Wind Regimes	*Building architecture (layout, form, orientation), ventilation design*

Table 1: Correlation between climate and building design

The holistic design of a sustainable building typically starts with an in-depth study of the general trends in variation of climatic parameters at the site location. Table 1 summarises the main climatic parameters to be considered, with the corresponding impact on the respective elements of building design.

The building architecture (layout, form, orientation, fabric and glazing) has a direct bearing on the thermal and visual comfort of the building occupants and in turn influences the design of the building systems (lighting, ventilation and air-conditioning).

2.2 Two Climatic Zones in Mauritius

Figure 1: Map of Mauritius showing location of Vacoas and Plaisance

\Plaisance and Vacoas have been set as representative locations for Climate Zone 1 (warmer coastal areas) and Climate Zone 2 (cooler central plateau area) respectively in the Building Control Bill and the Energy Efficiency Building Code, and for consistency the same basis has been used in this Guidebook.

The two climatic zones present differing characteristics and require different solutions.

Elements of building design will be discussed in order to describe and illustrate how energy efficiency can be delivered in the two climate zones of Mauritius.. The following section presents an analysis of the climatic parameters for the two climate zones – to investigate similarities as well as disparities that may affect the preferred design solution for each zone.

2.3

Climate parameters for Vacoas and Plaisance

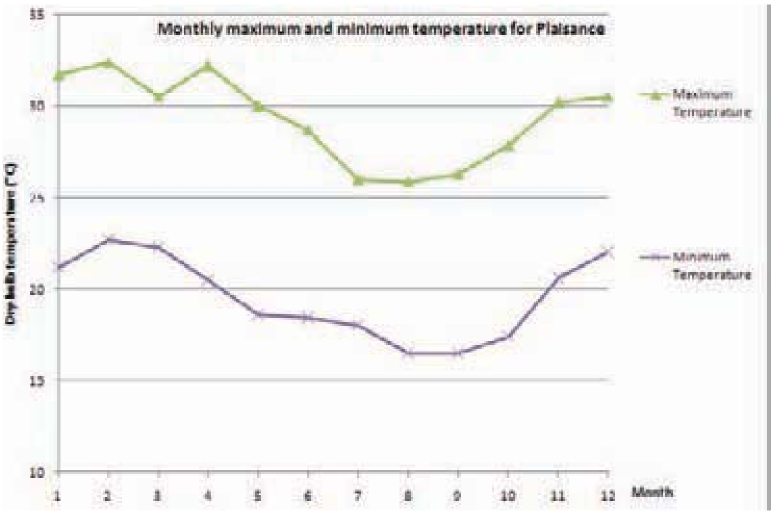


Figure 2: Plaisance: Variation of monthly minimum and maximum dry-bulb temperatures

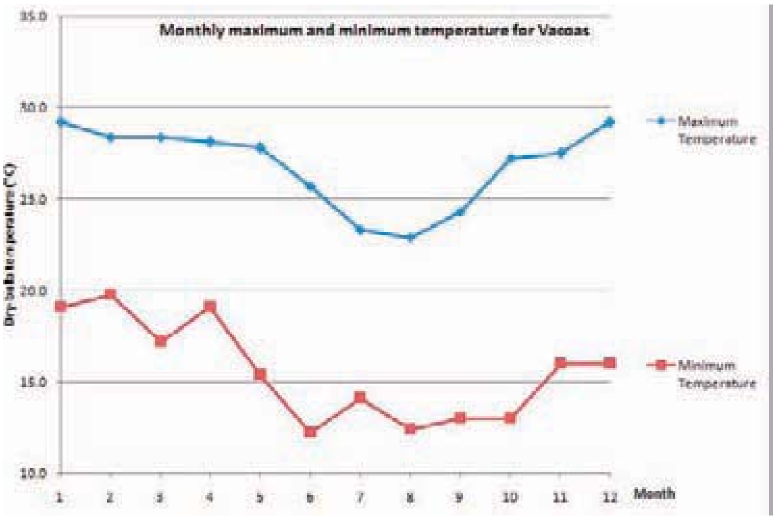


Figure 3: Plaisance: Variation of monthly minimum and maximum dry-bulb temperatures

The climate data provided by the Mauritius Meteorological Services, http://metservice.intnet.mu/ in line with International best practice standards has been compared for the two climate zones. Figures 2 and 3 show the monthly maximum and minimum dry-bulb temperatures for Plaisance and Vacoas.

The difference in the graphs shows following:

- Summer temperature: Plaisance 2-3°C hotter than Vacoas;
- Winter temperature: Vacoas 4-5°C cooler than Plaisance.

Another important observation, based on 23°C cooling design temperature and 15°C heating design temperature, is as follows:

- Plaisance requires cooling all year and no heating;
- Vacoas requires cooling for most of the year at lower capacity than Plaisance;
- Vacoas may need heating for certain months.

2.4

Degree Days

A Degree day is a unit used to determine the heating requirements of buildings, representing a fall of one degree below a specified average outdoor temperature (usually18°C or 65°F) for one day.

The Cooling Degree Days (CDD) and Heating Degree Days (HDD) for Plaisance and Vacoas with base temperatures of 23°C and 15°C respectively can be used to get a quantitative indication of the absolute and relative importance of heating and cooling for the two climate zones. In literature, these parameters are commonly abbreviated as CDD23 and HDD15. The values obtained are given below:

Plaisance:
HDD15 = 0°C; CDD23 = 18,397°C

Vacoas:
HDD15 = 79°C CDD23 = 4,341°C

These cooling degree-days figures show a considerable difference in heat gain between Plaisance and Vacoas. However, it is also evident that even for Vacoas, methods of reducing heat gains remain a priority for both climate zones.

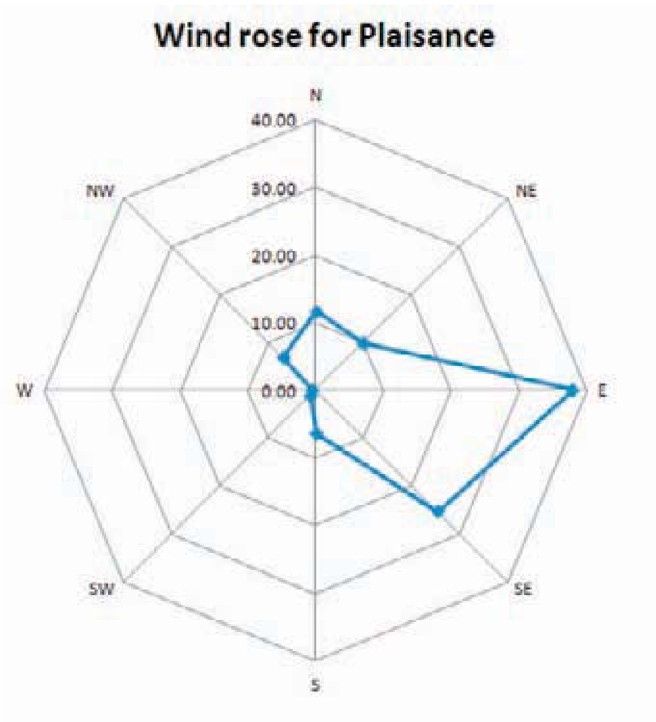
For Vacoas, it would be beneficial to design the building elements to reduce heat gains to the spaces in summer while allowing useful heat gain in winter. For Plaisance, the main priority will be to keep heat out at all times.

2.5 Wind regimes

The wind regime and its interaction with the mountain ranges yield a different set of climate factors for the north, east, south and west coasts, despite all being warm regions. The prevailing wind regime over the island is the south-east trade wind, which because of the central plateau means that the east and south coasts are windward whereas the north and west coasts are leeward.

The wind blows clouds over the central plateau, which condenses and yields the high rainfall intensity over the high grounds. This also explains why the north and west regions are drier compared to the rest of the island. Due to relatively small size of Mauritius, the humidity level is generally high over the whole island, with averages of 70-80% being common, and values above 90% occur routinely over the Central Plateau.

Figure 4 shows wind roses for Plaisance and Vacoas. They illustrate the predominance of the east and south easterly wind directions. This has direct bearing on the siting of openings to foster natural ventilation and the general layout of the spaces as discussed in the following sections.



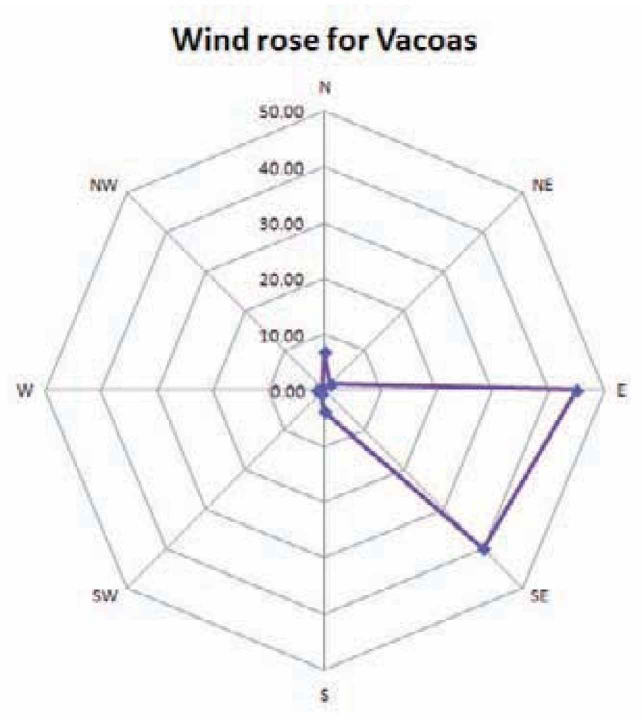


Figure. 4: Wind roses for Plaisance and Vacoas

2.6 Solar path for Mauritius

The solar azimuth and elevation (altitude) angles for different hours of a day and each day of the year needs to be investigated closely as the path of the sun directly influences the heat gains into the building. The definition of these two solar angles are illustrated in Figure 5 where the observer is typically the building under consideration and the azimuth and altitude angles shown allow to uniquely identify the angular position of the sun with respect to the building. The azimuth angle is an angle defined in the horizontal plane containing the building and is the angle swept clockwise or anti-clockwise from a reference. The reference chosen is normally the north, meaning north is an azimuth angle of 0° and east has an azimuth angle of 90° clockwise of north and west an azimuth angle of 90° anticlockwise of north. The other angle is then the elevation angle from the horizontal plane, defined in a vertical plane, to reach the sun. This means that, for a particular building, during the day, the elevation is positive being above the horizontal plane defined and negative during the night.

A solar chart is a good way to depict the variation of the solar angles over a year. The sun has its highest elevation angle at a point of the year known as the summer solstice (typically 21st December) and its lowest elevation angle at a point known as the winter solstice (typically 21st June). The solar chart for Mauritius is shown in Figure 6. For example, it will be observed that the sun rises at around 6.30 a.m. and sets at around 5.30 p.m. on the winter solstice day in June with a maximum elevation angle of around 45° at noon. The corresponding movement of the sun at the summer solstice in December yields sunrise and sunset times at almost 5 a.m. and 7 p.m. respectively with a maximum elevation angle of around 90° at noon.

This difference of 45° in the elevation angles of the summer and winter solstices shows the significant change in the solar path over the course of a year. The solar chart gives a clear representation of the orientations of the building which receive low and high angle sun respectively. The hourly variation in solar angles can thus be

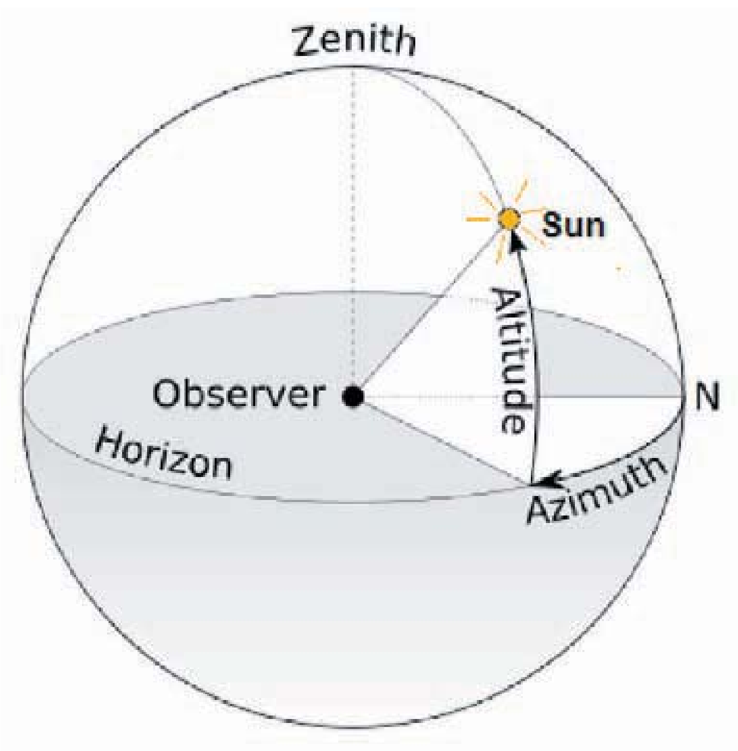


Figure 5: Definition of solar angles (adapted from Wikipedia)

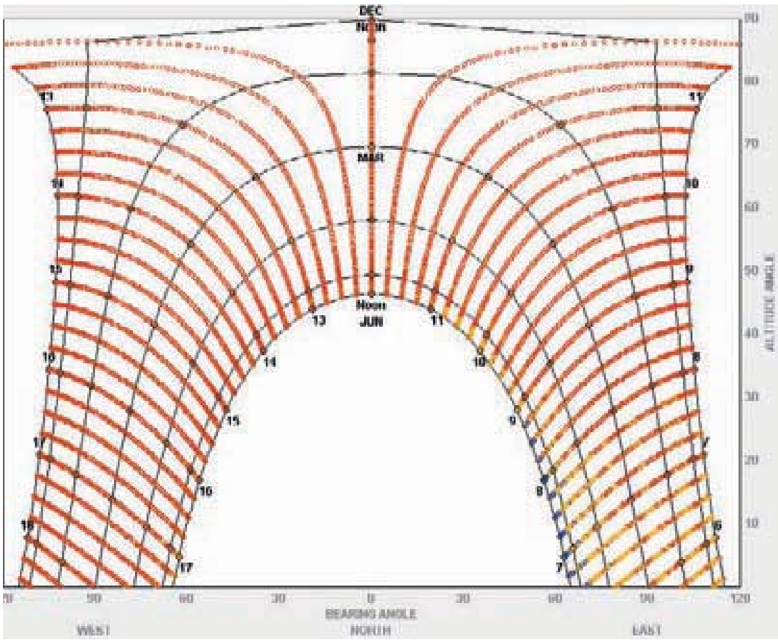


Figure 6: Sun path for Mauritius

used to size external shading devices for facades which receive high angle sun to either totally block direct solar radiation through openings or allow useful heat gain to the internal spaces in winter over certain periods of the day. This has been an important design consideration for sizing overhangs for the north façade for Plaisance and Vacoas, where the goal has been to limit heat gains as much as possible for Plaisance and provide a shorter overhang for Vacoas to block direct solar radiation in summer and allow useful heat gains in winter.

Furthermore, through the solar chart, it can be ascertained that the south does not receive direct solar radiation throughout the year whereas the east and west receive low angle sun, which cannot be blocked by fixed shading elements.

2.7 Orientation and Heat Gains

Due to the small size of Mauritius, the same solar path can be used for both climate zones with negligible loss in accuracy. The heat gains obtained for equally sized areas of a building as a function of orientation are generally similar for the two climate zones of Vacoas and Plaisance. Whilst there are minor differences for Plaisance and Vacoas, the common principle is that the preferred orientation for buildings to minimise solar gain would be, where practical, to orientate the building with the main facades facing the north and south orientations, that is, with the longer axis lying along the east-west orientation.

The external sources of heat gain in a building are conduction through the wall and roof fabrics, direct solar radiation through openings (e.g. windows and doors) and infiltration of air through cracks and leaks in the building envelope.

The peak summer heat gain occurs when the sun rises south-east instead of east (as shown on the solar path diagram). The lower sun angle at the beginning and end of the day delivers considerably more solar radiation along the south-east and east, and similarly along the north-west and west directions.

So in general, the aim of laying out the building should be to maximise spaces along the north (which can be easily shaded with horizontal louvres) and south facades and minimise areas along the east and west sides. Despite being shown to have a relatively high heat gain, regularly occupied spaces, such as classrooms, can be located in the south-east. The wind blows from this direction, causing a cooling effect, and there is no direct solar gain.

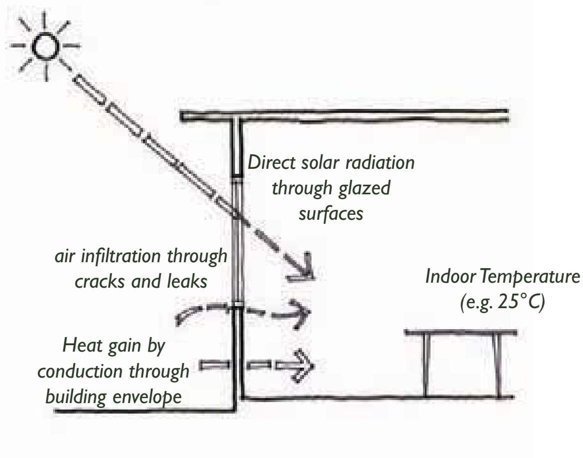


Figure 7: Sources of heat gains in buildings

2.8 Considerations of Building layout

To limit excessive heat gains from the sun, it is preferable that regularly occupied spaces such as offices, classrooms, clinic and shops not be situated along the northeast, east and west orientations as it harder to block the sun from entering along these directions. Other spaces such as toilets and storerooms can be located in these areas.

However, given that the prevailing direction of wind is south-east, toilets are better situated along the west and northwest orientations to prevent foul smells being carried through the building.

This general rule serves as a good starting point for setting the preliminary layout of the building. However, it will be found that it is not always possible to exclude regularly occupied spaces along the heat prone orientations, principally due to space limitations and constraints laid by site geometry. Mitigating measures need to be taken to limit heat gains where this cannot be avoided. The next section introduces a series of measures that can be effectively applied to tackle the problem of heat gains in these areas. Thereafter, the concluding sub-section discusses how these techniques can be applied for various configurations of building layout.

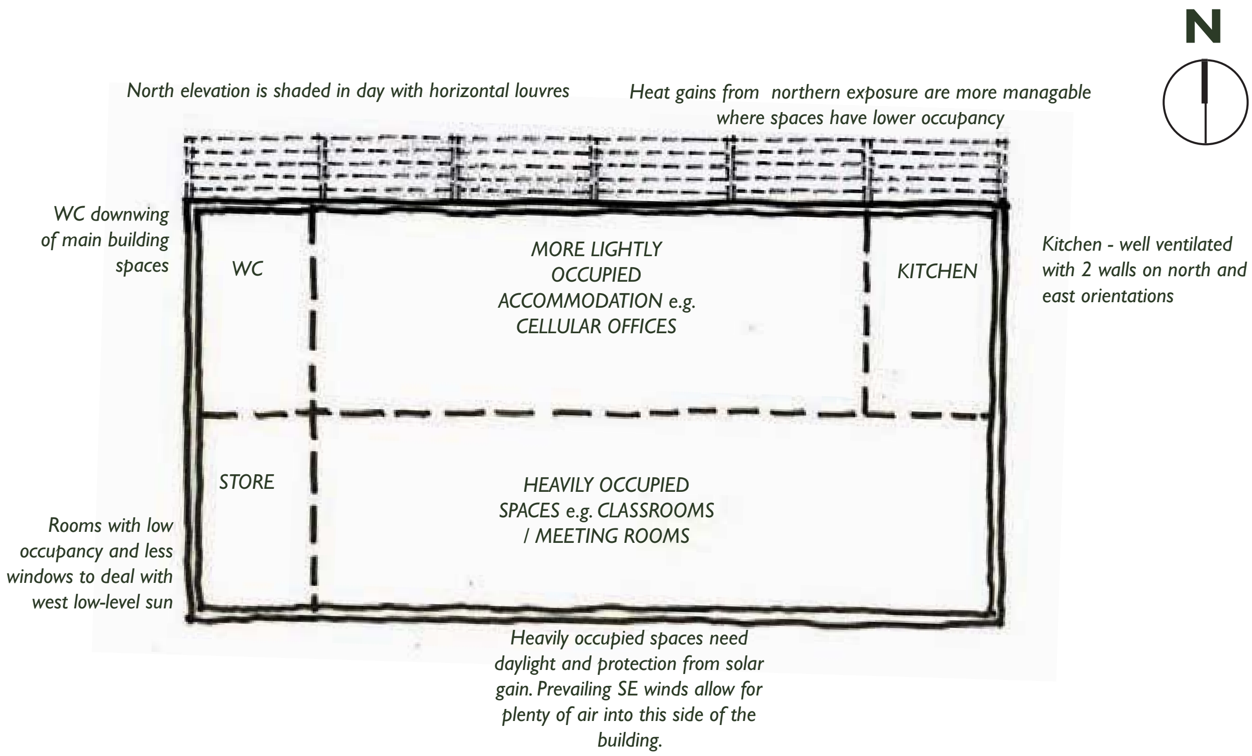


Figure 8: Recommended layout for regularly occupied and ancillary spaces in a dwelling house

3

The Building Envelope as Climate Modifier

3.1 Introduction

The previous section shows clearly that for both of the climate zones considered in this Guidebook, there is a primary need to control and reduce overheating in buildings to maintain comfortable conditions.

