Preparation of standard designs for low and middle-income housing, schools and other building needs

Review of International Best Practice

March 2011

gef GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET

PRO-DESIGN
Engineering Consultants Ltd

Sarah Wigglesworth Architects

archineers
simple, sustainable solutions

Executive Summary

The UNDP has appointed Sarah Wigglesworth Architects (SWA), Archineers and our local partners Pro-Design in Mauritius as consultants for the preparation of standard designs for low and middle income housing, schools and other buildings.

During this phase of the project we have been undertaking a review of international best practice in the tropical regions across the globe. This will help us identify the relevant examples of comparable buildings that have been successfully employed elsewhere addressing the criteria considered within our Inception Report to increase energy efficiency in both the design and construction of buildings within similar climatic zones. The aim is to use these as a sourcebook for methods that are appropriate to the task of designing low and middle income residential and targeted non-residential building types for Mauritius.

The following conclusions have been drawn from the completion of this report:

• Our standard designs need to provide specific responses to the specific conditions of the two climatic zones for our standard designs in Mauritius.
• Low cost and low tech solutions are going to be most appropriate for Mauritius.
• The engagement of a local community can bring much added value to a project, particularly in regard to the education of the reasons why increasing energy efficiency within the construction industry is globally important.

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1.0 Introduction

1.1 Learning from others
Following the acceptance of the Inception Report this report forms the second part of our output in respect of our investigation as part of the UNDP-Global Environment Facility (GEF) project " Removal of Barriers and Energy Efficiency and Conservation in Buildings". The overall project aims are as follows:
- To reduce green house gas emissions in a manner that can be sustained.
- To promote the market demand for energy efficiency in new and existing buildings.
- To prepare the ground for climate change adaptation.

This report aims to lay the foundations for establishing global best practice in the sector typologies relating to our study to develop standard designs for residential and targeted non-residential buildings for Mauritius.

This specific report will look at the following topics:
a: How best to learn from international best practice in achieving the goals of our project
b: Understanding the specifics of Mauritius with particular attention paid to the climatic, demographic, infrastructual and topographical conditions.
c: Identify the next steps for the project.

1.2 Outputs

This report forms the output for this stage of the project.

1.3 Report Authors

This report has been produced by Sarah Wigglesworth Architects together with Archineers and Pro-Design.

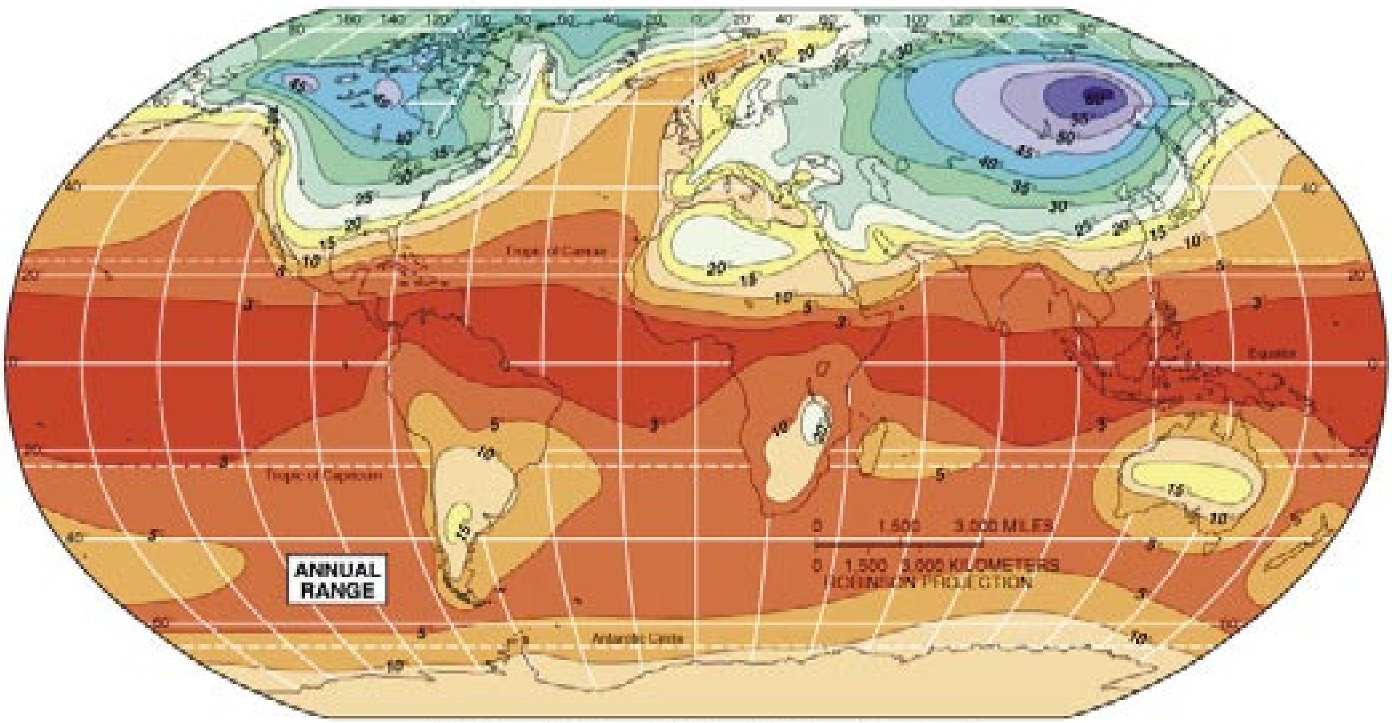
2.0 Comparative Review of International Practice

2.1 Assessment Criteria

In order to critically appraise the following international projects we have established a set of criteria by which the projects can be measured against. These criteria are:

Description: A brief description of the project.
Year: The year built.
Architect: The architect of the project, if known.
Location: Location with particular relevance to the tropics.
Income Level: Low, middle or High
Shading Strategy: The approach taken to shade the project.
Climatic Issues: The specific climatic conditions for the project, highlighting the challenges these conditions may bring.
Ventilation Strategy: How the project is ventilated.
Rainwater dispersal: The methods employed for the removal of rainwater and re-use if appropriate.
Technology Level: The level of technology employed to aid energy efficiency and thermal comfort within the projects. This ranges from:
Low - totally passive, manually operated systems to
High - fully automated pieces of kit.
Materials: The materials used to construct the projects with particular reference to the distance from which the materials were sourced from the project. This looks at the embodied energy of the materials.
Cyclone resistance: The strategies employed to ensure resistance to high winds.
Relevance to Mauritius: What strategies can be successfully employed in Mauritius.