This section describes various design approaches that assist in this aspect, for given locations, orientations and climatic zones. The main driver is to understand how the building envelope – specifically walls, windows, façade and roof – can function as a modifier of the external climate between exterior and interior occupied spaces.

The approach to improving energy efficiency for the non-residential buildings has been to optimise a building's passive cooling potential through thermal mass, natural ventilation and shading. If the recommendations of this report are followed correctly, it is possible that air conditioning units should not be required, or at the least, they will be smaller than current practice.

3.2 Current Traditional Practice

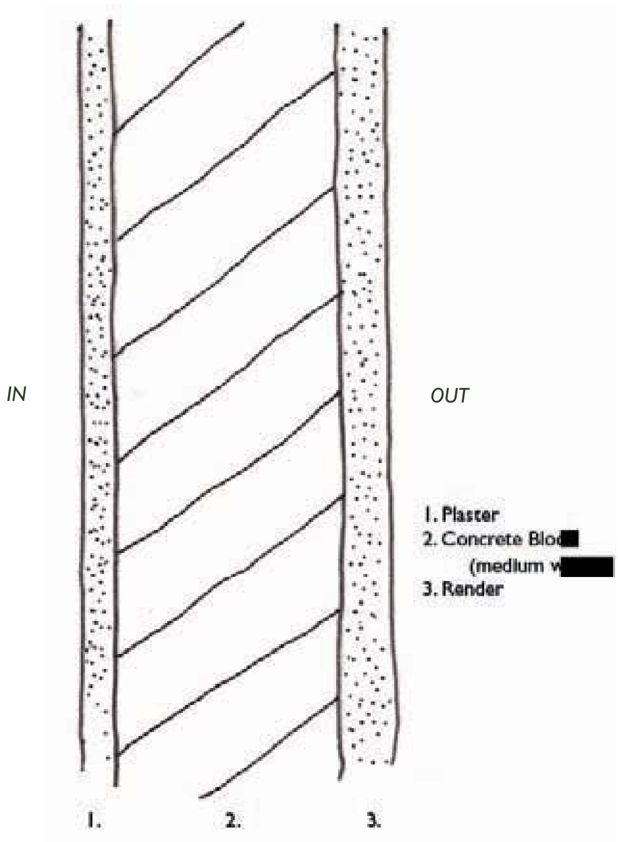


Figure 9: Typical construction for wall, with rendering on either side of concrete block (U-value = 1.83 W/m^2°C)

Buildings made of concrete blocks and cast concrete slabs are common in Mauritius, and have been found to be very resistant to cyclonic conditions.

The most commonly used construction fabric is a 150mm/200mm block construction rendered on both sides as shown in Figure 9.

This construction has a high thermal mass that slows down the rate at which heat is transferred through the material. It has been shown that it takes around six hours for the heat absorbed through direct solar gain to be transmitted to the interior surface.

The impact upon thermal performance of this time lag – or decrement factor – associated with thermal mass, needs to be carefully considered during the design stages of the building. One of the critical reasons for this is because the six hour time lag cycle could mean that the heat that has been building up through the day could be transmitted into the interior of the building when it is still being used.

The decision to guard against this solar exposure to limit heat gain, is program specific. That is: the activity in the building zone should dictate the need for shading or insulation. This point is illustrated in the following example:

School classroom:

- Hours of occupancy: 6 hours (8am-2pm);
- Classrooms empty within the 6 hour limit.
- Therefore shading/insulation could be reduced as a construction cost saving;
- Risk: 'after school' uses in the classrooms may be uncomfortable.

With a direct approach for energy efficient, this Guidebook presents ways in which the popular concrete block constructions can be made to transmit less heat to the interior space. Further more sustainable alternatives to concrete as a construction material are presented in Section 10 of this Guidebook.

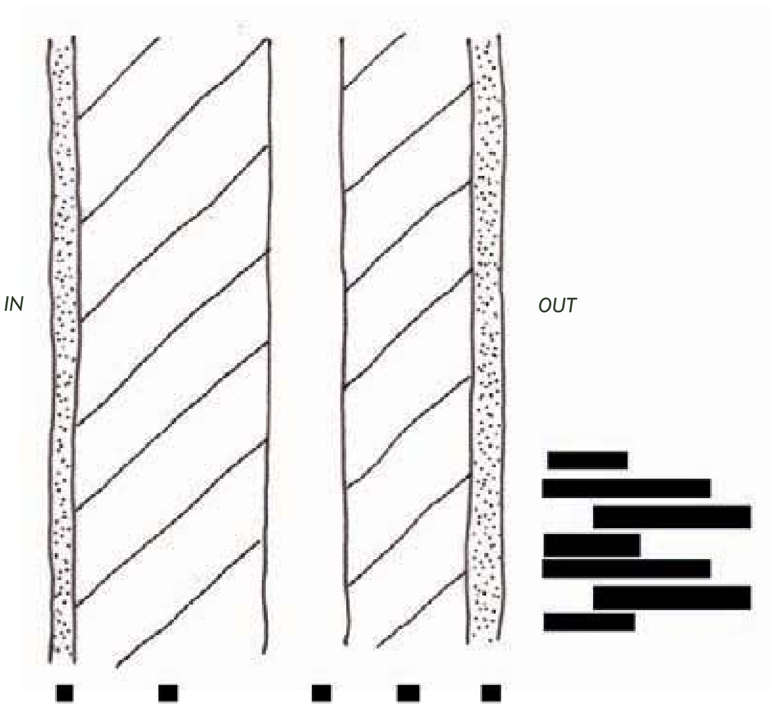


Figure 10: Reducing heat gain by using a Sandwich Wall (U-value = 1.08 W/m²°C)

3.2 Improving Energy Efficiency: Walls & Façades

An effective method to improve the performance of the building envelope is to build a double wall, typically known as a sandwich wall, with an air gap between two layers of concrete blocks as shown in Figure 10.

As illustrated above, both climate zones need to limit heat gains in summer, so this type of wall construction will be beneficial for both regions. Simulations have been carried out without shading device and with 25% glazing on all facades. Using a sandwich wall with a 50mm air gap has shown a reduction in heat gain of over 10 % for both climate zones compared to a normal block wall.

"Using a sandwich wall with a 50mm air gap has shown a reduction in heat gain of over 10 % for both climate zones compared to a normal block wall."

Further development of improved building fabric to limit heat gains, the air gap can be filled with insulation to further decrease the amount of

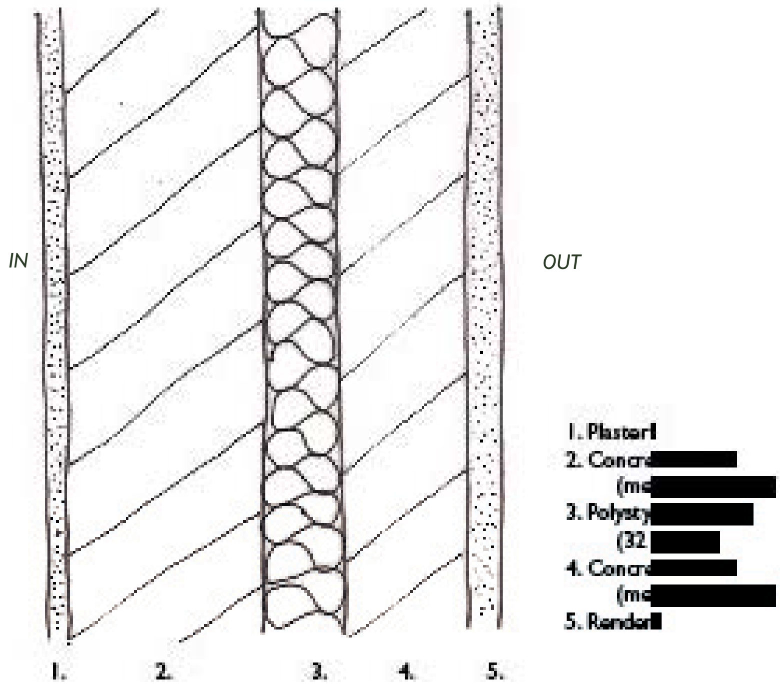


Figure 11 : Improving envelope thermal performance using insulation in the cavity (U-value = 0.443 W/m²°C).

heat allowed to be transmitted from the exterior to the interior. Figure 11 shows a construction with two layers of blockwork as before, but with the air gap filled with thermal insulation. This material is available on the local market, and is known to have a very positive environment rating based on life-cycle assessment.

This measure further improves the thermal performance of the wall, leading to over 15% heat gain reduction in both climate zones over the single layer normal wall construction. Life-cycle cost analysis has shown that thickness of 35-50mm of polystyrene is a cost effective investment when weighed against a reduction in air conditioning energy.

In an unconditioned building, the return is measurable in terms of better occupant comfort. Further guidelines on using insulation are provided in the following sections.

3.4 Insulation

"Life-cycle cost analysis has shown that thickness of 35-50mm of polystyrene is a cost effective investment when weighed against a reduction in air conditioning energy."

Although an extremely effective product for reducing heat gains, the high cost of building insulation currently prohibits its mainstream use on Mauritius such that insulating a building would give a long payback period (see glossary).

Insulation materials include the following, as shown in Table 2 below. These have been appraised to give a comparison of different types.

Currently, there are no insulation products manufactured in Mauritius, however some is made on Reunion Island. Mauritius has plenty of material out of which insulation could be manufactured (palm, sugar cane and other crop or animal-based material). Developing this new industry could help the Mauritian economy while also helping reduce energy demand.

Insulation material	Thermal performance	Embodied Energy	Durability	Capital Cost
Fibreglass batts	Medium	Low	Medium	Medium
Rockwool	Medium	Low	Medium	Medium
Expanded Polystyrene	High	Medium	High	Medium
Extruded Polystyrene	High	High	High	High

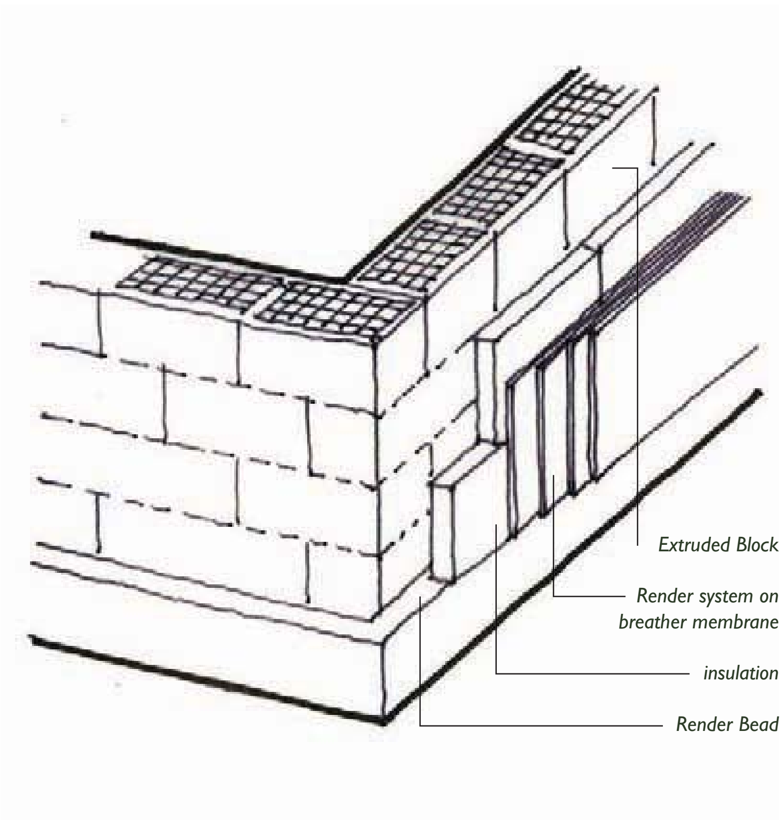
Table 2. Comparison of insulation materials.

3.5

Building Openings and Minimum Surface Area

Climate Zone	Minimum glazing ratio[1]
1	25%
2	15%

Table 3: Minimum glazing ratio for two climate zones.
1 Percentage of façade area



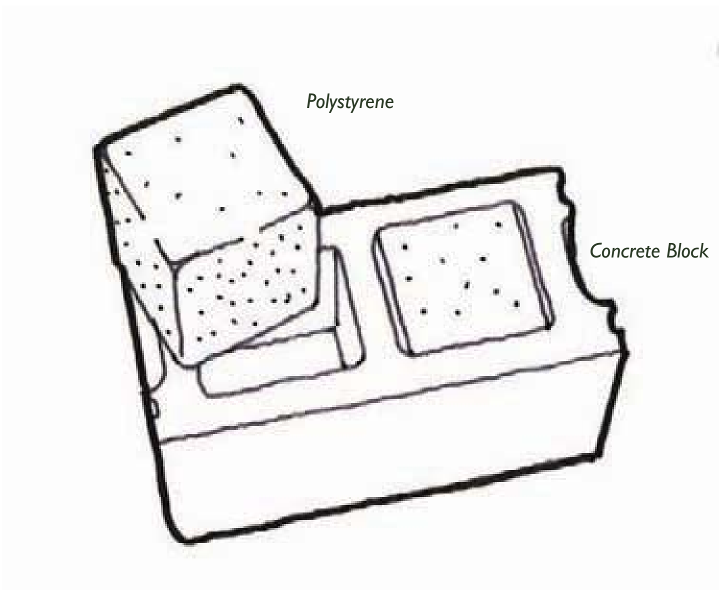


Figure 12: Insulation Materials

Openings play the essential role of providing a visual and ventilation link to the exterior, both of which have been shown to have a profound effect on the well-being of the occupants. By properly sizing and siting openings around the building facades, the building users can be given access to external views while allowing air to naturally circulate within the internal spaces and natural light to get in.

However, glazed openings are notorious for contributing significantly to heat gains. Therefore, whilst trying to optimise daylight penetration and views, particular attention needs to be given to preventing solar heat gain. To reduce heat gains from windows, **minimum** (i.e. the facades should have glazed areas greater than equal to the values given) for the two climate zones should be observed, in accordance with table 3.

Based on the solar path analysis presented earlier, it is clear that glazing along the east and west facades are harder to shade due to the low angle of the sun.
The south façade is always in shade (apart from during higher summer, and then only at he end and beginning of the day), which means that there is potential for more glazing, e.g. 35% to maximise views and daylighting. The use of daylight in non-residential buildings is a more important factor, as south light is 'glare-free' and means that clear, diffuse light enters the space, minimising the need for artificial light. As the sun will shine on them throughout the day, windows on the north façade need careful attention. Some devices for limiting solar gains are described below:

3.5.1

Recessed Window Frames

The type of frame used for the window helps to reduce solar heat gains. For example, the glass component of the window should be located as close to the interior wall surface as possible, thereby increasing the depth of the window reveal and improving the natural 'self shading' characteristic.

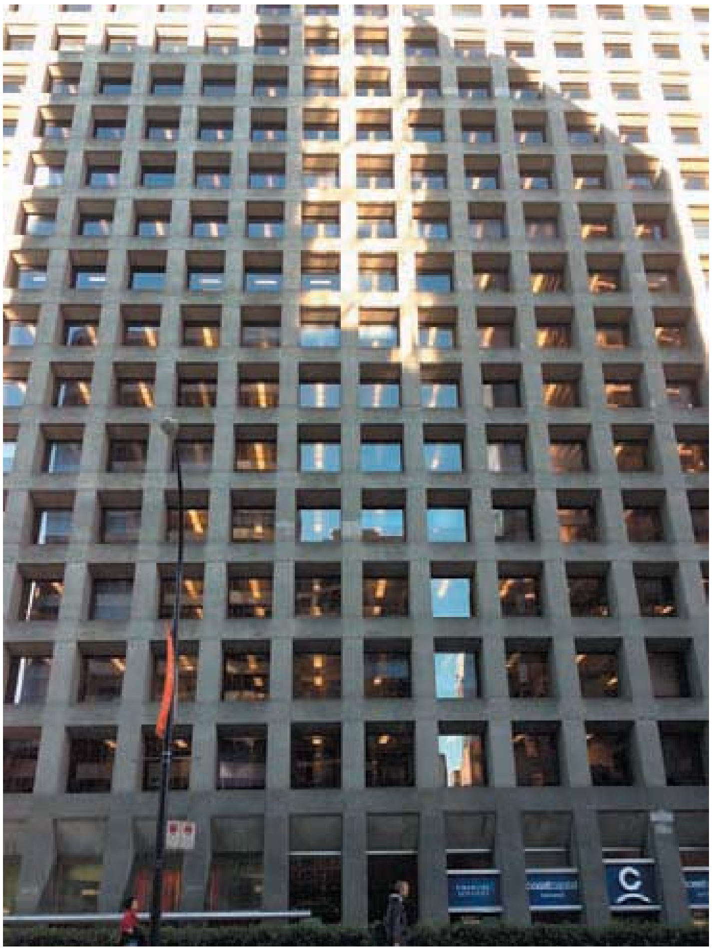


Figure 13. Recessed windows on office building, Vancouver, BC.

3.5.2 Glass Properties

The quality of the glazing is also important. Heat gains through single pane glazing are considerably higher than double-glazed window panes. To specify better glazing products, it is important to consider the following physical criteria:

- Thermal conductivity (U-value)
  Lower U-value = better energy performance. Typical good practice windows are for 4.0 W/m^{2}K (single glazed) and 2.0 W/m^{2}K (double glazed).

- Light transmission (%)
  High proportion of light transmission is favourable for energy efficient buildings. Typical good practice range is 70-80% (or better).

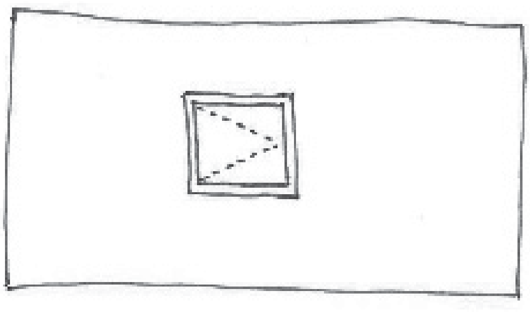
- Heat transmission (%)
  Modern glass will let light through but will control heat transmission – also referred to as the solar heat gain factor (SHGF). Good practice for Mauritius would be in the range 30-40% SHGF.

For further ways of shading openings, see section 3.8.

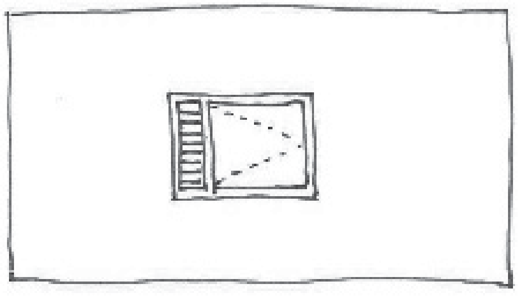
3.5.3 Secure grilles/louvres for natural ventilation

In some instances, the cost of opening windows can be a limiting factor to their viability. In this case, the option would be to provide the opening – for ventilation – via secure grilles or louvres.

The window would still provide useful daylight, but the grilles would provide the fresh air natural ventilation. It is often beneficial to use grilles/louvres in any case, as they offer a more secure method of venting the building, with a much larger free area than an opening window could provide.



Option 01 - Openable window within a wall. Less effective method of naturally ventilating a space.



Option 02 - Openable window and secure louvre within a wall. More effective method of naturally ventilating a space as the air can always move through the louvre.

Figure 14: Windows for natural ventilation.

3.6

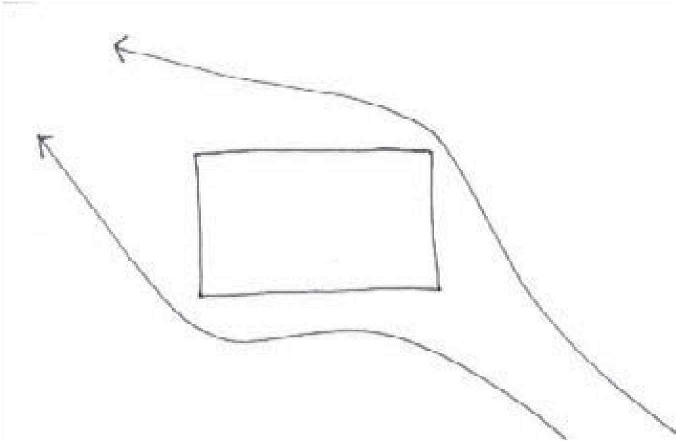
Vertical fins

To help to capture the prevailing Trade winds and push them deep into the interior, vertical elements "fins" should be constructed adjacent to windows or openings to help channel breezes into openings in the facade.