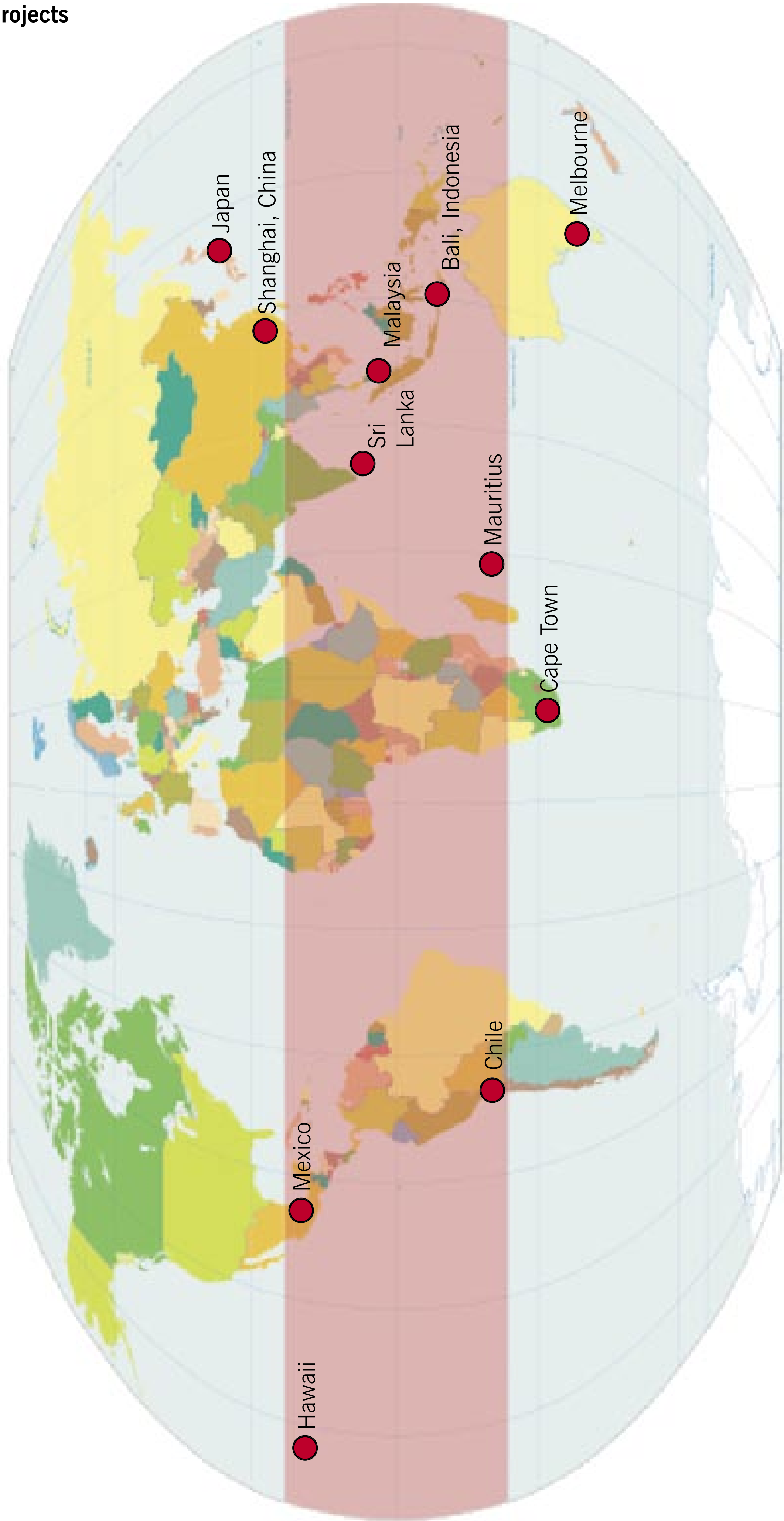
We have looked at a range of examples from across the world, focussing on the tropics but also including some examples which although geographically located outside of the tropics still have relevance to Mauritius. The map on page 5 shows the location of the projects. We have also considered examples of projects which lie within similar thermal zones to Mauritius. These thermal zones are highlighted on the map below.



F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

Thermal regions across the globe

2.2 Map of projects

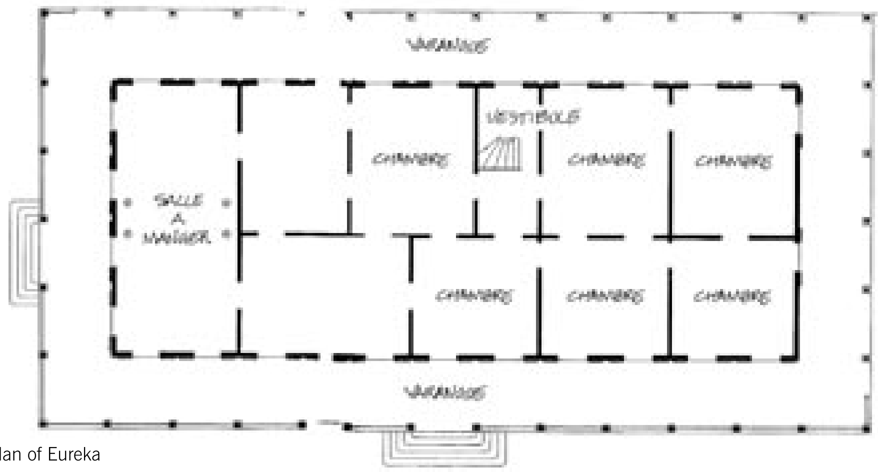


Tropical region highlighted in red

3.0 International Best Practice - Residential

3.1 Eureka, Moka, Mauritius.

Description: Eureka was built in the 1830’s close to Moka on the Central Plateau of Mauritius. It provides an example of a Creole Mansion described as a “masterpiece of tropical design[1]”. It employs the passive design strategies that work to keep the house cool.
Year: 1830’s
Architect: Unknown
Location: Moka, Mauritius.
Income Level: High.
Shading Strategy: A large pitched overhanging roof which forms a veranda to all sides of the house. The veranda which wraps around the house provides a shaded external seating area with the added benefit of limiting the direct sunlight to the main volume of the house. The shading strategy is supplemented by planting.
Climatic Issues: High humidity, high temperatures with high solar gain.
Ventilation Strategy: Naturally ventilation. The airflow movement through the house is controlled by the opening of manually operated vents above all internal doors. The dual aspect of the house does not present the best conditions for achieving cross ventilation.
Rainwater dispersal: The large pitched roof drains to gutter at the eaves of the roof.
Technology Level: Low tech.
Materials: The house is constructed of timber, the vast majority of which was imported. Therefore the embodied energy of the materials is high and not appropriate to low and middle cost housing in Mauritius today.
Cyclone resistance: High, it has stood since 1830.
Relevance to Mauritius: High.



Plan of Eureka

Planting to shade the veranda

Front elevation of Eureka

Opening vents above all doors

1. Tom Masters, Jean-Bernard Carillet, Lonely Planet: Mauritius, Reunion & Seychelles, London, Lonely Plant Publications PTY Ltd 2007, page 94.

3.2 Traditional Huts, Bali, Indonesia.

Description: Traditional Balinesse huts constructed of primarily locally sourced materials such as Bamboo and other local timbers. The buildings are raised off the ground to protect against moisture ingress, allow free air movement around and through the buildings and traditionally provide protection against dangerous animals.
Year: Unknown.
Architect: Unknown.
Location: Bali, Indonesia.
Income Level: Low.
Shading Strategy: Overhanging roof eaves together with planting to provide shade.
Climatic Issues: High humidity, high temperatures with high solar gain. Very similar to Mauritius.
Ventilation Strategy: Cross ventilation strategy combined with the form of the buildings which is designed to pull the hot air up and out of the opening in the roof.
Rainwater dispersal: Rainwater runs off the roof straight to the ground.
Technology Level: Low tech.
Materials: Locally sourced bamboo and timber mean the materials used have a low embodied energy.
Cyclone resistance: Medium, they have withstood cyclones.
Relevance to Mauritius: Medium - the passive cooling strategies are very relevant but not so the materials and building form which are strongly associated with Bali.

Traditional Bali huts

3.3 Qunita Monroy Housing, Iquique, Chile by Elemental Architects.
Description: This is a social housing scheme in the Tropical region of Chile to the North of the country. The cost to build is low, part funded by the government. There is a large degree of flexibility in the units as they are developed by the owners. The basic unit is just 32m2 but is extendable up to 70m2.
Year: 2005
Architect: Elemental, Chile.
Location: Iquique, Chile. Tropical region.
Income Level: Low.
Shading Strategy: None.
Climatic Issues: High daytime temperatures but a more extreme temperature range than found in Mauritius so some heating is required in the winter.
Ventilation Strategy: Naturally ventilated via opening windows.
Rainwater dispersal: Flat roof with parapet and gutters.
Technology Level: Low tech.
Materials: Blockwork and concrete construction, although locally sourced the actually materials have relatively high embodied energy particularly the concrete.
Cyclone resistance: High.
Relevance to Mauritius: This scheme provides for the owners of the dwellings to self build up to 50% of the total housing unit. The basic unit is constructed as a row of houses with spaces left to in fill both underneath and to the side of each individual unit. The typology is of particular relevance to Mauritius as it provides a model for the extension and improvement of the basic housing unit by the residents.
It manages to provide an element of control for the extensions for the dwellings which in turn helps to limit the effects of over development of the housing units.

The recently completed scheme

Resident in-fills

Site plan

Ground Floor Plan

3.4 Ecohouse, Shanghai.

Description: The Ecohouse was built as part of the Shanghai Expo 2010 as an exemplar for sustainability energy efficiency in housing.
Year: 2010.
Architect: Unknown.
Location: Minhang Region, Shanghai, China.
Income Level: Middle to high.
Shading Strategy: Automatic internal blinds adjust to the movement of the sun coupled with solar glass to double glazed units.
Climatic Issues: High humidity and high summer temperatures.
Ventilation Strategy: Whole house integrated heat and air recovery system. This is powered by ground source heat pump.
Rainwater dispersal: All the rainwater is recycled and used within the building.
Technology Level: High tech.
Materials: Steel, brick with very high levels of insulation.
Cyclone resistance: High.
Relevance to Mauritius: This projects relevance lies in setting an example for a sustainable, very low carbon method of living within cities in the future. The specific solutions are not particularly relevant to Mauritius but the aspirations of the project are.

Front of the Ecohouse

Rear showing the stairs and balconies

3.5 10 x 10 - Cape Town, South Africa by MMA Architects.
Description: To celebrate the 10th anniversary of the Design Indaba a design programme consisting of ten teams of international architects often paired with a local architects in South Africa to work on low cost housing solutions.
Year: 2007
Architect: MMA Architects
Location: Cape Town, South Africa.
Income Level: Low
Shading Strategy: Some overhanging roof eaves.
Climatic Issues: High daytime temperatures with low nighttime temperatures.
Ventilation Strategy: Natural ventilation through opening windows.
Rainwater dispersal: Flat roof and gutters.
Technology Level: Low tech.
Materials: Timber and metal truss frames to support walls. Sandbag walls filled with local sand finished with render.
Cyclone resistance: Low
Relevance to Mauritius: Medium - this is a house designed to provide affordable housing for very little cost: 50,000 South African rand (which is about US$ 6,000). The 10×10 House, can be built using local materials and with very few tools and unskilled labor. Here is a system that not only provides very low-cost housing, but does so in a way that engages the community and provides them with a sense of investment and participation in the process.

Sandbag walls being construcuted

3.6 Hakogi House, Kobe, Japan.

Description: Traditional Japanese thatched houses with large and steep thatched roofs. Internally there is an elevated floor with open space corridor formed around the main room of straw mat floor.
Year: Approximately 300 years old
Architect: Unknown.
Location: Kobe, Hyogo Province, Japan.
Income Level: High - at the time.
Shading Strategy: Overhanging roof eaves and very small window openings.
Climatic Issues: High summer temperatures and relatively high humidity.
Ventilation Strategy: A passive ventilation system draws the hot air out through the building. The stack effect required is driven by wind turbines on the roof of the building.
Rainwater dispersal: Runs off thatched roof.
Technology Level: Low.
Materials: Timber house with thatched roof. Local materials were used.
Cyclone resistance: High, it has stood for 300 years.
Relevance to Mauritius: Medium. The principle of a locally produced thatched roof in Mauritius is known as are the benefits of the cooling properties of this type of roof. Thatched roofs on houses in hot and humid climates can benefit the internal comfort for the occupants. The measured results in summer showed that the inside air temperature of the main house was about 2–3ºC lower than outside and earthen floor surface temperature further 2ºC lower than room air, while natural ventilative cooling was effective in the house.


Interior of Hakogi House

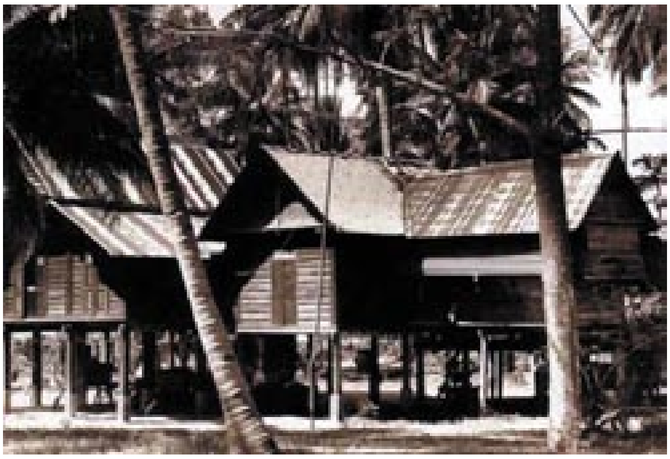

Exterior of Hakogi House


Interior of Hakogi House

3.7 Malay House, Malaysia.

According to Bezemer (2008), it could be argued that thermal comfort in the tropics can be achieved at much higher ambient temperatures and humidity levels because of occupants acclimatization, however, the vernacular understanding of optimum designs in hot humid environments combined with present day technological advances and 'knowledge' should only be advantageous.