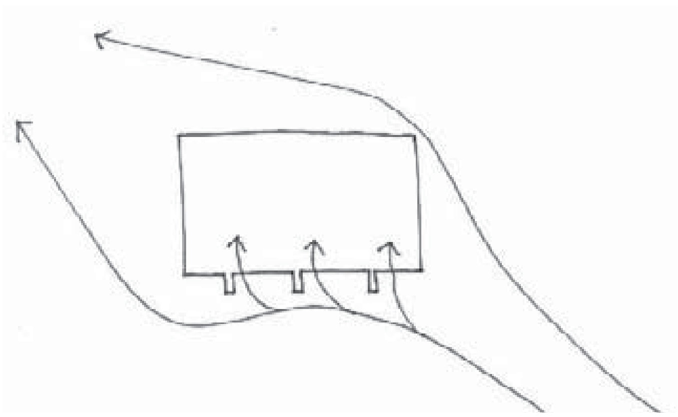
The position of the fins is very important. They need to be located on the opposite side of the openings to the prevailing wind direction. This will means as follows:

- South elevation: fin is located on the west side of the window/opening;
- East elevation: fin is located on the north side of the window/opening;
- North elevation: N/A;
- West elevation: no direct trade wind access, however to help shade the lower angle sun, the fin is located on the north side of the window/opening.

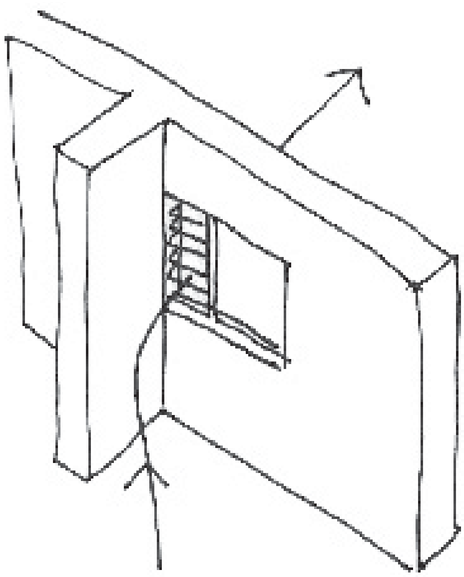
The minimum size of the fins protrusion is 500mm, but larger fins are more effective at drawing the prevailing wind into the building.
The fins can to be constructed of blockwork and reinforced concrete if necessary, although any solid vertical element (e.g. wooden or metal fins) are acceptable



Plan of house with no fins. The wind passes across the house.



Plan of house with fins. The fins catch the wind, forcing the wind into the house.



Prevailing wind is forced into the house by the fin.

Figure 15: Vertical Fins

3.7

Improving Energy Efficiency: Roofs

Flat roofs are particularly prone to overheating from direct solar gain, especially in summer. This in turn radiates heat down to the upper floor/ceiling. In order to limit the effects of this, some form of shading of the building fabric should be provided:

3.7.1 Better insulation

Concrete roofs provide some barrier to the direct heat hitting their surface at the start of the day. However, by early afternoon, the roof will have absorbed the heat, and will begin to transmit this heat into the internal spaces below the roof. The effect of this can be reduced through better insulation standards as shown overleaf. The roof fabric – most typically cast

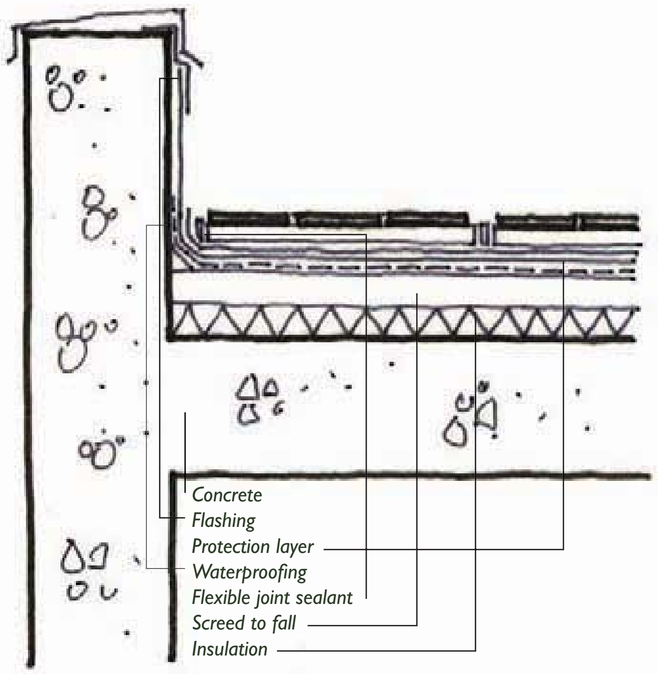


Figure 16: Roof Insulation

Climate Zone	Depth of overhang (m)	Depth of shading device (m)
1	1	0.75
2	0.75	0.5

Table 4: Recommended depth of overhang and awning on the north facade for both climate zones

concrete – can be enhanced by having a layer of insulation (e.g. polystyrene) to limit heat gains. Simulation results show a reduction in heat gains of over 12% in both climate zones with this measure alone. Figure 16.

3.7.2 Lightweight Roof with ventilated cavity.

Our research has shown, through discussions with Dr. Heeramun, that by using a lightweight roof material, such as steel sheet (which is law in Reunion island), the passive design benefits can be improved when compared to the concrete slab of most Mauritian buildings.

The core passive design concept here is that the steel sheets are cooler than ambient night time air by about 2°C due to black body radiation. The ceiling structure is made from plywood with radiant barrier (aluminium sheet) under the steel roof to limit solar gain during the day. Air in this attic space is flushed through using an efficient 30 W extractor fan until it cools below ambient. At this point, the airflow can be reversed to blow cooler air into the building. This cool is stored in the thermal mass of the blocks.

3.7.3 Shaded roofs

Flat roofs are particularly prone to overheating due to exposure to the sun throughout the day, especially in summer. This in turn radiates heat down to the upper floor/ceiling. In order to limit the effects of this, some form of shading of the building roof fabric can be provided. This can be as simple as a roof shade made of canvas that can be rolled back in periods of heavy gust or a more rigid metal roof structure that can be used as an attic space. Additionally, light-coloured reflective paints and waterproofing materials can be used to reduce the absorption of heat.
Metal sheeting can be used provided it is supported properly and due consideration is taken to securing the roof in the event of a cyclone. Planting, both adjacent to the roof and plants in containers on the roof will all help to shade the roof.

Figure 17 shows a simple structure that has been used to provide temporary shading. The building is in an area of Canada that is prone to tornados – during which time the temporary roof structure is removed until the storm has passed.

3.8 External shading

3.8.1 Façade Shading

External shading can be provided by means of architectural features (e.g. overhangs), additional shading devices (e.g. fins) and trees. The design of the overhang and external fins can be made to suit the particular needs of the building in a given climate setting.

The north sun can be readily blocked by fixed shading devices but openings on the east and west orientations need flexible shading elements, principally to control glare during early morning and late afternoon respectively. The element of user control provided to the occupant to customise their immediate environment is a key component of a sustainable building. The flexible shading element permits the user to control glare and heat gains as well as maximising the opportunity for natural ventilation and access views when appropriate.

Horizontal shading/overhangs are effective methods of shading the high-angle north sun. If the shading is correctly designed, the north façade can also have large glazed opening areas provided they are adequately shaded.
Examples of external shading elements that can be used on the north façade are:

- Eaves
- Awnings
- Louvers
- Light shelf

Examples of adjustable external shading devices that can be used on the east and west facades are:

- Retractable awnings
- Adjustable louvers

Table 4 shows the typical dimensions used for determining the depth of horizontal overhangs and awnings, which would help to control the direct solar radiation permitted into the building as per the requirement of the two climate zones. A floor to ceiling height of 3m is recommended for optimising daylight and natural ventilation as described in later sections.

Figure 17: example of a retractable shading device.

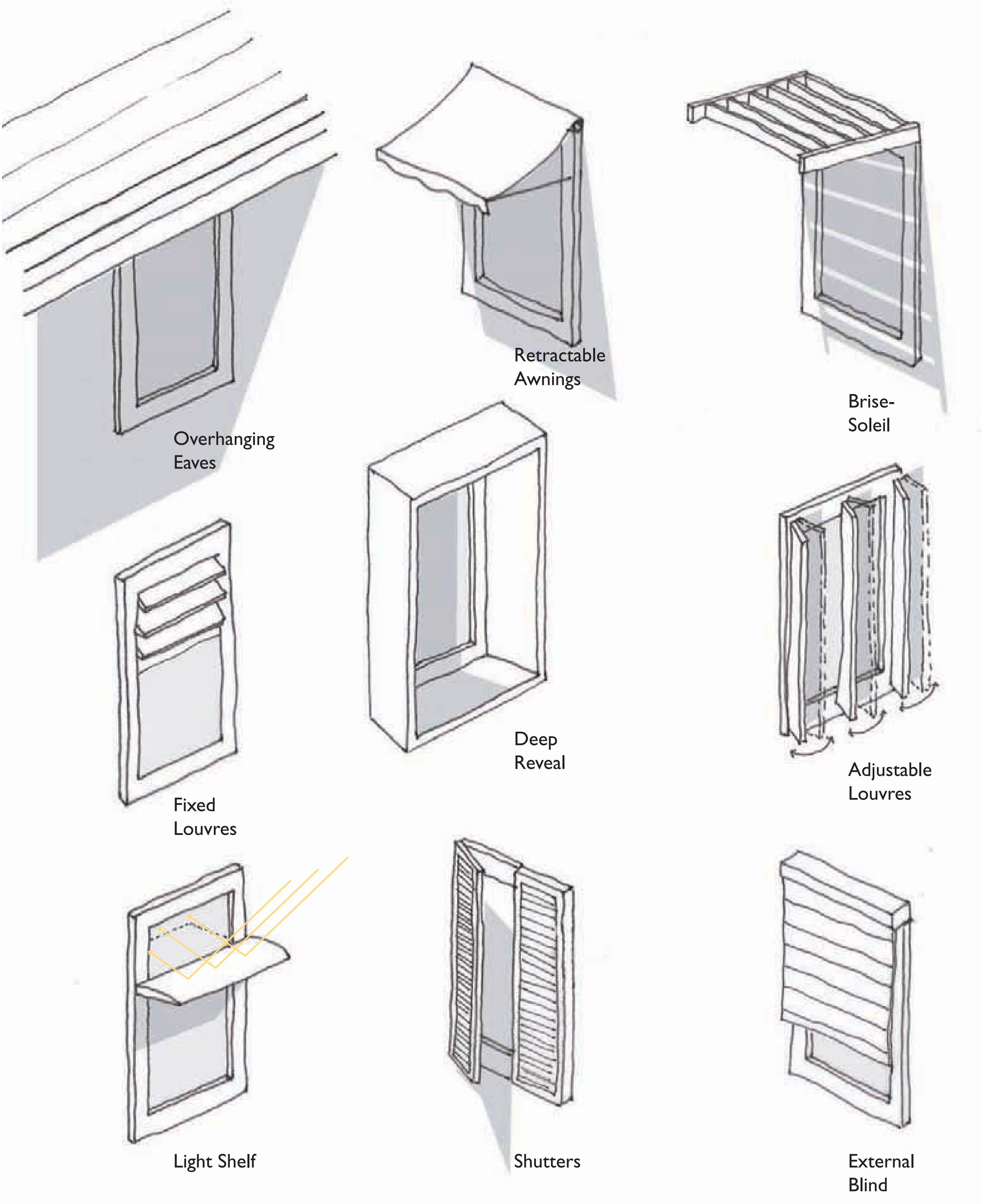


Figure 18: external shading devices

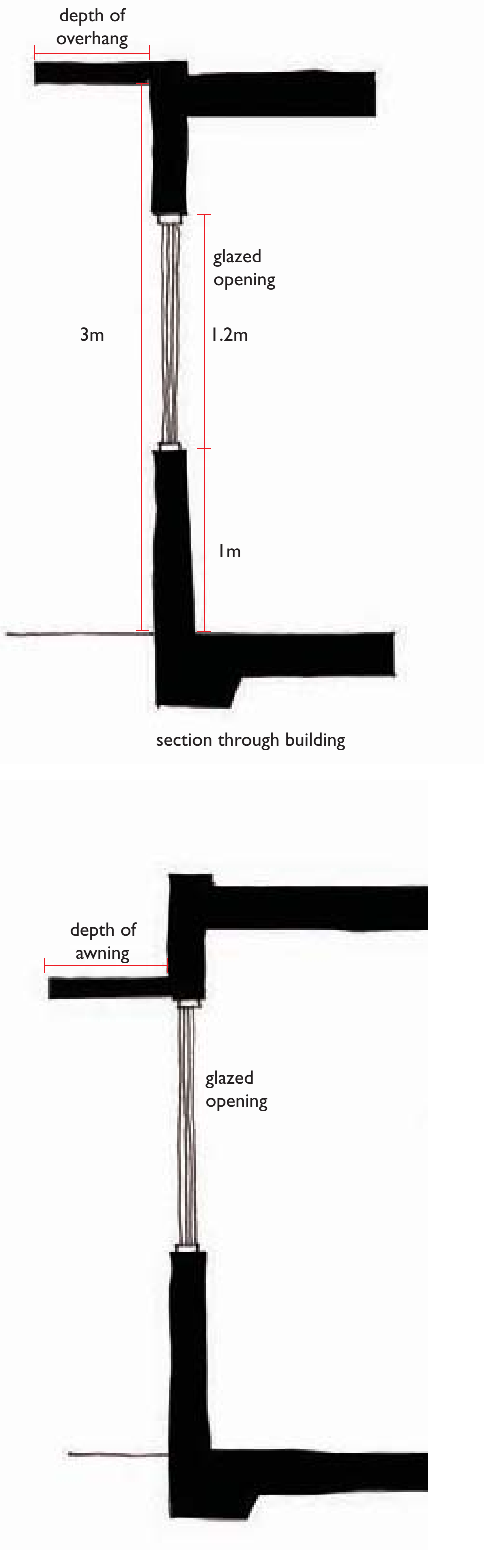


Figure 19: Diagrammatic section through building to show overhangs and awnings for both climate zones.

The recommended depth for horizontal awnings and overhangs on the north façade, for both climatic zones, are given in figure 19.

By introducing shading devices with these specifications in the simulation, a reduction in heat gain of over 20% was obtained, which shows that heat gain through direct solar radiation is a major source of heat gain to interior spaces and shading is a very effective way to prevent unwanted heat.

3.8.2 Planting and Natural Shading

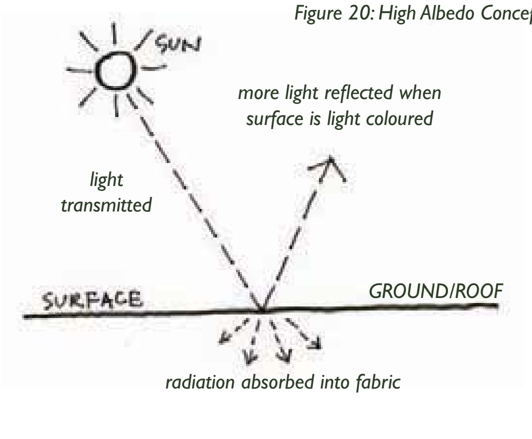
Appropriate planting can be an extremely effective method of providing shading to a building because the plant creates shade. There are also further minimal benefits to the micro-climate from evapo-transpiration – where the plant emits cooler air which can be captured and then drawn into the building. In particular, planting in front of the north and west elevations is particularly effective at reducing internal temperatures.
Plants contained within pots positioned on the roofs of buildings will also have some benefit of cooling. They will provide shade, helping to limit the effects of the sun onto the roof. Care must be taken to ensure the structure of the roof is adequate to carry the additional load.

3.9 Colour and Reflectance

The surface of the building envelope plays an important role in determining the degree that direct solar heat affects the building. Lighter colours and higher reflective materials provide a more effective solution to help reduce heat from being absorbed through the building fabric.

Roof surfaces with high Albedo finishes should also be considered, especially in Mauritius with the high overhead tropical sunshine. (Figure 20)

Figure 20: High Albedo Concept



3.10

Coping with site restrictions

In the light of the recommendations given so far, this section analyses how to cope with circumstances where the geometry of the site places restrictions on the building orientation, making it difficult to orientate the major axis of the building along the east-west direction or even affecting the building shape such that there might not be a major/minor axis (Figure 21).

Considering layout (a) in Figure 21, if the building can be orientated to align the major axis with the east-west direction, then this configuration is optimal and should be aimed at as far as possible. As discussed earlier, the regularly occupied spaces should then be located in the north and south directions leaving ancillary spaces like stores, kitchen and washrooms for the remaining areas. However, if the site geometry favours a major axis along the north-south direction, then layout (b) in Figure 21 should be aimed at as far as possible so that areas facing north and south are maximised. This will necessarily mean that regularly occupied spaces (classroom, clinics, office and shops) have to be located along orientations known to yield low heat gains.

The ability to provide comfortable internal environments as a result of restrictions placed by site characteristics are illustrated next using a hypothetical example of a segment of a community (Figure 22). In this example, the optimal orientation is to have the larger façades facing towards the north and south (e.g. types A, B and D), but some buildings could be orientated with the major facades facing east and west (type C), north-west/south-east (type E) and north-east/south-west (type F).

It will be generally the case that access to the road is used to set the geometry of the plot of land, which can place limitations on the geometry of building that can be erected. Let us consider each configuration in turn. Types A and B, having road access to the north and south respectively, are ideally located and the guidelines provided earlier can be followed to limit heat gains in the different directions.

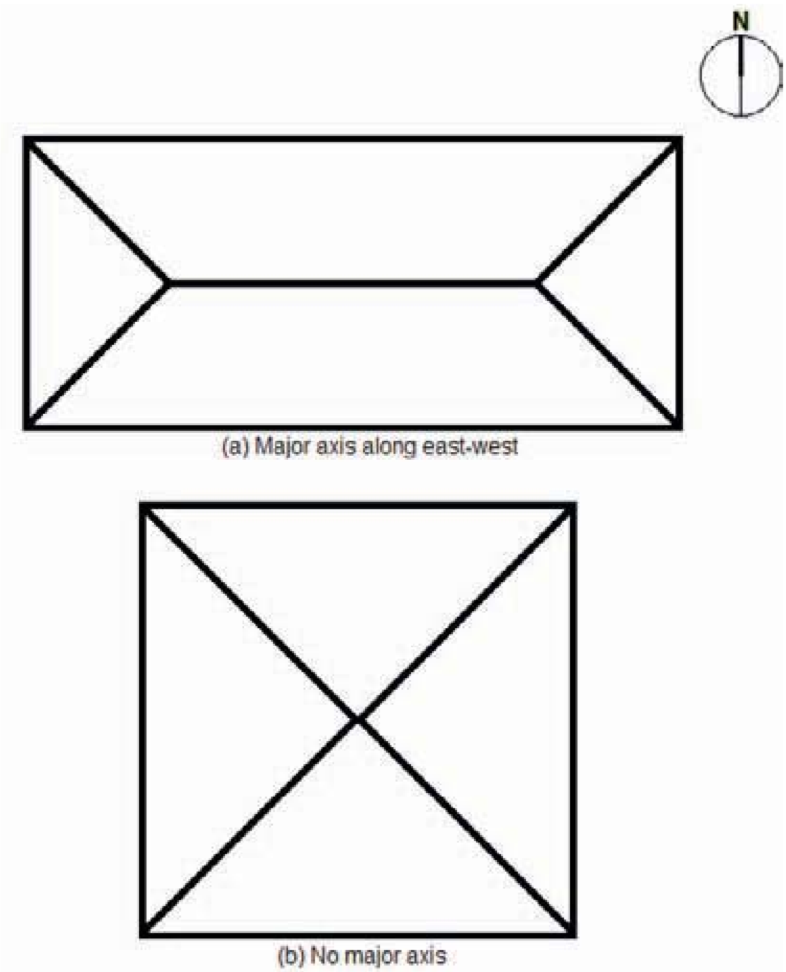


Figure 21: Building geometry (a) recommended geometry (b) site geometry may force a building plan to have no major/minor axis

Types C and D have road access either on the east or west. For type C, the major axis is north-south due to site constraints; however, one should try to increase the façade along the north and south sides to aim for a building shape as close as possible to layout (b) in Figure 21. Type D remains the configuration of choice for plots with road access to the east or west, and the strategy for heat gain reduction remains the same as for types A and B.

Openings on the east and west main facades need to be shaded by using adjustable external and internal shading devices as described earlier. Furthermore, guidelines are provided in Section XX on the use of high trees as part of the landscaping to provide shading against low angle sun typical in the east and west directions. Any opening on the north façade can be effectively shaded by fixed shading devices e.g. overhang or awnings, based on the prescriptions given in Section 3.6. The South façade does not need any shading device.

Types E and F layouts have their main façades orientated along the south-east/north-west and north-east/south-west respectively. Based on the analysis of distribution of heat gains with respect to direction done before, it can be ascertained that these two type layouts are among the highest ranked in terms of heat gains and if possible, such configurations should be avoided. Type E has one of its major façade facing south-east, so this orientation is better than Type F, which has both of its major facades facing the high heat-prone north-east and south-west orientations. If these layouts are unavoidable, the openings along the main facades need to be shaded by adjustable shading devices or by planting high trees.