The traditional Malay House has to cope with tropical climate and extremes of high humidity levels, temperatures and solar radiation. Humidity reduces cooling via evaporation as the air is already saturated, so by ventilating a space, the saturated air is removed, increasing the rate of evaporation and convection that dissipates heat from the body, building structure and fabric. Solar shading is also an efficient means of keeping cool.



Traditional Malay house

Traditional Malay house

3.8 Reunion Island – Low-cost housing

Two new dwellings and especially low-cost housing developments - La Trinite and La Decouverte – have been designed for maximum passive cooling. The passive cooling is achieved through excellent airflow design of passive cooling techniques has been evaluated thanks to a simulation code.

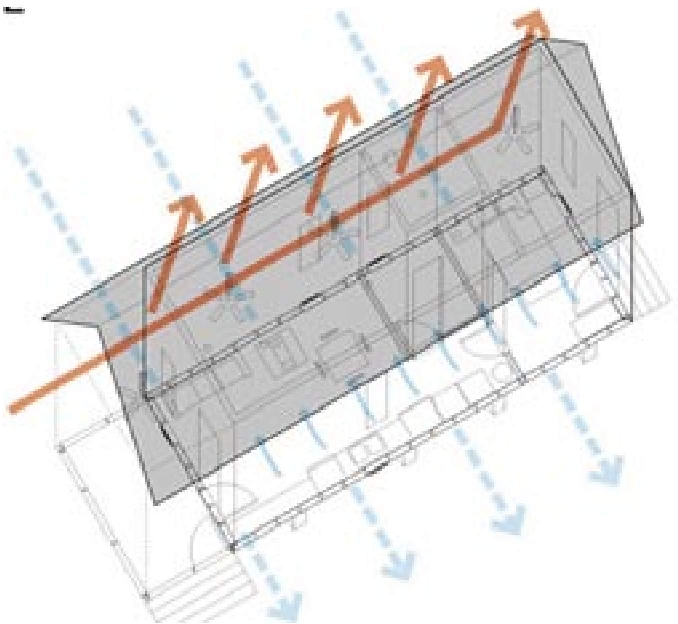
The local cyclone climate factors have also featured in the design to withstand hurricanes and heavy rainfall, as well as corrosive salt-laden air.

3.9 Sri Lanka – House Analysis Bandarawela

The research carried out showed that the house having an upper floor in a part of it could offer a better solution than a single-storey house, since it would provide sufficient spaces with different temperatures for occupants to respond as they encounter thermal discomfort.

A two-storey house with the same area on ground and upper floors also would not be able to offer such freedom efficiently. A sketch of the conceptual house is given for adaptation to suit the needs of individual clients. Once such a concept is selected, it would be possible to further improve the thermal performance by adopting additional passive features.

3.10 $20K House, Newbern, Alabama, United States.
Description: Prototype house.
Architect: Rural Studio
Year: 2009
Location: Alabama, United States.
Income Level: Low.
Shading Strategy: Covered porch/veranda, overhanging eves.
Climatic Issues: High summer temperatures with high humidity.
Ventilation Strategy: Natural ventilation through stack effect, cool air drawn in below building.
Rainwater dispersal: Runoof from roof.
Technology Level: Low.
Materials: Timber frame with metal deck rof covering.
Cyclone resistance: Medium high..
Relevance to Mauritius: This is a prototype house with the aim of being reproduced on a large scale by a contractor for $20K. It is a very simple, standardised construction aimed at being a viable replacement for "trailer" home. The $20K is a reference to the highest available mortgage a person on a low income in this region is able to get. By standardising the design and construction process the overall cost of construction can be driven down.

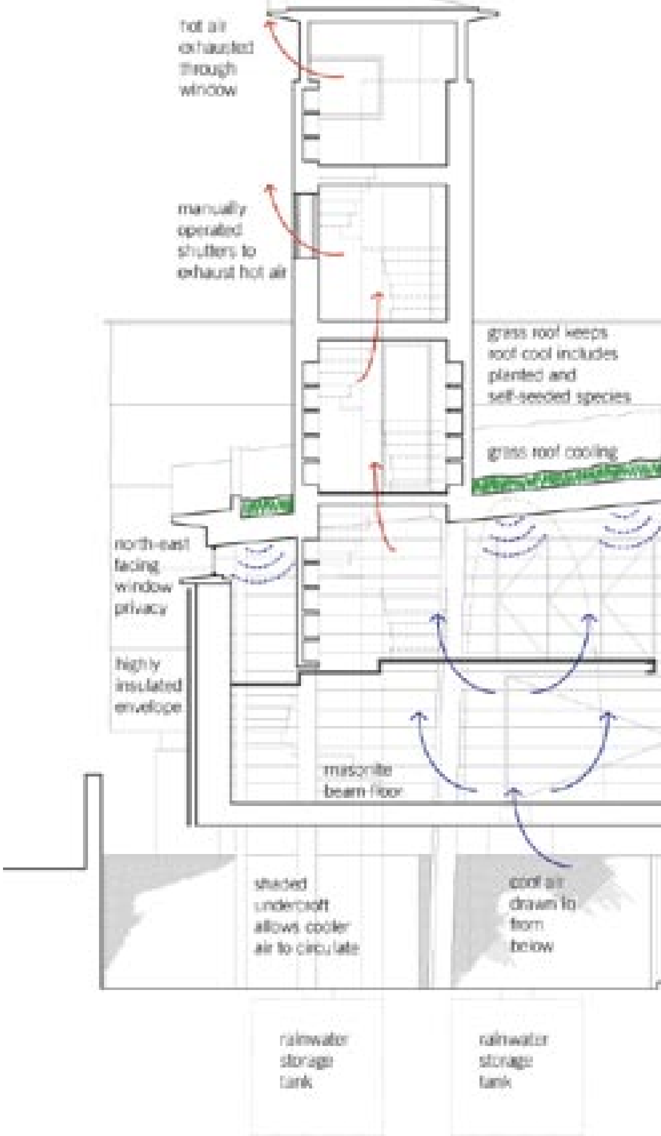


Ventilation Strategy

Finished house

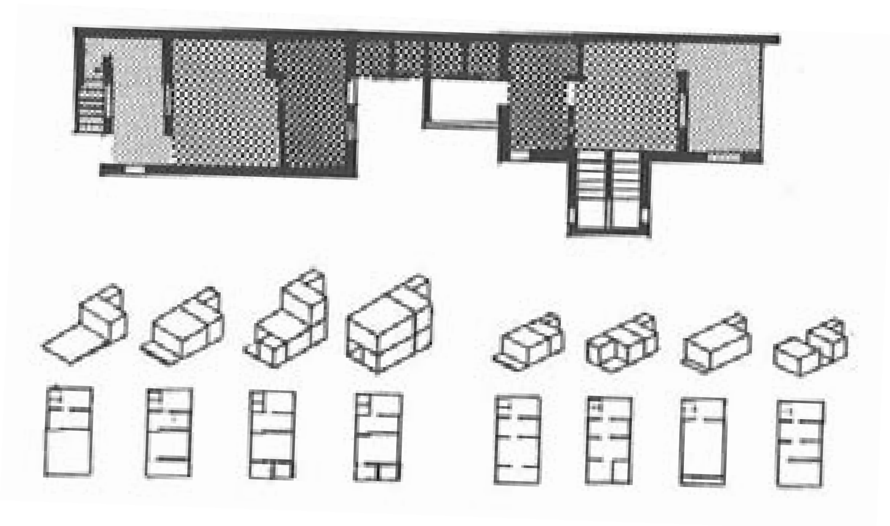
House under construction

3.11 Stock Orchard Street, London, United Kingdom.
Description: Sustainable live/work office.
Architect: Sarah Wigglesworth Architects
Year: 2004
Location: London, United Kingdom.
Income Level: Middle.
Shading Strategy: Various.
Climatic Issues: Northern European climate, cold winters relatively mild summers.
Ventilation Strategy: Natural ventilation through stack effect.
Rainwater dispersal: Underground storage tanks for rainwater, green roof.
Technology Level: Medium.
Materials: Various.
Cyclone resistance: Not relavant.
Relevance to Mauritius: The intention is to provide a model of sustainable living in an urban setting. The building uses a number of technologies based around principles of sustainable design, many of which are being introduced in an urban context for the first time. These include a new system of walling incorporating straw bales. At the same time, the project introduces innovative spatial, formal and material solutions to housing design.



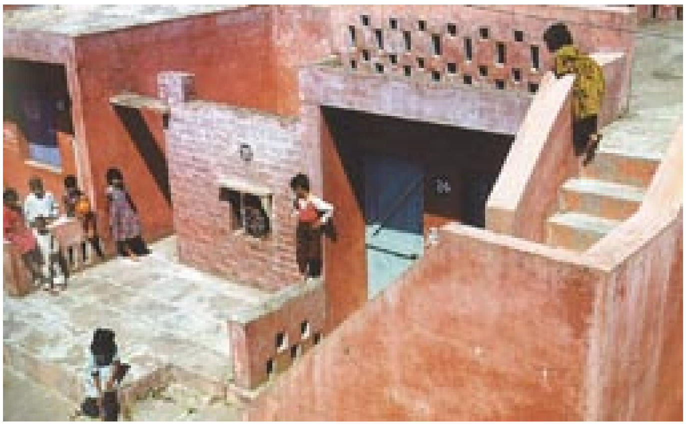
Ventilation strategy diagram

3.12 Aranya, Indore, India.
Description: Low cost housing devlopment.
Architect: Balkrishna Doshi
Year: 1983-86
Location: Indore, India.
Income Level: Low.
Shading Strategy: Various.
Climatic Issues: Tropical climate.
Ventilation Strategy: Correct solar orientation, shared external walls.
Rainwater dispersal: Flat roofs.
Technology Level: low.
Materials: Brick walls, prestressed concrete enclosure walls with a floor of cement and local stone.
Cyclone resistance: Not relavant.
Relevance to Mauritius: High - Doshi's approach looked to reorganise slum areas into districts and active streets with shops and craftsmen. He waned to allow the free of the individual owners to be able to build and extend their own dwellings. Doshi abandoned grid formations and organised the project into six sectors fed by an avenue.

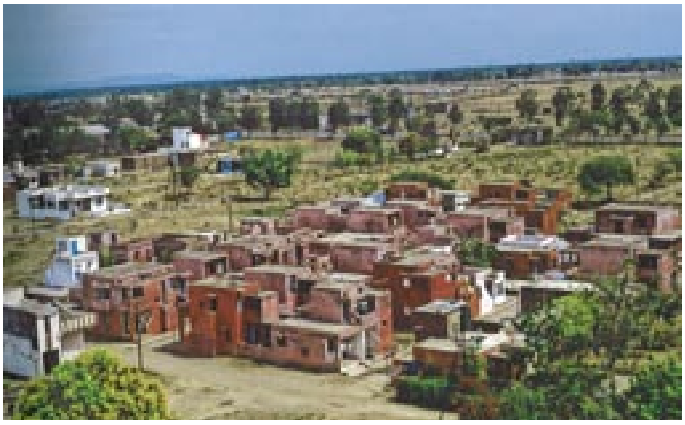


Flexible housing units

Streets of housing



Clusters of houses



Clusters of houses

3.13 Houghton Regis, United Kingdom.

Description: Sustainable masterplan and design for ecological dwellings that could be acheived within funding limits for affordable homes.
Architect: Sarah Wigglesworth Architects
Year: 2006
Location: Houghton Regis, United Kingdom.
Income Level: Low.
Shading Strategy: Various.
Climatic Issues: Northern European climate, cold winters relatively mild summers.
Ventilation Strategy: Natural ventilation through openable windows.
Rainwater dispersal: Underground storage tanks for rainwater.
Technology Level: High. Photovoltaic panels to roofs, ground source heat pump to provide hot water, acoustically attenutated vents.
Materials: Various.
Cyclone resistance: Not relavant.
Relevance to Mauritius: We developed a masterplan of flexible housing units that allowed for a large degree of expansion in the future. Each flat type had an associated pocket of land into which they could extend, allowing for the housing units to grow as family sizes grew. All of this was done within a sustainable infrastructure set up within the masterplan.

Planted walkways through site

Flat/house type examples

Sustainable masterplan

3.14 Ikoyi, Lagos, Nigeria.

Description: Private house.
Architect: Fry, Drew & Partners.
Year: 1960's
Location: Lagos, Southern Nigeria.
Income Level: High.
Shading Strategy: Large overhangs.
Climatic Issues: Tropical climate.
Ventilation Strategy: Accommodation on the first floor to allow cooler air to drawn from below and up into the dwelling.
Rainwater dispersal: Flat roofs.
Technology Level: low.
Materials: Reinforced concrete frame building with concrete ventilation and shading screens..
Cyclone resistance: High.
Relevance to Mauritius: This house demonstrates the benefits of appropraite planting strategies. The air is colled thorugh the ventilation beofre being drwan up into the house.

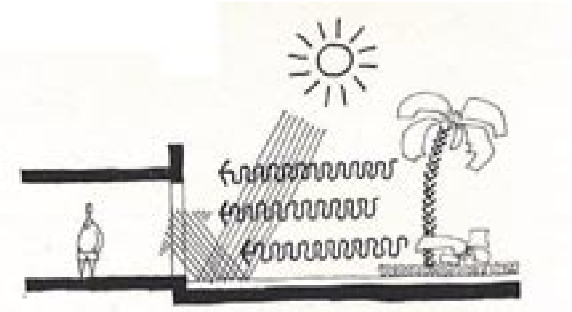


Diagram of air being heated by sun.