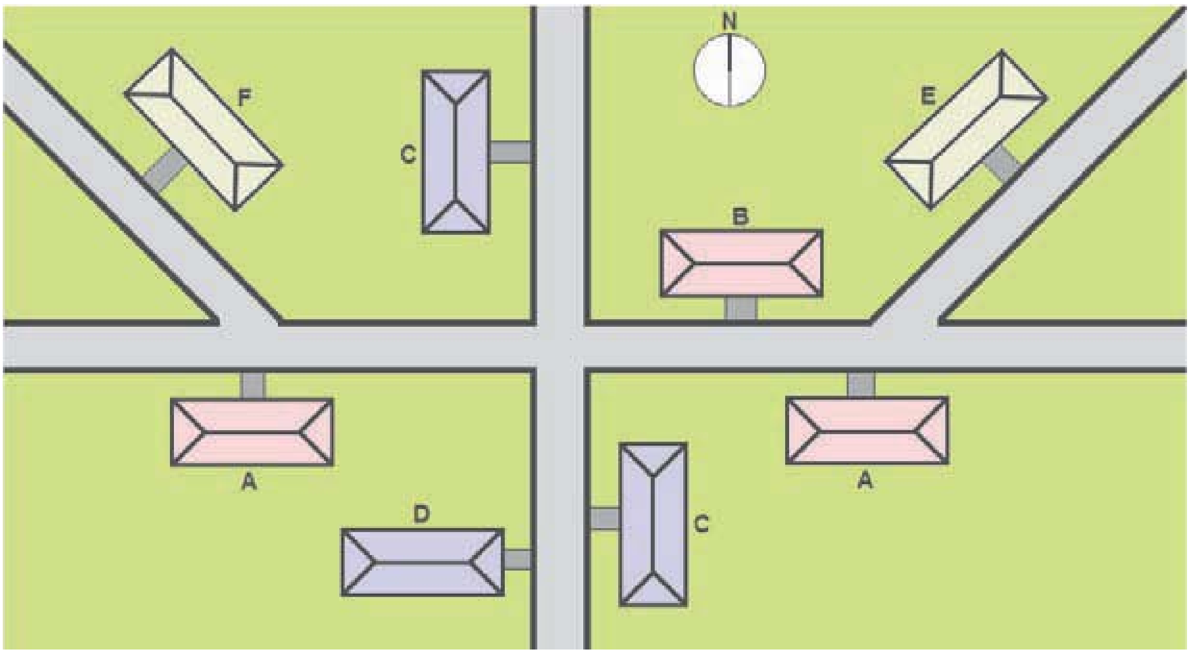


Figure 22: Hypothetical scenario showing different building orientations

4

Landscaping and Heat Island Effect

4.1 Introduction

The site external landscape around a building has a major influence on the ambient temperature. The difference in ambient temperature between urban and rural areas can be as much as 3-4°C due to the difference in thermal properties of the built environment. The hard landscaping materials selected should have a light colour (e.g. light grey and white) to avoid the absorption of heat and a consequent increase in the ambient temperature – which would mean more cooling would be required.

Additionally, plants native or adapted to the local environment should be favoured as they promote biodiversity and generally require less water. Section covers the various ways in which plants can be used to improve occupant comfort in a sustainable manner.

The preferred strategy is to ensure planting of trees and shrubs around the vicinity of the building but it is accepted that some hard surfaces will be inevitable.

4.2 Paving and Hard landscape

In this regard, black tarmac surfaces should be avoided, especially in the vicinity of the building. Light coloured, interlocking blocks (open-grid) are good alternatives to cast concrete surfaces, with the added benefit of allowing rainwater to permeate through the blocks and recharge the underground aquifers. The open-grid pavement can be used as an integrated storm water management feature as elaborated in Section 4.5/

4.3 Plants

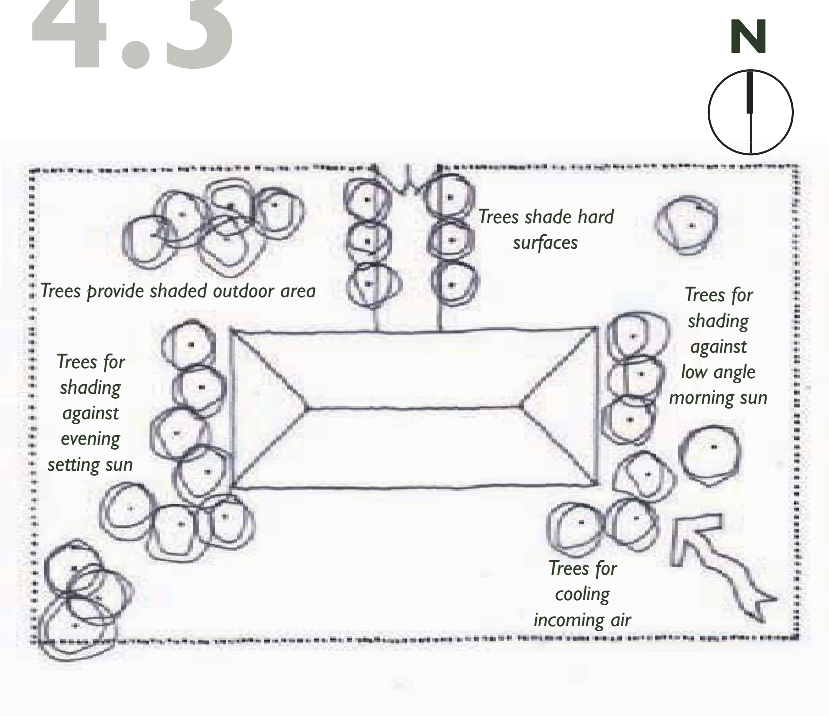


Figure 23: Advantages of plants on the project site

Native plants play a vital role in maintaining and promoting biodiversity in our environment, and more importantly, they have the fundamental function of converting carbon dioxide into oxygen. As discussed in the previous section on indoor environmental quality, a proper indoor air quality is achieved by ensuring adequate ventilation (either mechanically or naturally) to remove stale air and bring in an oxygen-rich supply of air. It is well known that construction of the built environment is leading to a systematic depletion of green areas, so it should be the aim of every building project to restore as much green area around the building as possible.

Appropriate planting can be used as an extremely effective method of providing shading to the building and the external hardscape, and thus limit heat build-up in the internal areas. They are particularly effective in blocking the low angle sun rays that radiate on the east and west facades. Plants contained within pots positioned on the roofs of buildings will also provide shade, helping to limit the effects of the sun on the roof, although green roofs (presented in Section 1.1 achieve even better thermal insulation properties. High trees can also be used to shade car park areas as well as provide comfortable outdoor spaces.

Plants are known to cool air by the process of evapo-transpiration, so when planted in the south-east direction, incoming air can be cooled before it enters the building. This will contribute to thermal comfort even when external temperatures are higher than comfortable levels.

Finally, plants provide good quality external views, which is a key factor in promoting the health and general well being of the occupants. The attributes of plants around the building are summarised in Figure 23.

Finally, the choice of plants to be used for the landscape should be done with due consideration of their water requirement and their biodiversity value. Both of these requirements are suitably served by the plant species that are indigenous or have been adapted to the local climate. Therefore, the owner/developer is encouraged to enquire about indigenous species from local authorities (e.g. AREU) or landscaping. Another water efficient option is to choose plants that need watering only to establish them and thereafter rely only on rainfall to subsist.

4.4 Green Roofs

A green roof, also known as a living roof, is a system comprising an extension of the existing roof which consists of a high quality water proofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants as shown in Figure 24.

However, it is important to note that green roofs need to be designed and built correctly to avoid potential risks of leaks and roof damage. Specialist designers, including structural engineers, should be sought to advise on construction and maintenance matters associated with green roofs.

In particular, the following points need to be addressed.

- Slope / fall for drainage of roof to drain storm water away from the roof deck;
- Structure of roof deck needs to be adequate strength to support soil, plants, water and additional materials associated with green roof;
- Lightweight materials, such as sedum mats/blankets could be used in place of the extensive green roofs, to keep weight and cost manageable.
- Plant types and species should be selected to ensure that they will survive and grow in this exposed roof top environment.

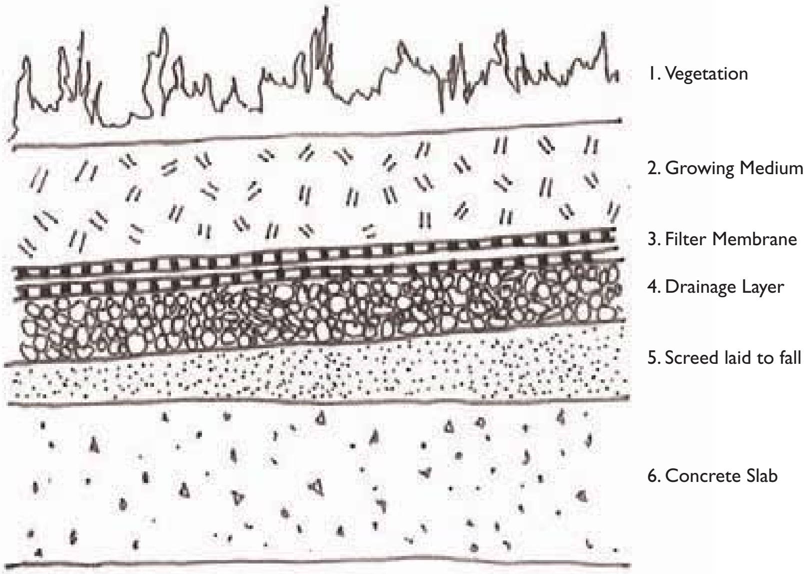


Figure 24: Layers of a green roof

If the above guidelines are followed closely it is possible that green roofs can provide a wide range of public and private benefits.

The benefits of green roofs:

- Improve the thermal insulation properties of the roof, thus reducing heat gains.
- Green roofs have been found to significantly reduce daily temperature fluctuations of the underlying roof structure. Green roofs protect the roof structure from thermal stress and increase the durability of the waterproofing layer.
- Green roofs provide cooling (by evaporation) and thus reduce the cooling loads.
- Fire retardation: Green roofs have a much lower burning heat load than do conventional roofs.
- Noise reduction: Green roofs have excellent noise attenuation, especially for low frequency sounds.
- Recreational: Green roofs can provide new amenity space such as gardens and children's playground in densely populated areas.
- Green roofs filter rainwater, which can be collected and used for non-potable ends.
- Agriculture: Green roofs can be used for growing of edible plants for personal use.

Further reading on green roofs here:

- www.livingroofs.org
- http://www.greenroofs.org/
- http://www.blackdown.co.uk/
- http://www.greenroofs.com/Greenroofs101/waterproofing.htm
- www.bauder.co.uk
- http://fra.sika.com/

4.5 Storm water management

The construction of a building necessarily leads to an increase in the imperviousness of the land plot as permeable land is covered with impermeable hard surfaces. This is detrimental in various ways, namely:

- Diversion of rainwater from underground aquifers, which hinders the ability of the latter to recharge
- Increased rainwater run-off from hard surfaces lead to erosion of valuable topsoil
- The quality of the run-off when carried over hard surfaces can be reduced due to contact with contaminants, e.g. oil, dust and debris.
- Discharge of the run-off into adjoining water streams leads to sedimentation of eroded topsoil and while the poor quality of the run-off can disturb marine life.
- The high volume of run-off, which normally finds its way to road drains, places pressure on road drain infrastructure and increases the likelihood of flooding.
- The building must be designed to handle high rainfall intensity (typical during cyclones and peak rainy season) in a sustainable way. Best practice would be to restore the original permeability / percolation of the site by using various technologies.

As discussed in Section 9.2, storm water management can be effectively integrated with rainwater harvesting, which in itself helps cope with the quantity and quality of the water by retaining the run off. Rainwater harvesting helps to reduce the demand for potable water by directing it towards non-potable ends. During periods of heavy rainfall, the retention system can be made to discharge water at a controlled rate while acting as a buffer against the volume of run-off generated from hard surfaces. Rainwater collection and filtration systems are available on the market that removes the debris and particulates, improving the quality of run-off.

Run-off occurs at two levels: the roof and ground. Rainwater harvesting is generally done for rain falling on the roof due to its easy collection and storage and better quality as compared to run-off from hard surfaces at ground level. Solutions for rainwater harvesting are presented in Section 9.

To reduce the effect of storm water run-off from hard landscaped areas around the building, impermeable materials (such as tarmac, which as per Section 9, is discouraged and cast concrete slabs) should be avoided. In their place should be adjacent areas of permeable natural land with green areas and swales for collecting the storm water flows.

Suitable harder materials include interlocking (open-grid) pavement is used as illustrated in Figure 25. Interlocking blocks come in a variety of shapes, but the underlying principle of allowing infiltration over the whole area is very attractive. Colour selection should favour light tones.

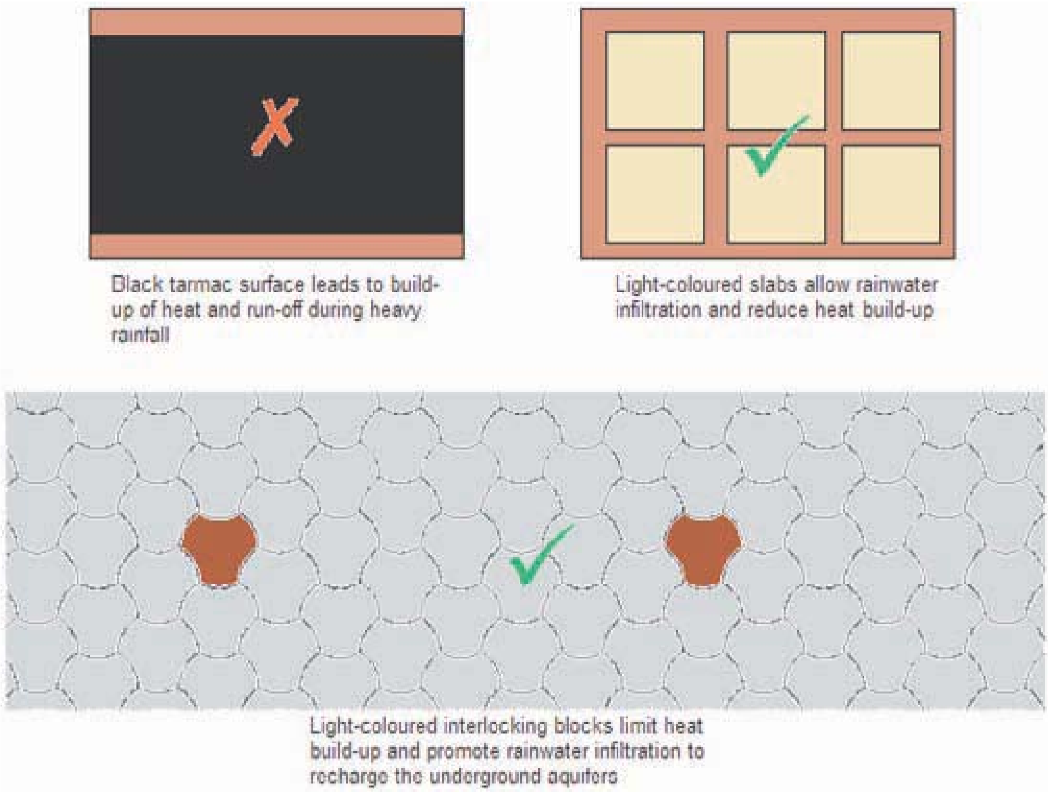


Figure 25: Options for walkways

4.6 Maintenance

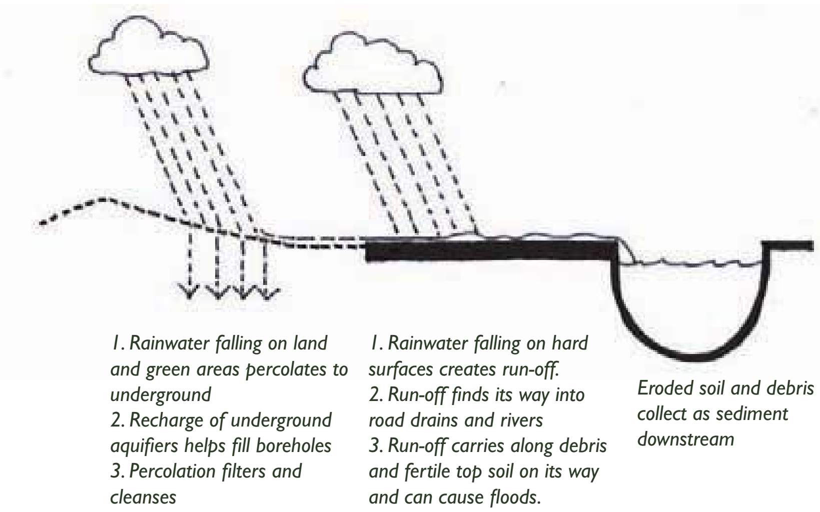


Figure 26: Impact of hard surfaces and attributes of open areas for storm water management

It is important that building elements are maintained by the user to ensure proper functioning of the buildings as intended. This is not an overly complex procedure, but it is important that a degree of maintenance is carried out to maintain energy efficiency.
Typically the maintenance points that need consideration are as follows:

- Waterproofing protection against cyclones;
- Painting external surface to reflect heat;
- Managing landscape around the building or shading;
- Keeping windows/vents clear for good natural ventilation air paths.

5

Indoor Environmental Quality

5.1 Introduction

The quality of the internal environment of buildings plays a significant role in the health and well being of the occupants. It is important that the criteria that effect IEQ are clearly understood and accounted for when designing and constructing a building.

In recent years, there has been a large amount of research and monitoring carried out in this area. Based on this research, the main criteria that need to be carefully considered and addressed in design are set out below.

5.2 Air Quality

The constituent parts within the air that surrounds us varies greatly from different environments. The most common factor with regard to buildings is the relative concentration of carbon dioxide in the air that the building occupants experience.

Guidance contained in ASHRAE 62 is dedicated for the role of ventilation with respect acceptable indoor air quality.The World Health Organisation (WHO) sets out guidance for controlling CO^2 levels to improve standards in air quality. They recommend that 1800mg/m3 (1000ppm) is the maximum allowable concentration of CO^2 in the internal environment.
In practice, sensors that measure CO^2 concentrations can be used to adjust the rate of ventilation to keep the air fresh.

5.3 Humidity

The impact of moisture in the air – often referred to as relative humidity – can be a cause of poor IEQ.

The humidity in the air requires more energy to produce a cooling effect, as the enthalpy (energy) in the air is more intense. The evaporation process associated with water or in the case of air conditioning, a refrigerant gas, creates a cooling effect. Humid air requires more energy to generate this evaporation, as the air already holds high volumes of water vapour, making it harder to use for cooling.

This is a common issue with tropical climates, and Mauritius is a clear example of how this needs to be addressed.

The risk of condensation is caused when the air is cooled below ‘dew point’. The dew point is the temperature at which water droplets (dew) are formed. The condensed water is often impure and may contain bacteria, which, if left unattended, may cause mould growth. The spores of mould can spread disease and lead to serious health problems.

Therefore the main recommendation is to try and use high volumes of air flow to flush through the building to create an air change that cools through convection, rather than through evaporation. The project recognise that in certain cases, it may not always be possible, and that energy efficient air-conditioning units may be employed in certain circumstances (5.13).

5.4 Acoustics

The internal acoustic environment of the building plays an important consideration of comfort. This should be born in mind when ventilation designs are being considered, especially with openings in the building façade and the use of mechanical ventilation equipment.

5.5 Volatile Organic Compounds (VOC)

The materials, furnishings and finishes used in buildings affect the indoor environmental quality significantly. It is important to know that many furniture, carpets, flooring, paints etc, contain chemicals that pose health risks to people.

Building components and the products used as finishes inside the building can have a detrimental effect on the quality of air and pose health threats such as lung diseases. The interior elements which can affect the indoor air quality can be grouped as follows: (1) Paints and coatings, (2) Sealants and adhesives, and (3) Wood products. The source of indoor air contaminants in the first two categories are is commonly called Volatile Organic Compounds (VOCs). These are carbon compounds present in vapour state at room temperature. VOCs are typically emitted during and once the product has been applied. Therefore, paints, coatings, sealants and adhesives should be applied in areas which are well-ventilated and as far as possible, outside the building.

When present in small concentrations, VOCs get diluted by ventilation, so products should be selected to have low VOC content in the first instance. The guidelines provided the south Coast Air Quality Management District (SCAQMD) Rule #1168 can be used to get an indication of acceptable thresholds of VOCs in adhesives and sealants[1].

The LEED Guidance ©USGBC, refers to the State of Washington, USA, with the following standards for these chemicals are listed below:

- < 5 mg/m3 of formaldehyde (State of Washington Program and IAQ Standards);
- < 5 mg/m3 of total volatile organics (State of Washington Program and IAQ Standards).

5.6 Types of VOC – producing products

5.6.1 Paints and Coatings

The use of paints should be referenced to specialist guidance from the LEED © USGBC criteria that refer to the Green Seal Standard GS-11. This lists the acceptable VOC concentration for paints and finishes.