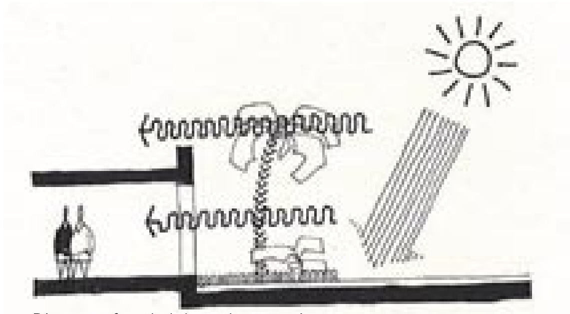
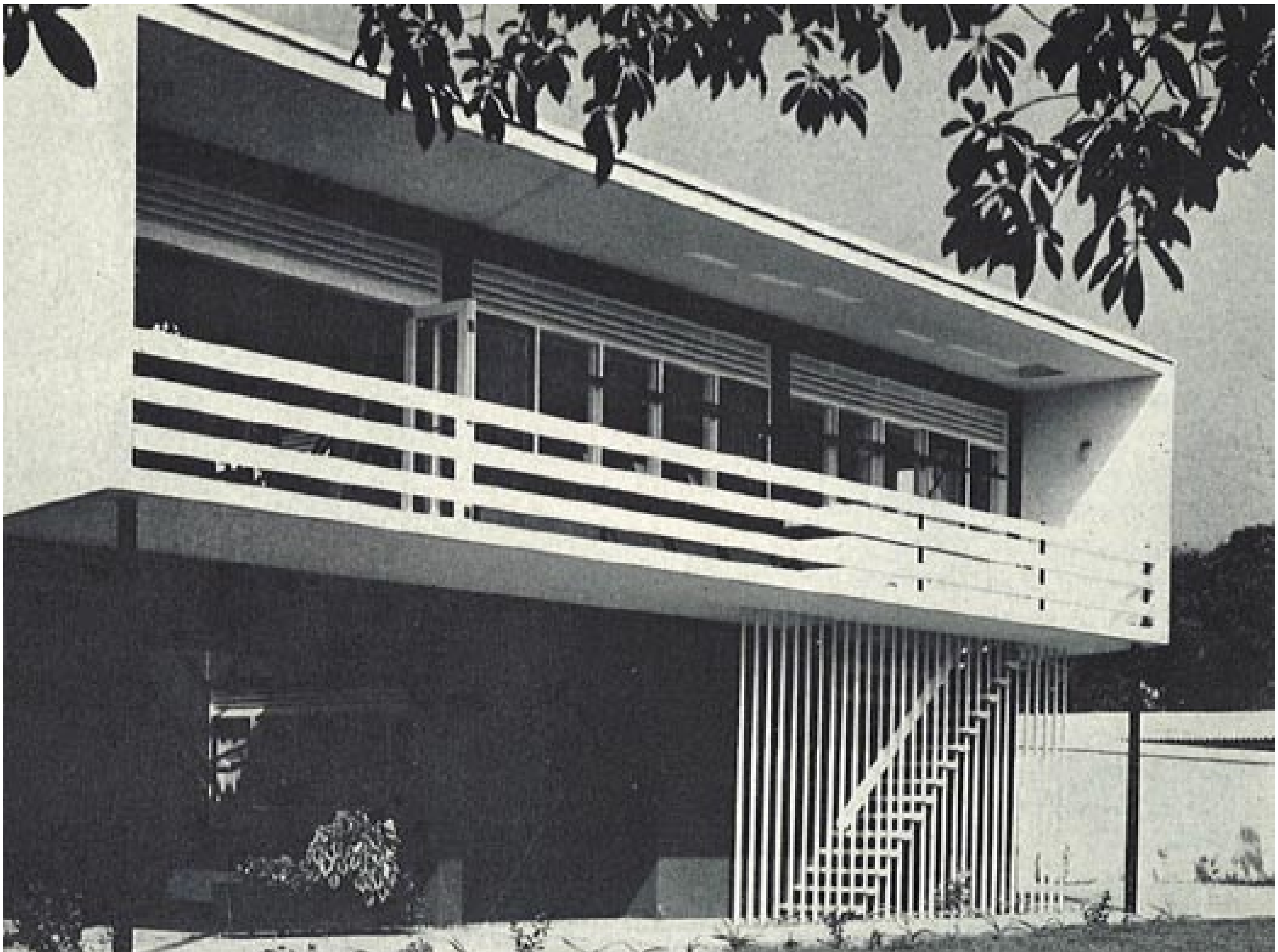


Diagram of cooled through vegetation


House with accommodation on the first floor.

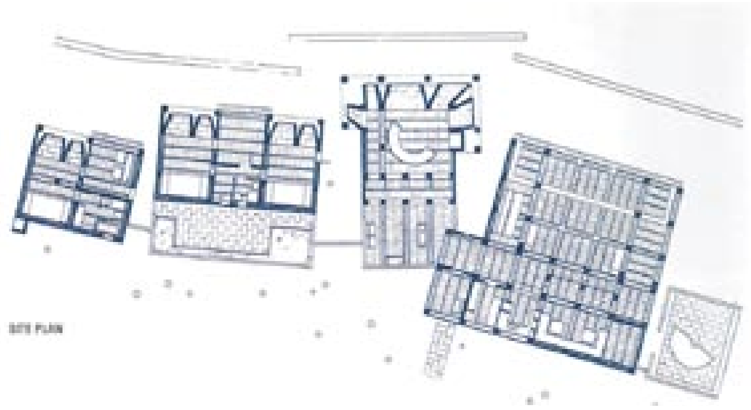
3.15 Macacos, Rio, Brazil.
Description: Social housing slum replacement.
Architect: Jorge Mario Jauregui Architects.
Year: 2009
Location: Rio de Janerio, Brazil.
Income Level: Low.
Shading Strategy: Large overhangs.
Climatic Issues: Tropical climate.
Ventilation Strategy: Unknown
Rainwater dispersal: Flat roofs.
Technology Level: low.
Materials: Concrete, blockwork and render.
Cyclone resistance: Medium.
Relevance to Mauritius: Through rigorous planning principles and low cost construction techniques the random and sometimes dangerous development of a Favela has been replaced with terraced blocks of housing. The sit cheek by jowl with the existing favela development. They provide a method for integrating modern methods of construction and design standards within tight urban contexts.


The new development within the context of the Favela.


New integrating with the old.