It is laudable that the local paint manufacturers (e.g. Mauvilac and Permoglaze) have taken the initiative to launch paint and coating products that have low VOCs and are environmentally friendly. The population should opt for such low VOC and eco-friendly paints to yield a healthy environment.

5.6.2 Sealants, adhesives and wood products

Wood products used for furniture and flooring makes use of adhesives and sealants, which should be chosen as per the guidelines mentioned above. Further, composite wood such as plywood, particle-board and medium-density board (MDF) make use of resins for bonding. If these resins contain formaldehyde, the latter will be emitted during occupancy and harm the air quality. Composite products with no added formaldehyde should be favoured to promote better air quality.

5.7 Internal shading

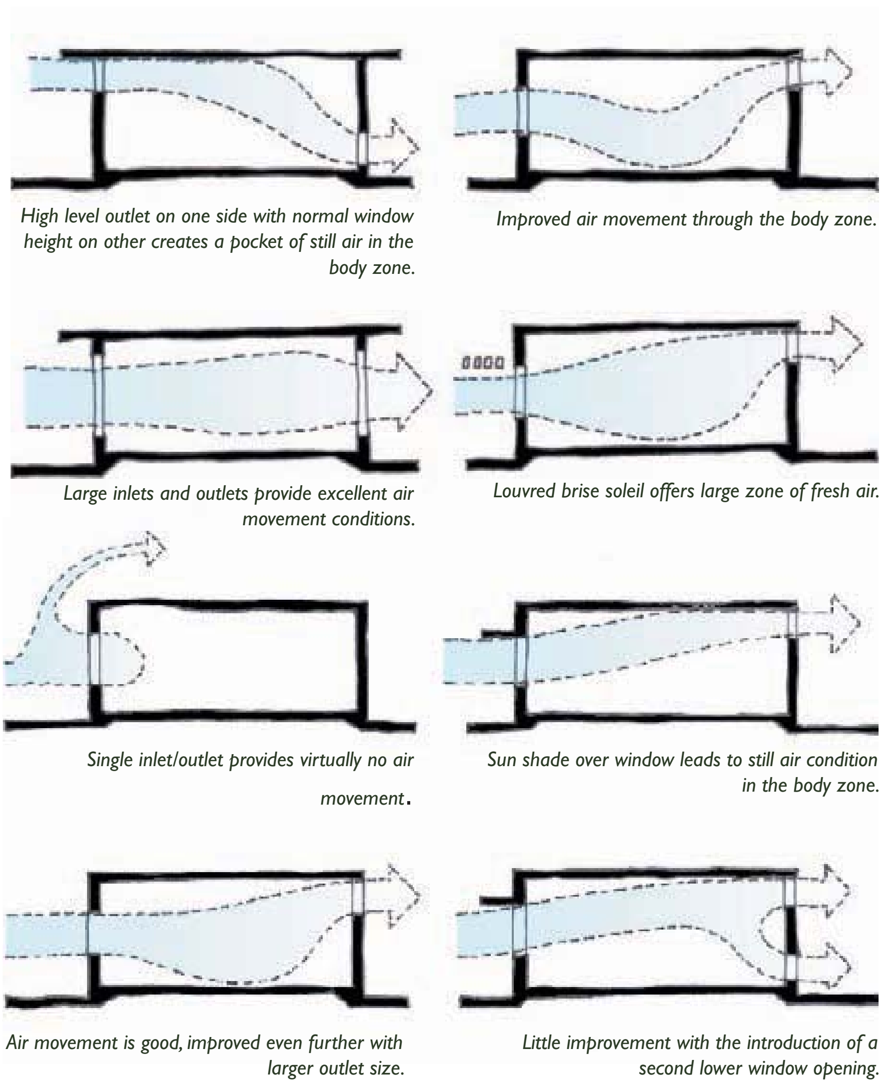
Internal shading is important to block the direct sun, and to prevent glare. Typical internal shading devices include vertical or horizontal blinds. Curtains are also commonly used in residential buildings to control glare and the admission of daylight.

In a similar principle to adjustable external shading, it is advantageous to allow the residential building occupant to configure the internal shading devices to suit their preferences.

5.8 Air Movement

Where higher ambient air temperatures reduce the ability of ventilation alone to provide cooling effects, the movement of air has been understood for centuries to provide cooling.

Air movement may be generated natural through well-orientated windows/opening to capture breezes or it may also be generated through ceiling fans or pedestal fans to circulate air through the buildings. The electrical energy to move the air is relatively low compared to air conditioning. See section 5.12



High level outlet on one side with normal window height on other creates a pocket of still air in the body zone.

Improved air movement through the body zone.

Large inlets and outlets provide excellent air movement conditions.

Louvred brise soleil offers large zone of fresh air.

Single inlet/outlet provides virtually no air movement.

Sun shade over window leads to still air condition in the body zone.

Air movement is good, improved even further with larger outlet size.

Little improvement with the introduction of a second lower window opening.

Figure 27: Building sections showing arrangements of openings to encourage natural ventilation

5.9 Natural Ventilation

To provide adequate free cooling, the natural ventilation strategy needs to be designed to encourage enhanced air change rates that provide a greater degree of convective (and evaporative) cooling.

In order to 'flush' the building rooms with outside air, the openings in the façade/roof need to be of the correct size to allow sufficient volumes of air through. Furthermore, as the outdoor wind conditions are not consistent there needs to be a degree of user-control that can close or open the vents / windows depending upon wind conditions and internal comfort. See section 3.5

5.10 Wind Catching Fins

To help to capture the prevailing winds and push them deep into the buildings, fins should be constructed to help channel the breezes into the buildings.

The position of the fins is very important: They need to be located on the opposite side of the openings to the prevailing wind direction. This will mean as follows:

- South elevation: fin is located on the west side of the window/opening;
- East elevation: fin is located on the north side of the window/opening;
- North elevation: N/A;
- West elevation: no direct trade wind access, however to help shade the lower angle sun, the fin is located on the north side of the window/opening.

The fins are to be constructed of blockwork and reinforced concrete if necessary. See section 3.6

5.11 Ventilation Control

Simple and low-tech solutions for controlling airflow are windows or louvres with integral storm-proof vents. In practice, the air change required will be dependent upon user comfort. The airflow required can be adjusted manually to suit by the building occupants. Air paths through openings must ensure secure operation to prevent insects, birds, mammals and burglary. The extract air should if possible be exhausted through windows on the opposite side of the building.

In the interests of security, economy and energy efficiency, the openings consist of both grilles/vents as well as windows. Depending upon user preference, windows may be fixed glass (non-openable) or openable with the primary intention of capturing daylight.

Grilles and vents are provided to allow fresh air ventilation in a secure (intruder free) manner, such that they can be securely left open at night for night cooling. During cyclones, a secure closing mechanism covers the openings may be required. See section 3.5.

5.12 Mechanical Ventilation

There are times when natural ventilation alone is not adequate to provide comfortable internal environment.

The recommendation here is to use mechanical ventilation systems such as ceiling fans or pedestal fans. These usually have small electric motors (<100 Watt) and are effective in creating air movement through the space.

5.12.1 Ceiling Fans

Consideration should be made with respect to safety of circulating blades, and protective measures followed to prevent injury.

Ceiling fans, are often set up to run in two directions – clockwise and anticlockwise. The reasons for this are that one direction draws the hot air away from the occupied space and pushes down cooler air – which is ideal for summer; and the other direction pushes down warmed air to the occupied zone – which is ideal for winter.
The preferred location for ceiling fans is generally in areas when the occupants are generally seated or resting. Ceiling fans should be avoided in areas with odours, for example, bathrooms, WC, kitchens.

5.13 Mechanical Cooling

There are times when neither natural ventilation nor mechanical ventilation is able to provide comfortable conditions.

In these instances it may be preferable to provide energy efficient air conditioning units to provide cooling to the buildings. It is important to note that the energy consumption of air conditioning systems vary greatly depending upon size, quality and refrigerant gas.

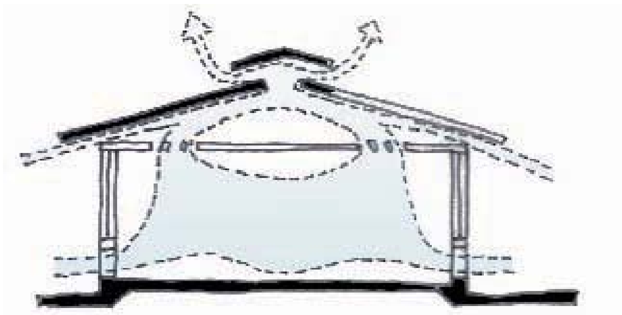
General guidance that should be followed is as follows:

- Coefficient of performance: 3.5 or higher
- Refrigerant gases:
  - o AVOID CFC & HCFC: R12, R22 etc
  - o use HydroFluoroCarbons (HFC): R134a, R410a, R407c.

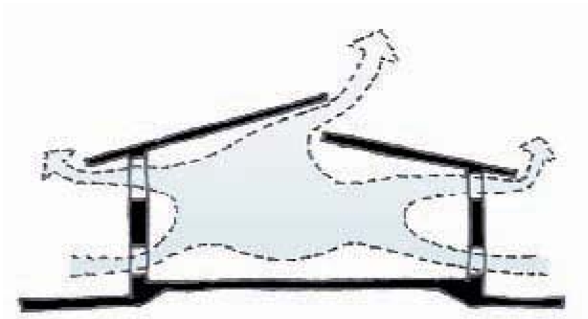
It is important to provide an insulated building envelope with openings that can be closed to conserve the beneficial cooling output generated by the mechanical system.

(Footnotes)
[1] http://www.aqmd.gov/rules/reg/reg11/r1168.pdf

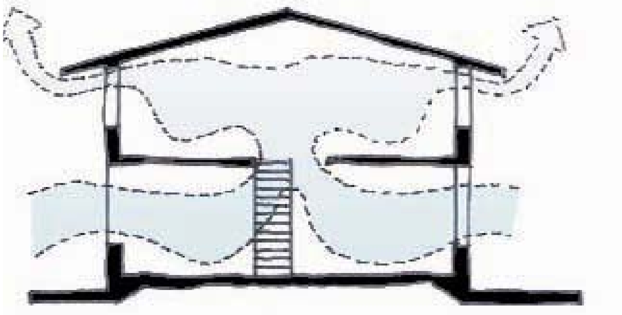
[1] http://www.aqmd.gov/rules/reg/reg11/r1168.pdf



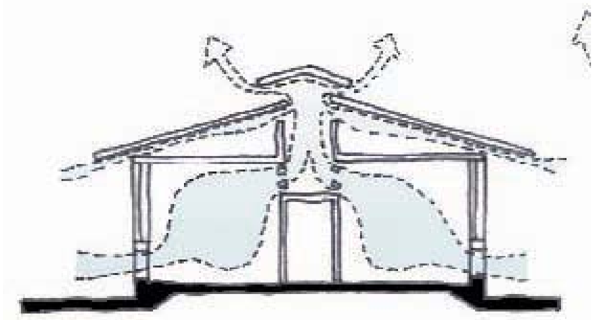
The location of openings within the building determines the effective route for air movement.



Stack effect ventilation relies upon a differential in temperature between the outside air and that of the air within a building.



Air movement resulting from stack effect. in a two storey building



Warm air is expelled at higher level to be replaced by cooler air drawn in at lower level.

Figure 28: diagrams illustrating potential strategies for stack induced ventilation for single and two storey buildings

6

Lighting

6.1 Introduction

Lighting represents the largest source of energy consumption in an unconditioned building, meaning there is considerable scope for energy savings. Sustainable lighting design should aim to:

- Maximise the use of natural light
- Design as per the required illumination level
- Use highly efficient lighting equipment and accessories
- Use lighting controls that provide lighting when, where and to the degree required.

Natural light has been shown to yield a better indoor environment to users with case studies showing higher levels of performance and better health. The main reason behind these findings is that daylight provides a psychological connection to the outdoors, and so the buildings should attempt to make maximum use of it.

6.2 Daylight

Daylight levels have been designed to allow good quality daylight while controlling solar gains and reducing overheating. The main facades of the buildings should face south where clear light is available with no glare or solar gain.

Rooms should be finished in pale colours to assist in improving levels of daylight.

6.3 Harnessing daylight

A floor-to-ceiling height of 3m is recommended for implementing daylighting strategies, which can take two main forms: side-lighting and top-lighting.

Side-lighting consists of allowing light into the building from openings around the perimeter wall, whereas top-lighting targets natural light through openings on the roof. Therefore, top-lighting in buildings without atria can be used only for achieving daylighting for the top floor.

Due to the sun's intense brightness, a daylighting system should be designed to avoid direct solar penetration into the occupied spaces. This can be achieved through careful placement of daylighting openings and the use of appropriate shading devices or reflective devices (light shelves). The design of the daylighting system should be based on diffuse light received from the sky-dome.

With knowledge of the solar path presented in the introductory section of this Guidebook, the following deductions can be made:
Light from the south orientation can be used to provide a more or less constant illumination without any of the heat gain and glare problems faced with north-facing openings.

East and west openings are prone to allow direct solar penetration due to the low angle of the sun.

6.4 Toplighting

Possible configurations of glazed openings for toplighting are shown in Figure 29, where the glazed areas have been labelled G. The last toplighting configuration, i.e. the atrium is generally used in non-residential buildings to provide beneficial daylight levels.

These toplighting schemes may also be designed to have openable areas to foster natural ventilation but the mechanism for operating these openings should be ready accessible to allow easy use, especially during cyclones or when it is raining.

The glazed openings can be made of transparent or translucent glass; the latter having the advantage of preventing direct sunlight into the spaces but to the detriment of lower daylight levels. Transparent glass provides more daylight into the spaces but can pose serious glare problems if not properly designed.

The roof monitor, clerestory and sawtooth configurations allow daylight through vertical glazed areas. Allowing light only from one direction, the clerestory and sawtooth configurations when orientated so that the glazed areas face south can be safely used as a toplighting strategy without the risk of having direct solar penetration and the associated heat gains; a transparent glass can be used for this purpose.

A roof monitor with the glazed openings facing north and south provides an effective way to allow diffuse light to enter the spaces while blocking the high angle north sun, but this is dependent on the height of the glazed areas and the separation between them. Therefore, this necessitates custom calculations to be performed by a designer to size the roof monitor and any supplementary shading element required.
Of relevance to Vacoas, the roof monitor can be designed to block direct sunlight during summer and allow in useful sunlight during winter, provided the concomitant glare does not adversely affect any tasks or activities taking place in the associated areas. Any problem of glare can be addressed by the design of transparent glass openings or by using appropriate translucent glass.

The two types of skylights (flat and dome-shaped) and the atrium generally allow daylight into the space through horizontal or near-horizontal openings. Thus when transparent glazing is used, they are prone to let in direct sunlight at any time of the day, especially around midday when the solar angle is high and are not to be recommended.

The risk of glare and overheating should be properly addressed, particularly in areas where visual tasks are carried out. Their implementation requires input from designers to dimension the glazed openings appropriately by means of daylight and heat gain simulations. Additionally, being mostly horizontal, skylights and atria receive intense solar radiation at high angle of incidence and thus prone to heat up and transmit heat to the interior. The U-value and Solar Heat Gain Coefficient (SHGC) of the glazed materials (both for transparent and translucent glass) should be considered by the designer.

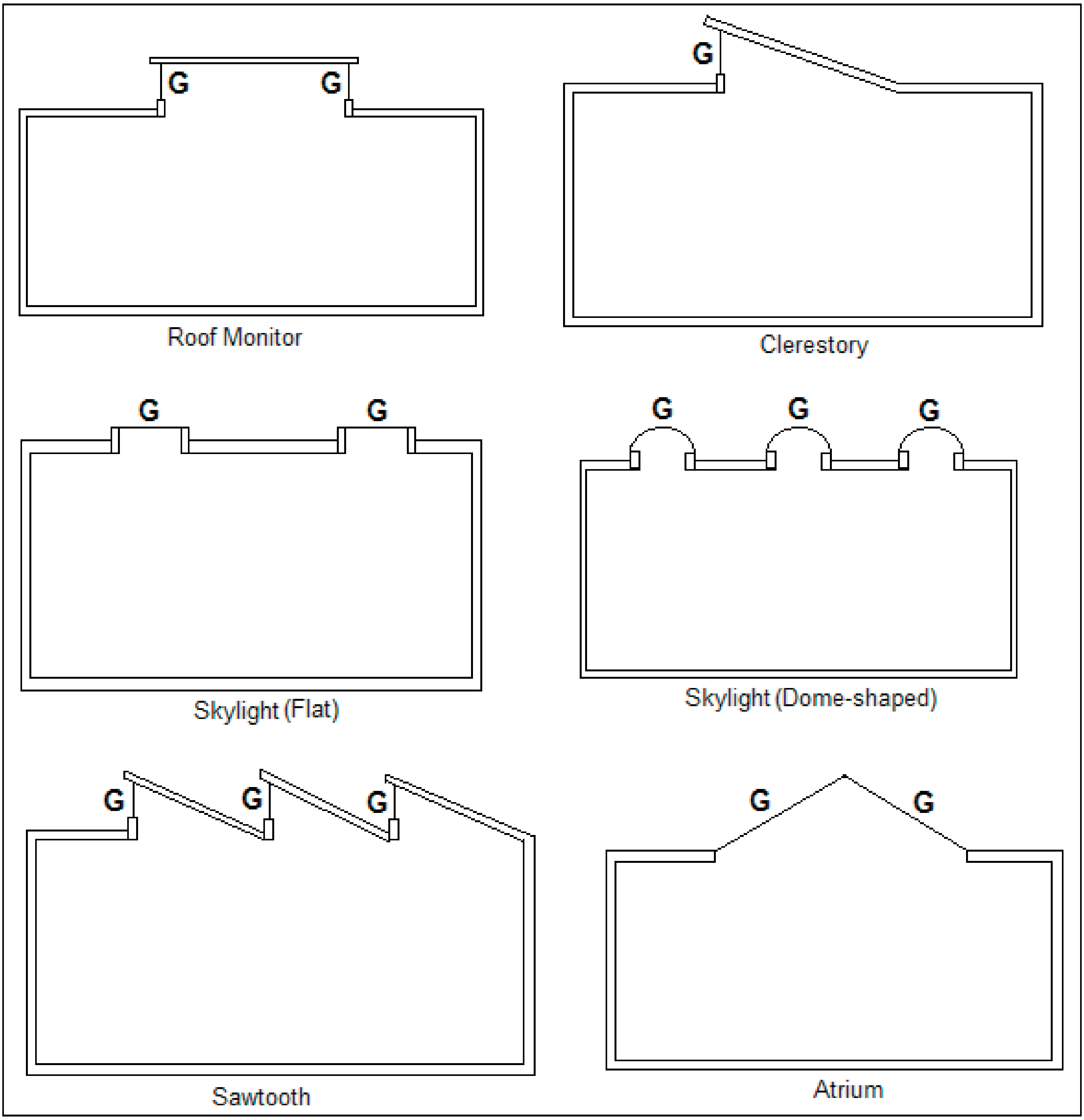


Figure 29: Toplighting configurations (glazed areas are labelled G.) Examples of good roof designs: 1, 2, and 5. Examples of poor roof designs: 3, 4, and 6

6.5

Side-lighting

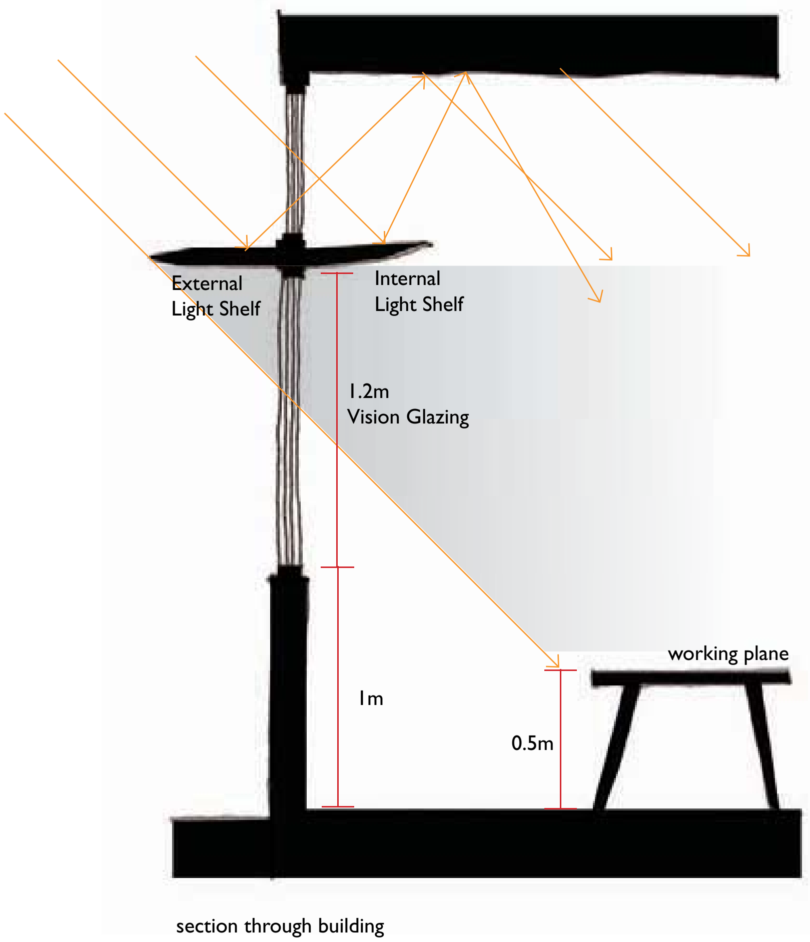


Figure 30: Combining vision and daylight glazing

For glazing facing south, windows can be used for daylighting. On the other hand, for north, east and west orientations, the fenestration is better separated into vision and daylighting openings. In this case, the vision glazing extends vertically from the sill height (typically at 1m) to a height of about 2m above the floor. The daylighting glazing then runs from the top of the vision glazing to the ceiling (Figure 30). A light shelf is typically a light reflective material that is used to channel light to the interior.

With this configuration, the external light shelf can serve the dual purpose of shielding the lower vision glazing and of directing light through the daylighting glazing. The internal light shelf, slightly inclined upwards, is used to prevent glare from low angle sun and thus is especially applicable for the east and west orientations.

The depth of the daylight zone in the internal space is generally taken to be twice the window height above the interior working plane. Based on the dimensions given in Figure 30, the depth of the daylight zone is 4.8m. The depth of the daylight zone should be used to set the electric lighting layout.

6.6

Energy efficient electric lighting

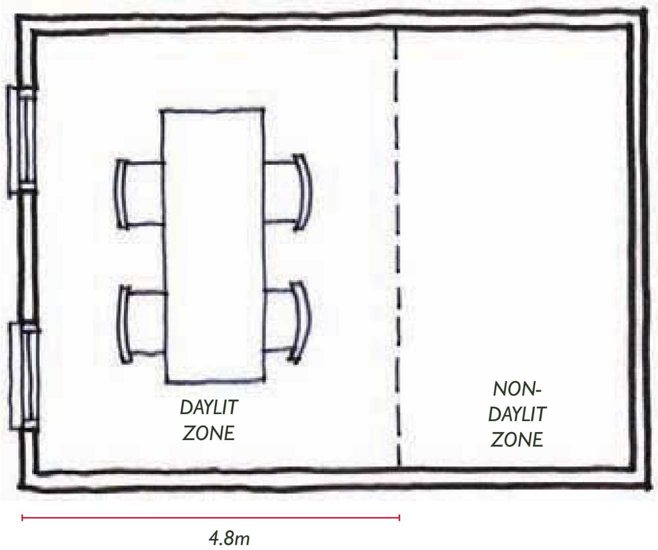


Figure 31: Daylit zone in plan

The government has taken the laudable step of subsidising energy efficient lights and through various campaigns encouraged the population to opt for them albeit their higher costs; the extra costs of the energy efficient lights are quickly recouped by the lower energy consumption and longer life. The population is again sensitised to opt for energy efficient light fittings e.g. Compact Fluorescent Lamps (CFL) and Fluorescent Tubes (described further). Nevertheless, an important factor to consider in the disposal of these lamps is that they contain mercury in small amounts, and if not properly discarded, the mercury can infiltrate into ground water and have harmful effects. The proper way to dispose the used lights is described in Section 6.7.

Figure 32: Incandescent lamp
(Source: Wikipedia)

Figure 33: Compact Fluorescent Lamp and fluorescent tube
(Source: Wikipedia)

To present the different energy efficient lighting alternatives available (in addition to fluorescent type lighting fixtures), the various types of lighting technologies are summarised next with a discussion of their pros and cons. Lighting technologies can be broadly categorised as: (1) incandescent, (2) discharge, and (3) light emitting diodes.

6.6.1 Incandescent lamps

Incandescent type lamps include standard light bulbs and halogen lamps that work by heating an electric filament. The light generation principle used is inefficient and contributes a lot of heat to the interior space. The halogen type is more efficient than the standard bulb and their respective life time is around 5000 hours and 1000 hours respectively (this means a standard lamp would need replacing every 3-4 months).

6.6.2 Discharge lamps

The most common type of discharge lamps used in building projects are fluorescent tubes and compact fluorescent light (CFL). They are highly energy efficient compared to incandescent lamps (6 times more energy efficient) and have life time of over 15,000 hours (15 times more than incandescent).

They comprise of the light fitting itself and a ballast to control the amount of current. Electronic ballasts consume less energy and cause less flicker as compared to conventional magnetic ballasts, and should be the preferred choice.

The most common type of fluorescent tube in application is the T8, with a tube diameter of 25mm, and normally equipped with magnetic ballast. Higher efficiency can be achieved by using the T5 type (diameter of 16mm), which comes with an electronic ballast.

Compact fluorescent lamps are four to five times more efficient than incandescent and have lifetimes between 10,000 and 15,000 hours. So even if they can cost 3-4 times more than incandescent lamps, their reduced energy consumption and longer lifetime quickly pay back for the extra cost.

Figure 34: LED light bulbs (top) and LED tube (bottom) (Source:Wikipedia)

6.6.3 Light emitting diodes (LED)

LED is a relatively new lighting technology. They offer comparable efficiency to CFL and are designed to offer very long lifetimes from 50,000 to 100,000 hours. Despite being in nascent phase of its development, useful lighting solutions have been marketed and can be considered for lighting design, although the cost is still on the high end.

6.7 Waste Lamps

Figure 35: Lightbulb recycling station

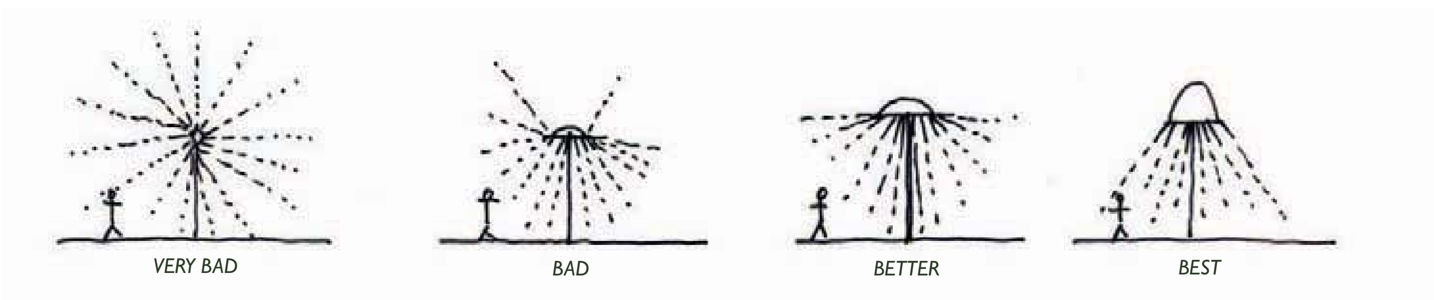
Fluorescent lamps are amongst the most energy efficient lamps sources used in the world today, with high standards of lumens per watt. However, they also contain mercury, which is a heavy metal that could cause toxic pollution if not correctly disposed of.

The practice of collecting and disposing of waste fluorescent lamps should be developed further in the island, so ensure that pollution is managed. There are now practices where fluorescent lamps can be recycled.

6.8 Controlling lighting pollution

As for external lighting, light fixtures should be selected to avoid light pollution. Light pollution occurs when the angle at which light is emitted is greater than 90° to the horizontal, meaning areas both within and outside the site are illuminated, to the detriment of visual comfort of neighbours and energy wastage. Light pollution can be prevented by choosing light fixtures that emit light at less than 90° to the horizontal and by locating the lights so that they illuminate the site only till its boundary as far as possible.

Figure 36: Lighting fixtures to reduce light pollution



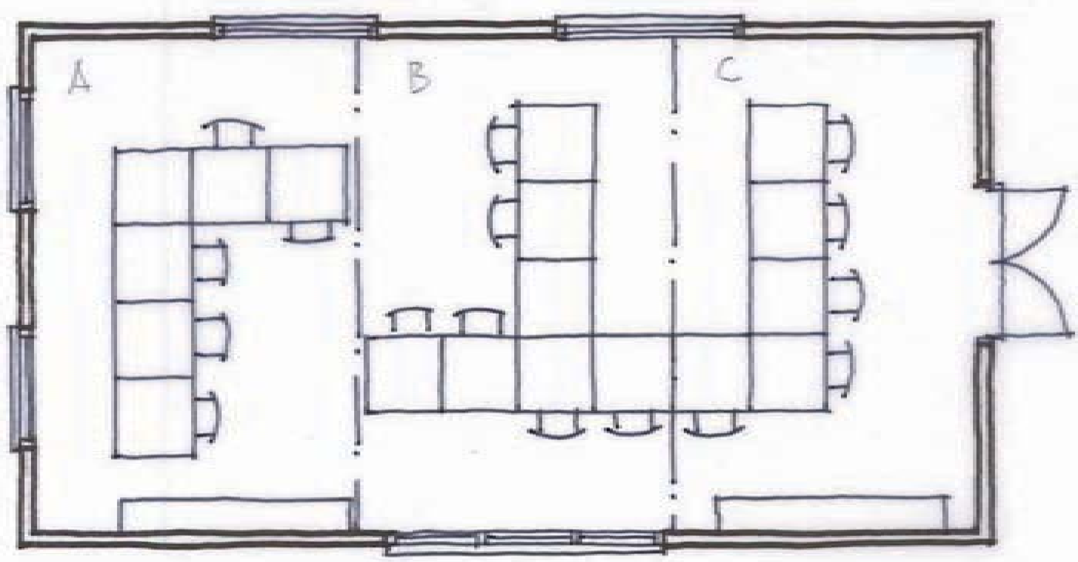
6.9 Lighting controls

Manual switching remains a very effective type of control for non-residential buildings, especially in regularly occupied areas such as offices, classroom, clinics and shops. The zoning for the lighting control should be set to allow switching off lights in areas where they are not needed.
In this way, the occupants can choose to switch off lights when there is sufficient daylight coming in. This control can be automated by the use of photoelectric switching, which uses a sensor to measure the daylight levels and control the intensity of the lights in the daylit zone accordingly.
An effective way to reduce lighting energy is by the use of dimming controls that allow decreasing the intensity of lights to suit the preferences of users.

Other areas such as staircases can be controlled by presence detection, but care should be exercised to ensure movement is detected early and the lights turned on before the safety of the occupant is put at stake, e.g. lighting the stairs well before the person reaches the stairs or a given level of the stair for multi-storey buildings. Presence detection control should be programmed with appropriate off-delay to prevent frequent switching of the lights, which reduces lamp life.

External lighting can be efficiently controlled through the use of light level sensors and/or automatic timers. Separate circuits can be used to provide a basic level of security lighting at appropriate times, with the option to switch on additional lights when there is the need for it, e.g. during outdoor activities in the evening.

For spaces which require localised lighting such as at study desks, task lighting (e.g. table lamp) can be used as an energy efficient option. Based on the depth of daylighting given earlier, the lighting circuit should be arranged to provide at least one array in the daylit zone (lights labeled A), which is separately controlled.



Separate areas into zones that can be lit individually.
Areas A, B, C have lights controlled separately
Use customised in addition to background lighting e.g. task lighting to each desk space

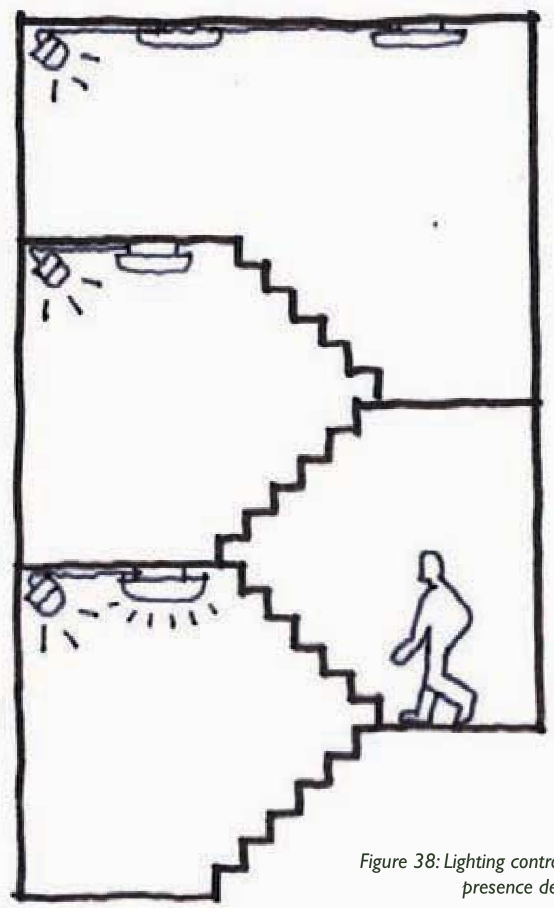
Figure 37: Arrangement of light fixtures and local controls

6.11 Lighting energy efficiency benchmarks

Table 5 gives benchmarks that should be used to assess the efficiency of lighting installations, with the goal to achieve the high end of efficiency. The last column provides guidance on how to improve the efficiency of the lighting installation.

Level of efficiency	Light Power Density (W/m²)	Accompanying lighting technology and underlying design principle
Average	25-35	Standard fluorescent fittings for uniform lighting
Good	10-15	High efficiency T5 tubes for uniform lighting
Excellent	5-8	As for 'Good' to provide background lighting and task lighting at workstations
Outstanding	2-5	As for excellent but with daylighting and photoelectric sensing for dimming

Table 5: Energy efficiency benchmarks for lighting



When PIR sensor detects movement, lights on the floor where presence is detected are turned on.

An appropriate delay should be used before lights are turned off when no presence is detected (e.g. 5 mins.)

Figure 38: Lighting controlled by presence detection

7

Energy Efficient Appliances

7.1 Introduction

Figure 39: Energy Star Logo as testament of energy efficiency (Source: Wikipedia)

Before purchasing any appliance for the home, it is good practice to check the energy label or rating on the packaging or product itself. The energy label will usually give an indication of the annual energy consumption of the appliance and rate its energy performance on a given scale. Two common examples of energy rating for appliances are:

- Energy Star sticker (by the U.S. Environmental Protection Agency), meaning the appliance exceeds minimum standards enforced in the US for energy efficiency (typically by 20-30%). It also shows that the product is one of the most cost-efficient available.

Figure 39 shows the blue Energy Star logo, which consumers can look for as a testament of the energy efficiency of the appliance.

- EU Energy label showing energy efficiency rating on a scale and expected energy consumption.

A sample of the EU Energy label for a washing machine is shown in Figure 40.

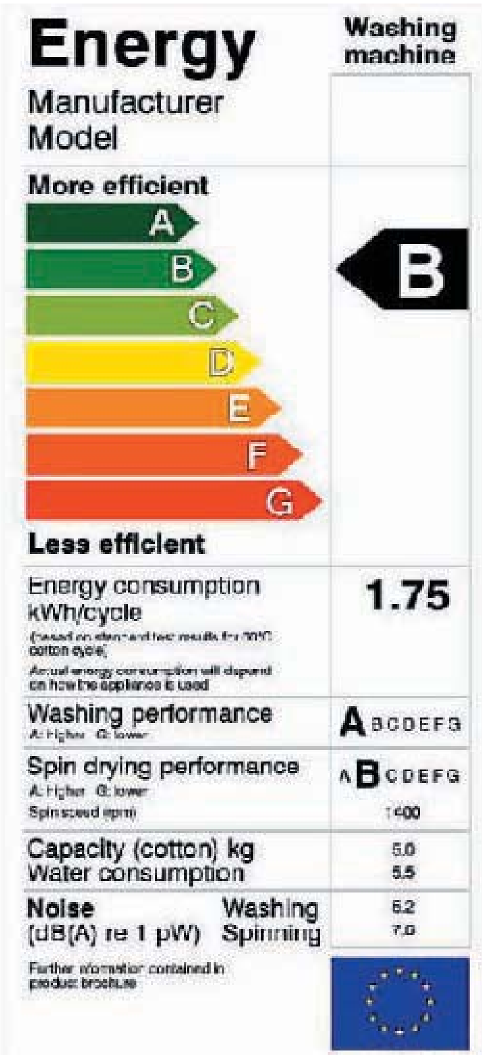


Figure 40: Sample of EU Energy label for a washing machine (Source: Wikipedia)

7.2 Appliances

Air-conditioning equipment and water heaters, the main energy consuming appliances in a typical Mauritian workplace are refrigerator/ freezers and washing machines. The following information is helpful in making a wise energy decision when purchasing such appliances.

7.3 Refrigerators

The refrigerator accounts for up to 8% of most typical energy bills. Side-by-side refrigerator/ freezers typically use 35% more energy than models with the freezer on top. If kept defrosted, manual-defrost models usually use about half as much energy as automatic defrost models. Chest (top loading) freezers are typically 10-15% more efficient than upright (front loading). There are exceptions to these rules, so it pays to check the energy rating of the appliance. The right size model according to needs has to be chosen to obtain the most energy efficient system.

8

Source: IPS Inter Press Service

Renewable Technologies

8.1 Solar Thermal (Hot water)

Mauritius and most countries of the African continent are known for their high solar energy yield (Figure 41), which makes hot water production a very cost effective investment for households. This has been made possible by the general improvement in solar collector thermal efficiency, currently up to 85% for evacuated tube collectors (Figure 42).

Based on the latitude of Mauritius and its location in the southern hemisphere, solar collectors should ideally be oriented towards the north, (with north-east and north-west being second best alternatives) and inclined at 20° ideally to the horizontal, although inclinations up to 45° can be used without significant decline in system performance.

The general public is encouraged to opt for solar water heating systems for their households, for which they can benefit from grants from the MID fund, although the scheme is not running at all times. The population is requested to direct their interest to the Ministry of Environment and Sustainable Development (MoESD) and the Development Bank of Mauritius (DBM) to get further information about the grant and also to get a list of approved solar water heater suppliers.

A typical solar water heating system for a 5-person household requires about 5m^2 space with a clear sky view to the north and ideally without shading during sunlight hours. Therefore, it is encouraged to reserve an area with these characteristics for accommodating a solar water heater, either during construction or as a later investment.

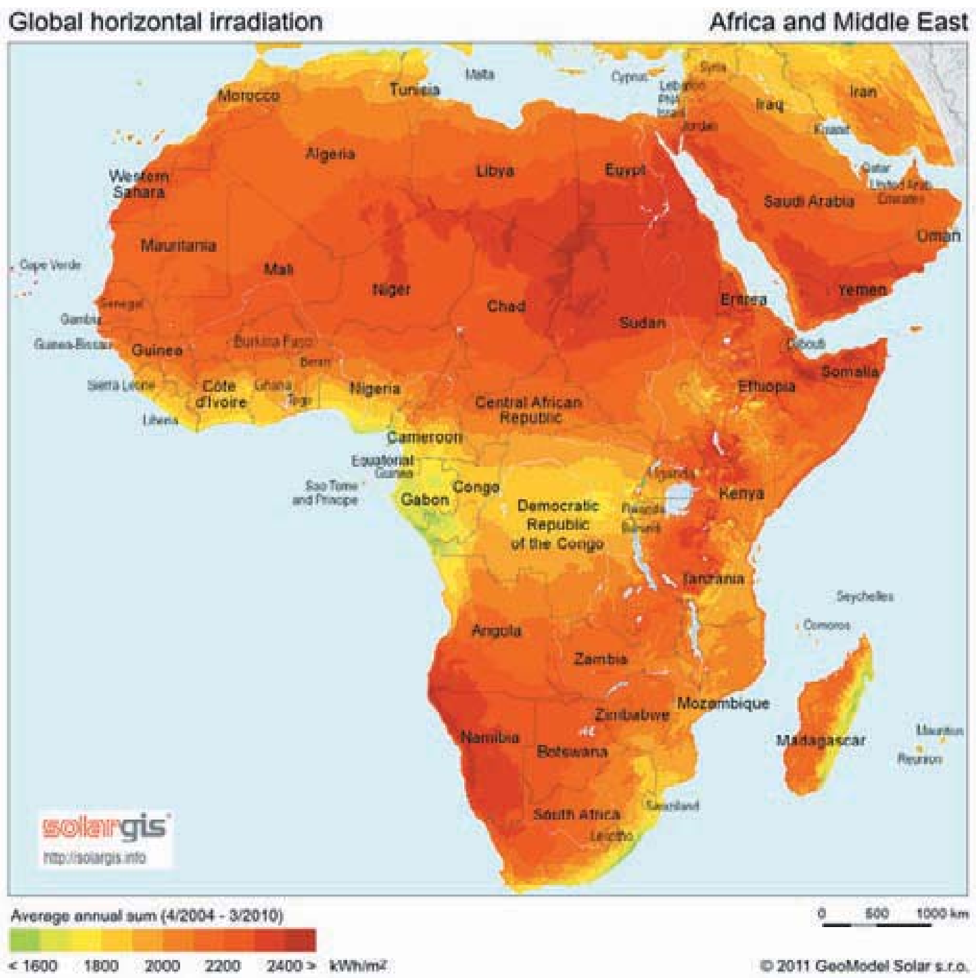


Figure 41: Solar map for Africa (Source: Wikipedia)

8.2 Photovoltaics (PV)

Figure 42: Solar collector for hot water production (Source:Wikipedia)

PV panels (Figure 43) allow the conversion of solar energy to electricity and have been an important source of renewable energy for producing 'green' electricity worldwide. However, the cost for this technology is still quite high, preventing a large scale penetration over the market.