The terraced rows of housing with planted space between

3.16 Private House, Porto Petro, Majorca.
Description: Private house.
Architect: Jorn Utzon.
Year: 1971
Location: Porto Petro, Majorca.
Income Level: High.
Shading Strategy: Covered terraces surrounding the house.
Climatic Issues: Hot mediterreanean climate.
Ventilation Strategy: Courtyard arrangement of house both shades and aids natural ventilation.
Rainwater dispersal: Clay interlocking tiles.
Technology Level: low.
Materials: Local stone, concrete and tiles, all locally produced.
Cyclone resistance: Not applicable.
Relevance to Mauritius: This house offers an example of the benefits of correct siting, orientation and integration with an existing landscape. Although the plan of the house is large the construction techniques are extremly simple, the house being predominantly constructed of just three elements. With no additional cooling the house is comfortable throughout the year.



Site plan

Covered terrace

The house integrated into the landscape

4.0 International Best Practice - Non Residential

4.1 CH2, Melbourne, Australia by Mike Pearce & Design-inc.

Description: The CH2 building is the new council headquarters for the City of Melbourne Australia. As such it is a leading example of green technologies in an attempt to dramatically reduced the energy in use of the building. By providing the occupants of the building with fresh, moving air throughout the whole depth of the floor plans the actual amount mechanically cooled air needed to keep occupants cool has been significantly reduced. The building generates its own energy through photovoltaic panels on the roof as well as reducing the reliance on energy through the use of solar thermal heating to provide water and phase change materials which cool water to be recycled through the chilled beams with the floor slabs of the building. The CH2 building is the first building in Australia to achieve a 6 star rating which signifies the building as a "world leader" in sustainable design and construction.

Year: 2006

Architect: Mick Pearce with Design-inc

Location: Melbourne, Australia.

Income Level: Not applicable.

Shading Strategy: Adjustable timber louvres to the sun facing facade

Climatic Issues: High summer temperatures and relatively high humidity.

Ventilation Strategy: A passive ventilation system draws the hot air out through the building. The stack effect required is driven by wind turbines on the roof of the building.

Rainwater dispersal: All the rainwater is recycled, some is used the dissipate heat in the summer to the lower retail units.

Technology Level: High tech.

Materials: Concrete framed building with chilled concrete floor and ceiling slabs. Local timber has been used for the adjusted louvres to the facade. All of the interior fit outs are from recycled and or non toxic materials.

Cyclone resistance: High as is its resistance to earthquakes.

Relevance to Mauritius: This is a very high tech project which proved expensive to build. However it does provide excellent levels of thermal comfort and user wellbeing as well as dramatic reductions in energy use and as such some of the principles and targets that the building has achieved are relevant to the Mauritian context.

"Living Wall" and balconies to exterior

Openable timber screens

4.2 Green School, Bali, Indonesia.

Description: Located in Bali, Indonesia Green School is a pioneering new project for a school at which sustainability is at the core of the curriculum. As part of the school's commitment to sustainability it is built primarily of locally sourced materials, typically bamboo.

The school's design and ethos challenges the pre-conceived notions of what a school can be whilst at the same time embracing local skills and technologies in the construction process.
Year: 2006
Architect: John and Cynthia Hardy (designers not architects)
Location: Bali, Indonesia.
Income Level: Middle to high.
Shading Strategy: Large overhanging roofs and planting strategy.
Climatic Issues: High humidity, high temperatures and high rainfall during the rainy seasons.
Ventilation Strategy: Open buildings, raised off the ground.
Rainwater dispersal: Steeply pitched roofs to encourage quick run off from roofs. Traditional roof building techniques.
Technology Level: Low tech.
Materials: All the building materials are primarily locally sourced and local skills have been embraced to construct a range of different buildings for the schools needs.
Cyclone resistance: Low
Relevance to Mauritius: The passive strategies and reliance on locally sourced materials are very relevant to Mauritius. The form of the buildings owe a lot to the vernacular architecture of Bali.

Classrooms at the Green School

The main Hall of the school

The main Hall under construction

4.3 Living Tebogo - Orangefarm, South Africa by Anna Heringer Architects.
Description: The first solar passive energy house in the southern hemisphere.
Architect: Anna Heringer Architects
Year: 2005
Location: Orangefarm, South Africa.
Income Level: Low
Shading Strategy: Large pitched overhanging roof with external veranda to provide shade.
Climatic Issues: High daytime temperatures with low nigh time temperatures.
Ventilation Strategy: Natural ventilation through opening doors and windows.
Rainwater dispersal: Pitched metal roof.
Technology Level: Low.
Materials: This is a community built building from locally sourced materials such as clay, straw, timber and blocks. The materials have a low embodied energy.
Cyclone resistance: Low
Relevance to Mauritius: Medium. The accommodation provided is very low cost and has also shown a significant improvement of the thermal comfort within the building. Without the use of external energy the building manages to maintain a temperature range of 18-26ºC which compares to a range of 2-45ºC in the surrounding shack buildings. The local community was heavily involved in the design and construction of the building and this is reflected in the high useage of the building since its completion.


The covered walkways


Under the entrance canopy


Elevation showing to open roof structure to allow cross ventilation

4.4 Sandal Magna School, Wakefield, Yorkshire, United Kingdom.
Description: Sandal Magna School is a recently completed 1.5 form entry primary school.
Architect: Sarah Wigglesworth Architects
Year: 2010
Location: Sandal, Wakefield, United Kingdom.
Income Level: Low, state run school.
Shading Strategy: Internal blinds.
Climatic Issues: Low external temperatures, acoustic pollution.
Ventilation Strategy: Natural ventilation through openable windows.
Rainwater dispersal: Underground storage tanks for rainwater.
Technology Level: High. Photovoltaic panels to roofs, ground source heat pump to provide hot water, acoustically attenuated vents.
Materials: Cross laminated timber, brickwork, various cladding types.
Cyclone resistance: Not relavant.
Relevance to Mauritius: This school has sustainablility at the very heart of all the major design decisions. To this end it has a predicted annual energy consumption for heating and cooling of 16.4KWh/m2/yr and an electrical energy consumption of 37.7KWh/m2/yr.