On its own, solar PV systems typically have return on investment of around 9-10 years, manufacturers offering over 25 years of warranty on the panels. With the recent initiative of government to enable small power producers to sell electricity to the grid, via the SSDG scheme, the return on investment can be reduced to 4-5 years. Interested parties can consult the CEB website for calls for new applications to join this scheme.

8.3 Wind Turbines

Figure 43: Solar PV for 'green' electricity generation (Source:Wikipedia)

Figure 44:Wind turbines for electricity generation (Source:Wikipedia)

Wind turbines are widely used around the world as energy generation alternatives both on large and small scales. Large scale mostly concerns implementation of wind farms generally in remote areas with high wind resource. In contrast, small scale projects consist of the implementation of urban wind turbines (UWTs) and they show some potential for green energy generation.
There are two common types of wind turbines, (Figure 44):

- Horizontal Axis Wind Turbines (HAWT);
- HAWT's have a propeller-type rotor mounted on a horizontal axis.
- Vertical Axis Wind Turbines (VAWT); VAWT's are typically developed for urban deployment. They have a series of blades rotating around a vertical axis.

The wind power resource class is important when considering wind turbine implementation. For this purpose, the annual average wind speed and the annual average wind power density (WPD) are of great importance when assessing potential sites. For example, the classification method used by the American Wind Energy Association can be used to assess the wind power yield potential for Plaisance and Vacoas. This classification rates the potential of a site through 7 levels, with 1 representing poor and 7 superb (Figure 45).

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Mean Speed range (b) m/s (mph)	Wind Power Density (W/m^2)	Mean Speed range (b) m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6(12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	200 - 300	5.6 (12.5)/6.4 (14
3	150 - 200	5.1 (11.5)/5.6 (12.5)	300 - 400	6.4 (14.3)/7.0 (15
4	200 - 250	5.6 (12.5)/6.0 (13.4)	400 - 500	7.0 (15.7)/7.5 (16
5	250 - 300	6.0 (13.4)/6.4 (14.3)	500 - 600	7.5 (16.8)/8.0 (17
6	300 - 400	6.4 (14.3)/7.0 (15.7)	600 - 700	8.0 (17.9)/8.8 (19
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

(a) Vertical extrapolation of wind speed based on the 1/7 power law
(b) Mean wind speed is based on the Rayleigh speed distribution of equivalent wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, mean wind speed must increase 3%/1000 m (5%/5000 ft) of elevation. (from the Battelle Wind Energy Resource Atlas)

Figure 45: Wind Power Class table
(Source: American Wind Energy Association (AWEA))

The wind power density (WPD) is the wind power available per square meter and the values for Plaisance and Vacoas are given in Table 1 for wind measurements taken at 10m heights.
The results show that Plaisance gets a rating of 4 (good) and Vacoas 3 (fair) showing potential for wind energy projects.

The installation procedures are usually more complicated than PV panels as consideration should be given for local wind conditions and obstructions causing turbulence. Local consultants and contractors can be contacted for an assessment of the suitability of wind turbine for a specific location for a more efficient design. Wind turbines are also covered by the SSDG scheme from the CEB as described in the Photovoltaics section.

Region	WPD (W/m²)	E, Annual available energy content (kWh/m²/year)
Plaisance	242	2,123
Vacoas	134	1,173

Table 6: WPD and energy content values obtained from average wind speeds.

8.4 Absorption Cooling

There is growing interest in a method of cooling buildings which uses a heat source e.g. hot water generated from solar energy, instead of electricity to run conventional air-conditioning equipment. The technology is known as absorption cooling. The biggest difference between this technology and the 'typical' vapour compression systems is that a heat source is used instead of a compressor and a refrigerant/absorber mixture replaces the refrigerant.

Despite being less efficient compared to normal vapour compression chillers, the only electrical element used by an absorption chiller is a pump to move the mixture through the system. These pumps consume much less power and produce less noise and vibration than a compressor. This latter point is useful if the chiller is to be sited near to a noise sensitive area. The configuration of an absorption chiller makes it less prone to break-down and involves lower maintenance costs as compared to a vapour compression system.

Running an absorption chiller system on electricity or gas to produce the heat does not offer an economically viable alternative when compared to vapour compression systems. However, given the high solar energy yield in Mauritius, the system can be coupled to a solar thermal system, which makes it a viable as well as a sustainable cooling system. With the big success of such absorption chiller systems in Reunion Island, we think this technology can be used as a low energy alternative wherever and whenever cooling is required.

9

Water Efficiency

9.1 Introduction

Water is vital for our subsistence and hence its sustainable consumption is essential as part of the operation of a building. We have recently gone through a severe drought period, reminding us of the need to use water judiciously at all times. This chapter describes the various means by which water efficiency can be improved in operation of the residential building, both interior and exterior.

9.2 Rainwater Harvesting

Rainwater harvesting has been encouraged by the client group to reduce water consumption of the buildings, with the knock-on benefit of reducing energy consumption and the treatment costs of the potable water supply. Rainwater in Mauritius is often collected from roof areas, and is stored in GRP or plastic tanks for use as an alternative source of water for irrigation, laundry and WC flushing.

9.3 Water efficient fixtures

In most buildings plumbing fixtures provide essential services to occupants like bathing, hand washing, and sewage conveyance. In all of these applications the water consumption depends on two basic variables: usage patterns and consumption per use. Usage patterns are largely a matter of personal preference, and building management can do little to change them. For the most part, lowering the water use in plumbing fixtures means improving your fixture technology to lower the consumption per use. Installing dual-flush cisterns, flow restrictors, aerators and self-closing devices are effective ways to reduce water consumption. These technologies often pay back for the extra investment in less than a year. Table 7 provides a comparison of conventional plumbing fixtures and water efficient ones, showing a potential reduction of 41%

	Conventional				Water efficient			
	Water demand per appliance		Estimated total daily demand (L)	Appliances	Water demand per appliance		Estimated total daily demand (L)	
	L/Flush	L/s			L/Flush	L/s		
WC	9	N/A	72	3/6L cistern for WC	3/6L	N/A	36	50%
WHB	N/A	0.15	36	Self-closing & flow limitation for WHB	N/A	0.067	16	55%

Table 7: Comparing conventional and water efficient fixtures

9.4

Dual flush cistern

Dual flush WC cisterns can be flushed either at half full volume depending on the use. A lever or a button operates the flushing mechanism, which is on the cistern, with varying capacity of the flush from 3 to 9 litres.

A typical 3/6 litre cistern uses 3 litres to dispose of liquid waste and 6 litres to dispose solid waste. The savings can be approximated to 13,000 litres per year.

9.5

Aerators/ Flow restrictors

Among the most useful instruments for saving water at home are aerators or flow reducers, which provide a reduced but still useful volume of flow from taps. Aerators are the simplest and easiest saving step that can be undertaken in an existing building. It's as simple as unscrewing the old and screwing on the new head with no change in pipe size or valve required.
Aerators when used on taps for wash hand basins and sinks help reduce water by up to 55%. Flow limiting devices, when integrated into showerheads, can save up to 70,000L yearly.

Figure 46: Water Aerator

9.6

Self-closing devices

Taps equipped with PIR sensors work the same way as occupancy sensors for lighting; they provide water upon detecting the presence of a person's hand under the tap. This eliminates the likelihood of a person leaving the tap open when not in use.

9.7

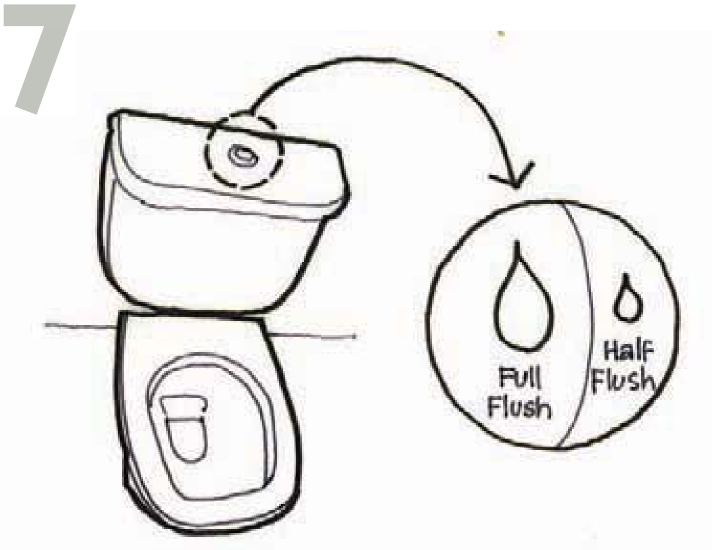


Figure 47: Dual-flush cistern

Irrigation

As well as rainwater harvesting, we recommend that greywater recycling also be installed to assist with irrigation of plants. The irrigation requirements of any Plants should be selected for their tolerance of raw greywater irrigation and their ability to survive long bouts of hot, dry weather.

10

Other Potential Applications

10.1 Heating

Whilst it is very rare, our stake-holder investigations have shown that there may be occasional requirements for heating during winter in regions in the same climatic zone as Vacoas. To reduce the need for heating, it is recommended that insulation be applied to all rooftops.

If heating is deemed necessary, the grilles/vents need to be closed to allow minimal air infiltration. Glazing needs to be oriented to benefit from passive solar gains which will assist with heating loads.

10.2 Solar Hot Water Heating

Solar hot water heating is one of the highest potential energy savings for the energy efficient designs project. Grants exist in Mauritius for proprietary evacuated tube type systems to be installed. However in certain cases, even grants can make these systems cost prohibitive.

An alternative design could be to use simplified, efficient solar hot water systems – that can be developed on the island. These systems offer energy efficient water heating – and could be also help to generate new industry for Mauritius. Typical systems could be as simple as coils of black plastic pipe linked to a storage tank

10.3 Roof level water storage

Roof level storage is a strategy that is becoming more widely adopted due to the benefits of using gravity to supply the water with no need for an energy-consuming pump. This means that for the whole of the building life, there would be no need for an electric pump to supply rainwater for flushing the WC or irrigation. The advantages of high level water storage are that it uses no energy, it requires no maintenance and offers a lifetime of free rainwater for WC flushing. This liberates more potable city water.

After reviewing the Island's building materials, the simple concrete channels are readily available and can be purchased economically throughout the Island. Waterproofing can be carried out in situ with waterproof paints or liners. An alternative would be to use a glass reinforced plastic (GRP) tank.

To eliminate the risk of mosquito propagation, all water storage must be completely and securely covered. The alternative would be to install a water tank/rainwater butt at low level and use a pump to supply the water from the storage tank.

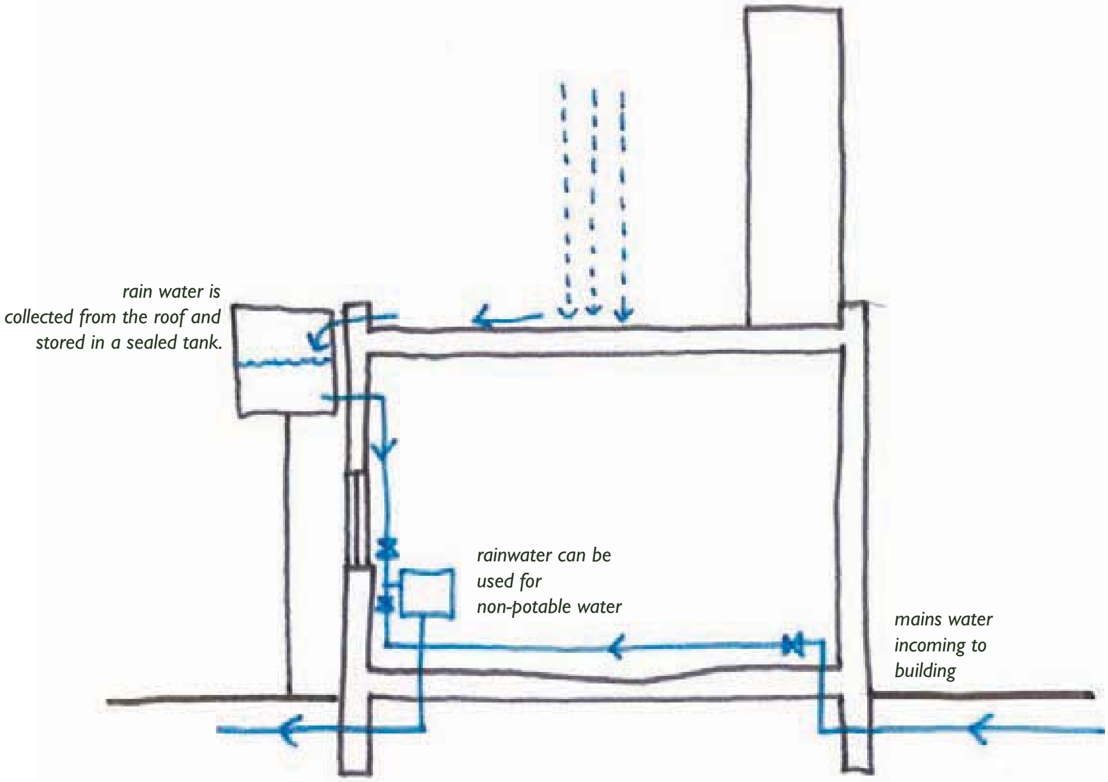


Figure 48: Rainwater harvesting system


II

Solid Waste Management

11.1 Introduction

The management of all wastes is increasingly important, and especially so for an island country, as limited space is available for processing or disposal.

This guidance refers to the management of solid waste from construction and operation of buildings.

11.2 Construction Waste

Waste from construction has been estimated to be around 10% of the volume used for construction. Furthermore, at the end of a building's life, the whole construction becomes demolished and needs to be managed.
There are examples around the world where waste is recycled and used in new products for construction.

As a minimum, the concrete blocks can be crushed and reused as aggregate in new blocks or as hardcore for foundations.

Figure 49 (Stock Orchard Street)

11.3 Municipal Waste

The existing campaigns to mobilize people to sort out their waste are being adopted in Mauritius, but what needs to happen now is for these waste streams to be collected separately and then processed and recycled.

Waste streams should be sorted as follows:

- organic waste – can be composted on site to provide improved soil.
- recyclable waste: paper, plastic, glass, metal;
- hazardous waste (used batteries and lamps) – separated with dedicated collection.

Appendices

A. The Project Team
B. Glossary of terms
C. Simulations
D. Energy Efficient Green Building References

Appendix A

The Team

Sarah Wigglesworth Architects

Award winning architects established in 1993. Our track record is in sustainable and ecological architecture and our uniquely beautiful work is characterised by a powerful sense of place and materials. Our growing portfolio includes structures for leisure and entertainment, masterplanning, cultural buildings, social housing and buildings for education for education, arts and sport. We have a strong research based ethos and direct links with academia.

Good architecture is the product of collaboration and depends on a time-based process involving listening and innovation. We work closely with clients and users, other branches of architectural research, consultants and related disciplines to develop working methods appropriate to each project.

We believe each project is a unique solution to a unique set of circumstances. Accordingly our output is wide ranging and our products formally diverse. We have won many awards for our work.

Archineers Consulting

A team of architectural engineers, led by Trevor Butler, that specialise in sustainable design.

Our expertise ranges from the micro-scale of finite energy analysis to the macro-scale carbon neutral strategies on community, city and country levels.

Our most exciting projects have sought to bridge the gap between architecture and engineering and champion the cause of sustainability in the design of the built environment. We have previous work experience in Mauritius, and are delighted to be working again on such an exciting project that will leave a positive sustainable legacy for local communities.

Prodesign

A firm of multi-disciplinary consulting engineers located in Mauritius specialising in mechanical, electrical, public health and sustainability engineering for the built environment.

Established in 1997, Prodesign expert teams have worked on landmark projects in all major sectors including office, commercial, healthcare, residential, sports, laboratories, data centres, hotels and leisure. The company was founded on the basis of providing creative and cost effective design, with a high level of service to clients. Our key commitment is in promoting sustainability for the creation of green buildings of the future.

Appendix B

Glossary

A

Absorption cooling – a form of air conditioning that uses waste heat rather than electrical compressors to generate cooling for buildings;
Aerators – a plumbing fixture used to reduce water flow through taps;
Air-conditioning – a mechanical system that generates cooling in buildings;
Albedo reflective roofs – a reflective coating applied to buildings to reflect heat from the sun;
ASHRAE – American Society of Heating, Refrigeration and Air-conditioning Engineers;
Awning – a deployable structure fixed to a building to provide shade/shelter;
Azimuth - the direction of a celestial object from the observer, expressed as the angular distance from the north or south point of the horizon to the point at which a vertical circle passing through the object intersects the horizon.

C

Climate zone – the environmental conditions associated specific place;
Coefficient of performance (COP) – the average operating efficiency of a machine;
Cooling degree day – the number of degrees that a day's average temperature is above a set standard (typically 18°C);

D

Daylighting – using natural light from the diffuse sky for illumination;
Daylighting glazing – window or rooflight opening through which natural light enters a space;
Depth of overhang/awning – the distance extended from the edge of the building;
Dual-flush cistern – a toilet flushing mechanism with two flushing options (typically 3 and 6 litres);

E

Eave – the junction of a buildings roof and wall, typically with an overhang;
Evacuated tube collectors – solar hot water system that uses glass tubes to collect heat from the sun;
External shading – an external fixture used to block the sun;

F

Flow restrictors – a plumbing fixture used to reduce water flow through taps;

G

Grey water – wastewater from showers, baths and laundry, often recycled for non-potable use;
Green roof – vegetation installed on a building roof;

H

Hard landscape – areas of paving, tarmac or concrete outside a building, street, etc;
Heat gain – thermal power generated by sun, people, lights and equipment;
Heat island effect – areas where the ambient temperature is hotter caused by a greater concentration of hard landscape and buildings;
Heating degree day – the number of degrees that a day's average temperature is below a set standard (typically 18°C);
Heating, Ventilation and Air-conditioning (HVAC) – mechanical systems of fans, pumps, boilers, chillers, duct, pipes and fittings used to control the internal environment of buildings;
Horizontal axis wind turbine – similar in appearance to a propeller: used to generate energy from wind;

I

Imperviousness – a material that blocks the flow of water;
Indoor environmental quality (IEQ) – a measure of temperature, humidity, acoustics, light, air movement and odours within a building;
Insulation – material used to reduce heat flow through a building envelope;
Integrated design process (IDP) – an inclusive approach to building design, construction and occupation;
Interlocking blocks – a construction system used for walls or paving;
Internal shading – blinds or curtains used to control light levels;

L

Landscaping – the area outside of buildings, normally contained within the property lines;
Life-cycle assessment (LCA) – appraisal of longevity of building components;

Life-cycle costing analysis (LCCA) – financial analysis of building components;
Light pollution – where artificial lighting spreads beyond the use for which is was meant;
Light shelf – a building fixture used to reflect light internally from the edge of a building;
Louvre/brise-soleil – a shading device fixed to the outside of a building;

M

Mechanical cooling – a machine that is used to provide cooling to a building;
Mechanical ventilation – a motorised fan used to move air within a building;

N

Native/adapted plants – indigenous flora occurring naturally in a location;
Natural ventilation – a method of moving air through a building without mechanical fans;

O

Occupant comfort – a measure of well being for building occupants;

P

Parts per million (ppm) – a measure of relative concentration, e.g. carbon dioxide levels in a building;
Payback Period - time taken to derive savings in energy equivalent to the capital expenditure of a specific piece of technology.
Photovoltaics – a device that generates electricity from the sun;

R

Rainwater harvesting – collecting and storing rainwater for re-use when required;
Refrigerant – a gas or liquid used to generate cooling in an air conditioning system;
Renewable energy – energy creation from natural and non-polluting sources;
Run-off – stormwater that cannot soak into the ground naturally;

S

Sedimentation – accumulation of fine material from process, that may cause blockages;
Self-closing device – a controller that automatically stops water flow after a set time interval;
Solar angle – the direction and intensity that the sun shines on a given orientation;
Solar path – the journey of the sun, through a day, season, year or other period of time;
Solar thermal – a device for collecting heat from the sun for use in a building;
Small Scale Distributed Generation (SSDG) – electricity generated to serve buildings within a limited area;
Stormwater management – a system to control rainwater, which may include storage, attenuation and reuse;

U

Underground aquifer – a water body from which water is abstracted through wells/boreholes;
U-value – a measure of the thermal conductance of building envelope (lower = better insulation);

V

Ventilation – air change and movement in a given space;
Vertical Axis Wind Turbine – a device to generate electricity from wind by the rotation in a vertical plane;
Vision glazing – a transparent panel in a door or wall;

W

Water efficiency – a measure of relative water consumption against a general benchmark;
Wind regimes – the effect of prevailing winds in a specific location;

Appendix C
Simulations

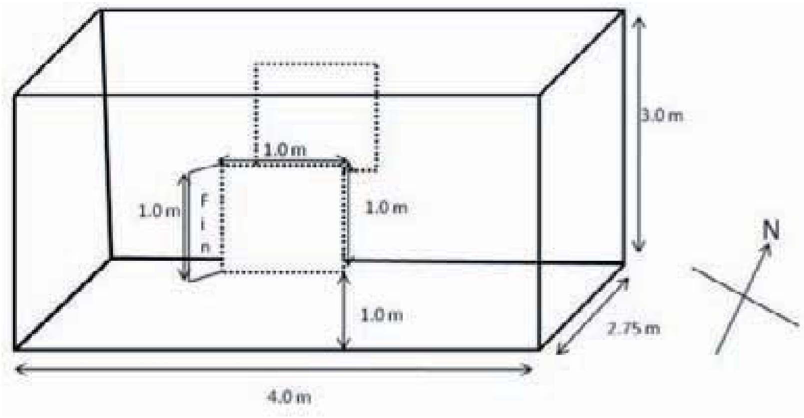


Figure 50: Schematic diagram of room considered with dimensions

Modelling effect of fins in CFD

Model set up:

To simulate the effects of adding fins to a window for a natural ventilated room, a 4.0 m by 2.75 m by 3.0 m room was considered. The room had two 1.0 m by 1.0 m windows on the north and south façade respectively. The width of the fin is varied from 0 (no fin) to 0.6 m Figure 50 is a representation of the room considered.

In all the simulations, it was assumed that wind blows in a south easterly direction at a speed of 3.0 ms-1.

The k- turbulence model was used to model the fluid flow in the room.

Results of simulation

The results of the CFD simulation performed are shown in Figure 51, showing a clear increase in air movement across the room with the presence of the external fin.

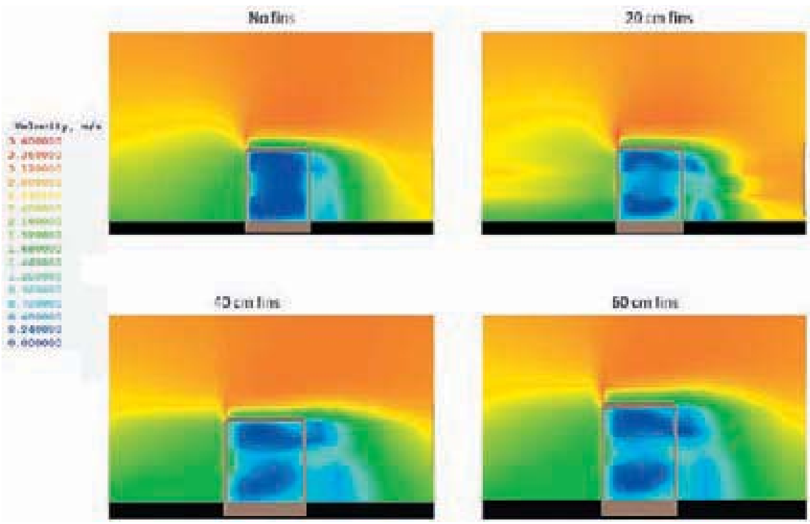


Figure 51:Velocity profiles in the room with increasing fin width (side view to show air movement across the space)

CFD

Fins — Modelling the effects of adding fins to a window in a naturally ventilated space

HEAT GAINS

Rectangular building — Determining the optimum glazing % for each orientation so as to maximise views and reduce heat gains for Plaisance

Determining the optimum overhang depth for a window in the north, east and west façade for Plaisance

Determining the optimum glazed facade

Parameters investigated:
In order to determine the amount of glazing to be allocated on each façade, two parameters were considered:

1. The internal floor area with views to the outside.
2. The solar gains in the room due to the glazing size.

Model set up:
A room 4.0 m long, 2.75 m wide and 3.0 m high was modelled. The windows in the room were placed at a height of 1.0 m above the ground. Window height was kept constant at 1.0 m while the width of the window was varied from 5 % to 100 % of the length of the wall of the façade being considered (Figure 52).

Overhangs were placed at 0.05 m of above the window while the overhang depth was kept constant at 0.45 m (Figure 53). The length of the overhang was the same as the window width.

The floor area having outdoor views was obtained by drawing sight lines on plan views. For all the cases considered, the window was placed in the middle of the room. The % floor area with views was calculated based on the internal floor area.

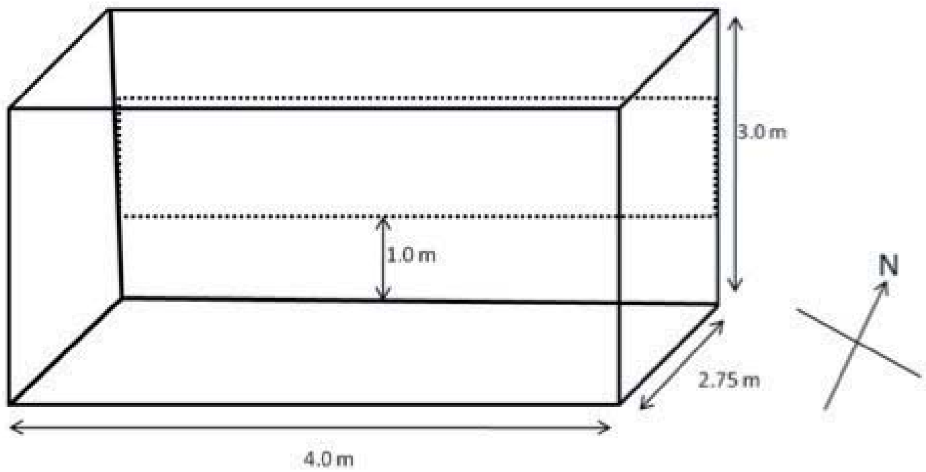


Figure 52: Schematic diagram of room with the north facade having 100% glazing

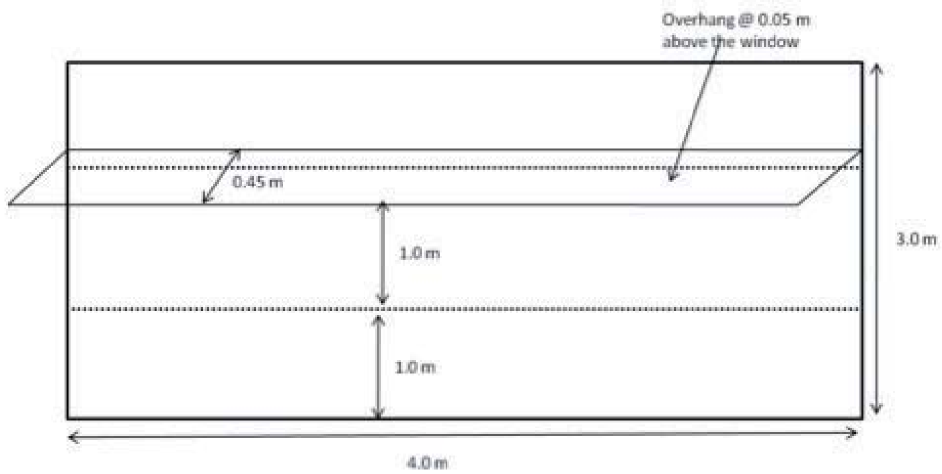
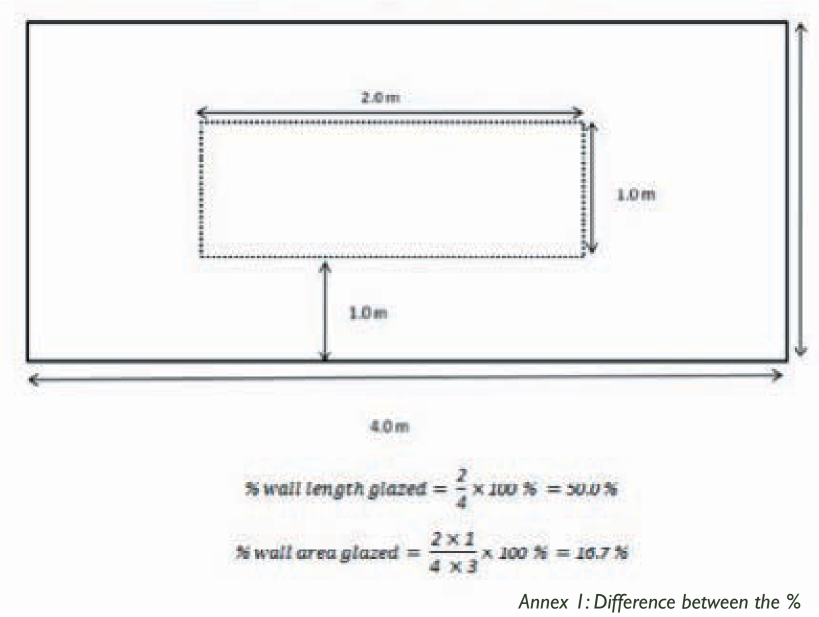


Figure 53: North facing wall with overhang



Annex 1: Difference between the % wall area glazed and % Wall length glazed

In order to determine the total annual solar gains, the following building envelope fabric was used

* U-values are the ASHRAE values as calculated by IES-VE 6.4

Occupancy, lighting and equipment gains were not considered in any of the simulation runs. ASHRAE load calculations were performed to obtain the total annual solar gain of the model room. The Plaisance weather file was used in all the simulation runs.

The variations of percentage views and heat gains (with and without overhangs) with respect to changing percentage of glazing on the different orientations are shown on the graphs below. It is found that as expected, overhangs are not effective on the south, east and west facades, but they are effective on the north façade. Additionally, a 25% glazing percentage generally provides access to external views to most of the internal spaces.

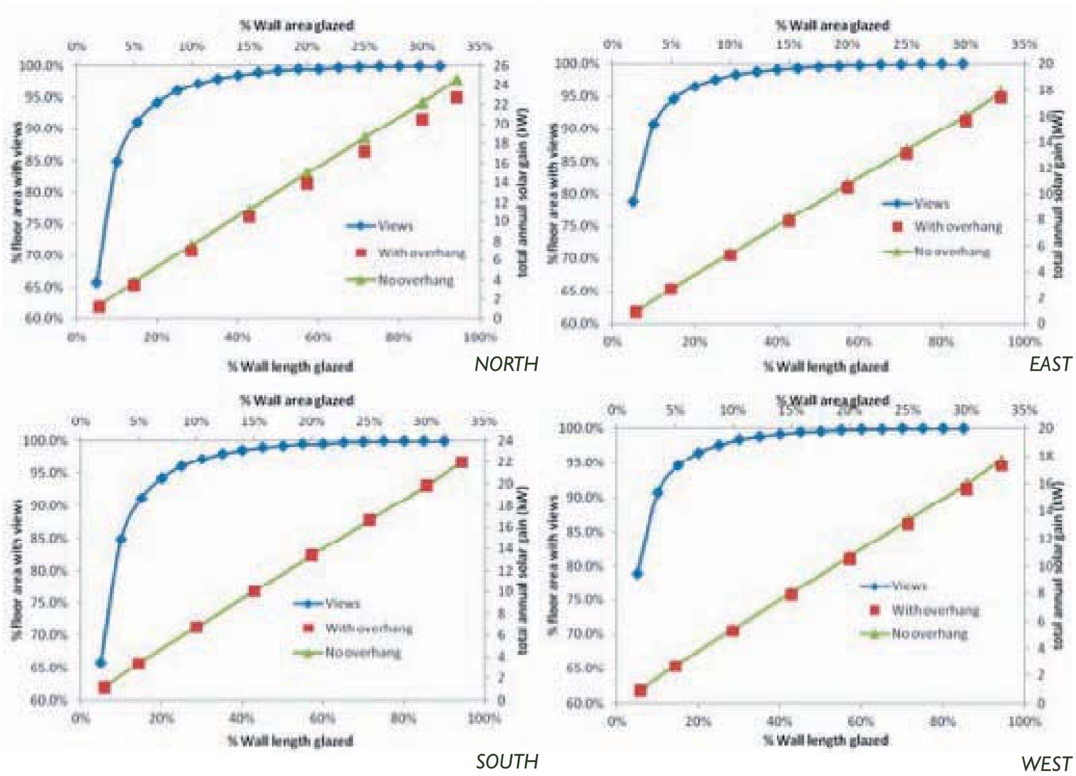


Figure 54: Results of simulation

Building element	Construction layer (from outside to inside)	U-value* (W/m²K)
External wall	19 mm external rendering; 200 mm medium weight concrete block; 13 mm dense plaster	1.6506
Roof	5 mm roofing felt; 75 mm screed; 150 mm dense cast concrete; 13 mm dense plaster	2.0844
External glazing	6 mm clear glass single glazed	5.8111

Table 8: Building fabric

Determining the optimum overhang size

Model set up:
In order to simulate the effect of overhangs on the building heat gains, a 4.0 m by 2.75 m by 3.0 m room was considered. The room had one window in the north facing wall. The window was 4.0 m long and 1.0 m high located 1.0 m above ground (Figure 55). Overhangs were place 0.05 m above the window as shown in Figure 56 and Figure 57.

In the north facade, the depth of the overhang was varied from 0 to 0.75 m while in the east and west facade, the overhang depth was varied from 0 to 1.0 m.

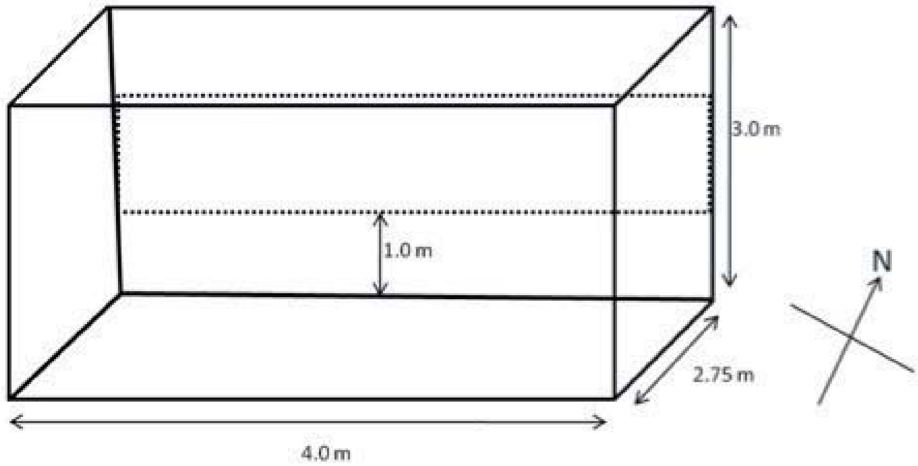


Figure 55: Schematic diagram of room considered with dimensions

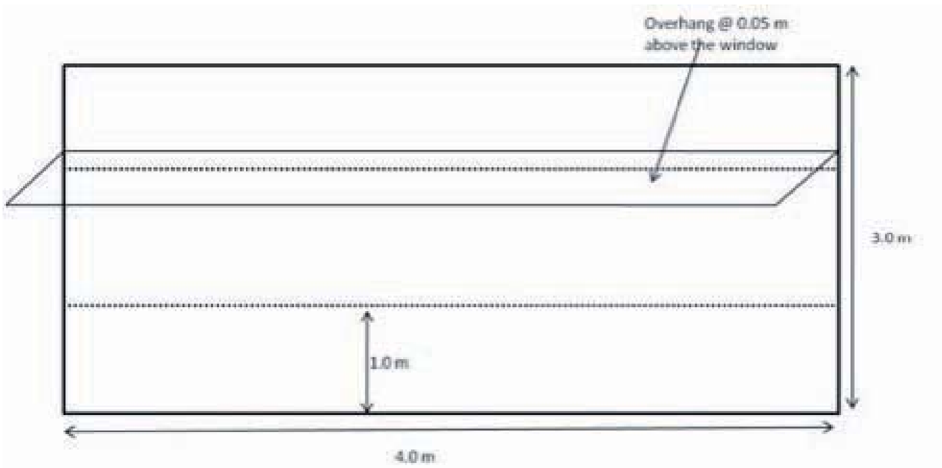


Figure 56: North facing wall

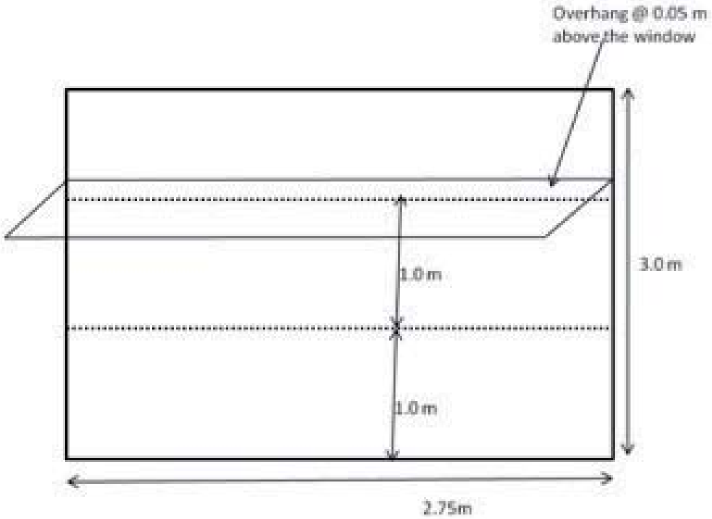


Figure 57: East and west facing wall

The fabric used for the building envelope was as follows:

* U-values are the ASHRAE values as calculated by IES-VE 6.4

Heat gain simulations were performed using the ASHRAE method in IES-VE 6.4. The weather data used was for Plaisance. No occupant gains, lighting gains or equipment gains were included in the simulations.

Results of simulation. On the north façade, an overhang depth greater than 0.5m is found to block most of the direct solar radiation. On the other hand, for the east and west façades, there is no significant change in cooling load when the overhang depth is changed, showing the inefficacy of overhangs along these orientations.

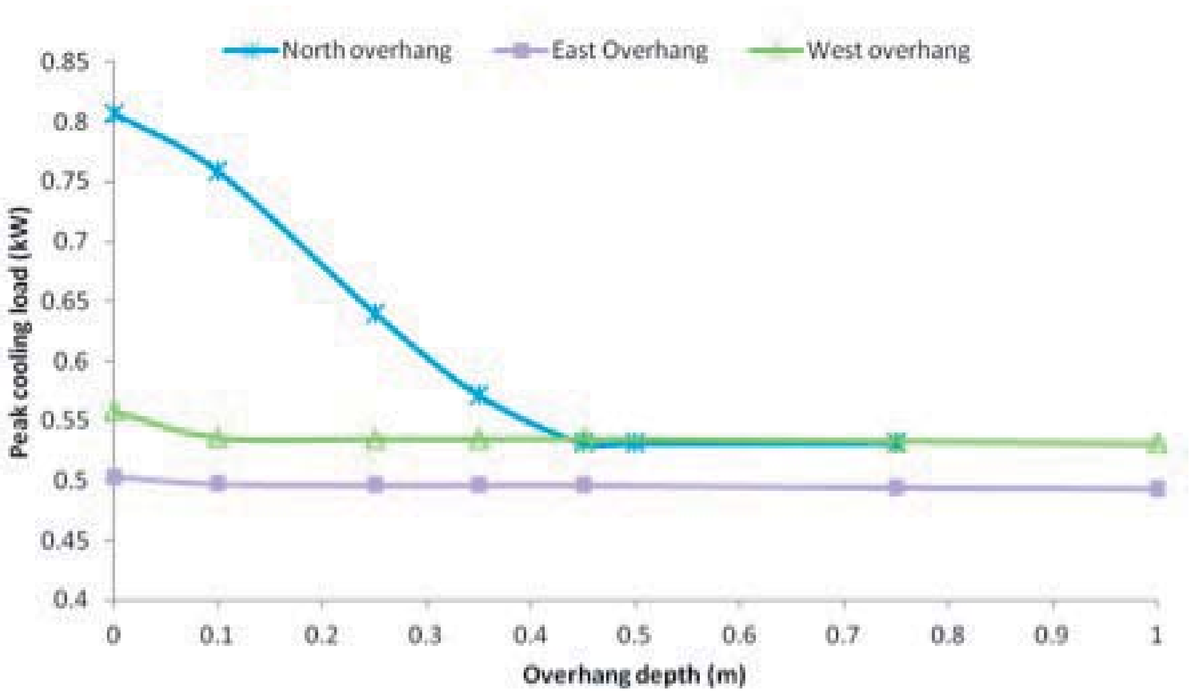


Figure 58: Variation of Peak cooling load with overhang depth

Building element	Construction layer (from outside to inside)	U-value* (W/m²K)
External wall	19 mm external rendering; 200 mm medium weight concrete block; 13 mm dense plaster	1.6506
Roof	5 mm roofing felt; 75 mm screed; 150 mm dense cast concrete; 13 mm dense plaster	2.0844
External glazing	6 mm clear glass single glazed	5.8111

Table 9: Building fabric

Appendix D

Energy Efficient Green Building References

Rocky Mountain Institute:
www.rmi.org

Chartered Institute of Building Services Engineers:
www.cibse.org

American Society of Heating Refrigeration and Air-conditioning Engineers:
www.ashrae.org

Building Research Establishment:
www.bre.co.uk

United States Green Building Council:
www.usgbc.org

Canadian Green Building Council:
www.cagbc.org

International Living Building Institute
www.ilbi.org