External louvres to shade sun

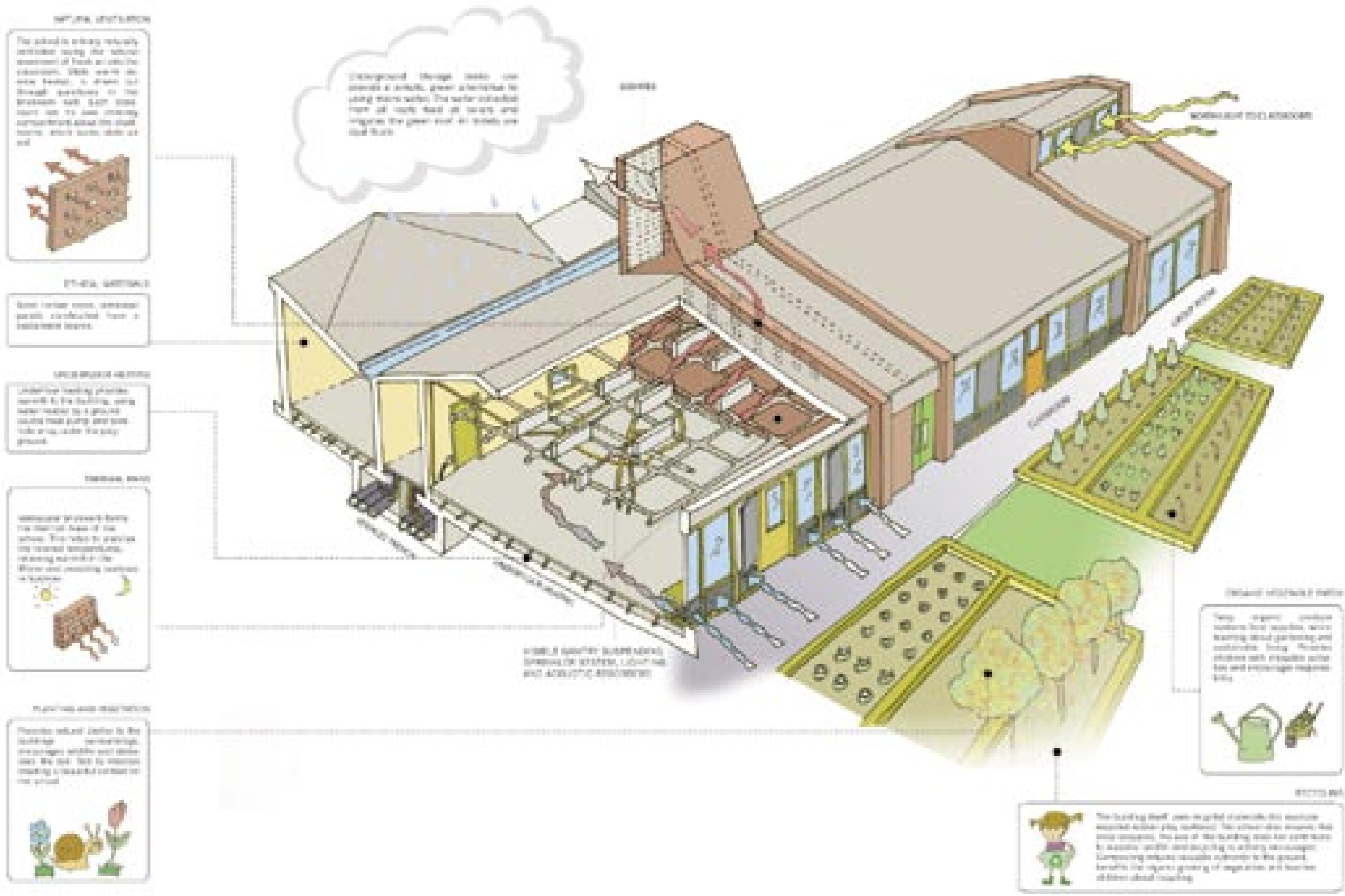

Photovoltaic panels to sportshall roof


Site wide sustainability strategy

4.4 Sandal Magna School, Wakefield, Yorkshire, United Kingdom.

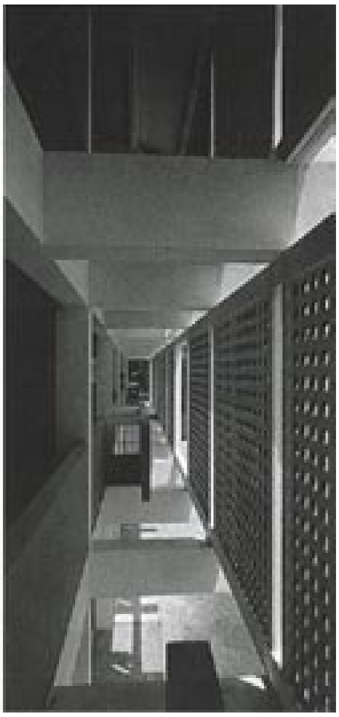
Ceiling grid with acoustic baffles, lighting and sprinkler system

Naturally lit circulation spaces

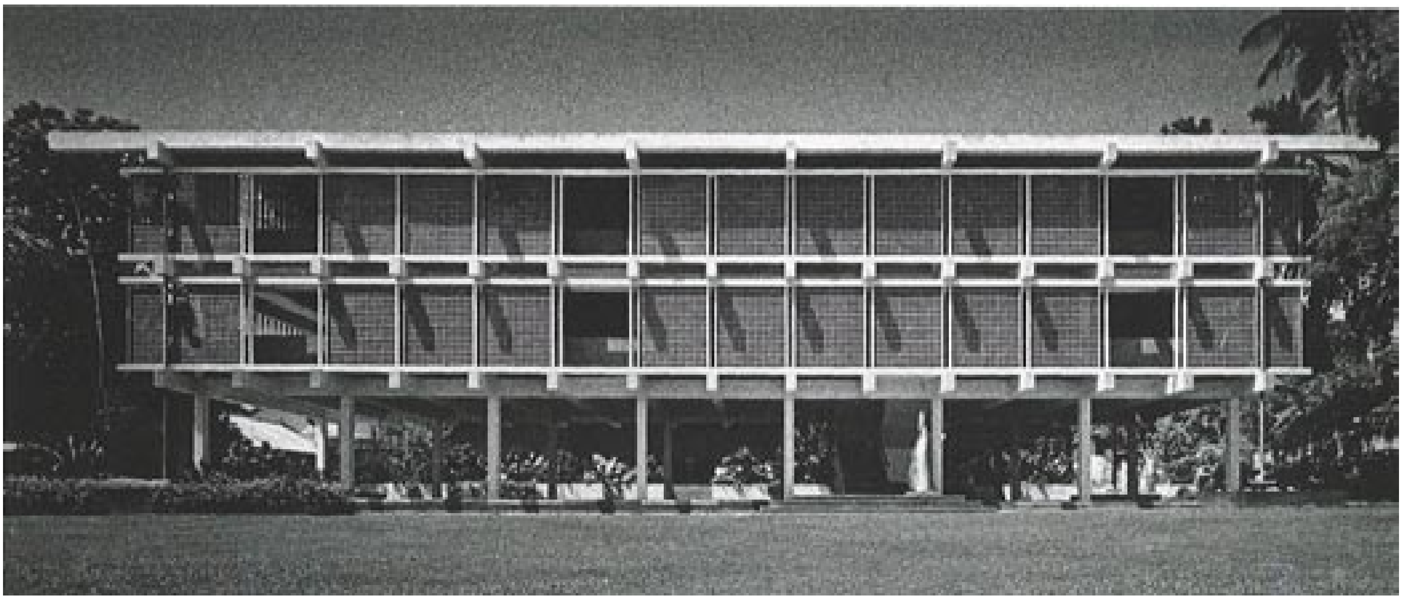


Sustainability strategy for classrooms

4.5 Bishops College, Colombo, Sri Lanka.
Description: Three storey teaching block to Bishop's College.
Architect: Geoffrey Bawa.
Year: 1960-63
Location: Colombo, Sri Lanka.
Income Level: Medium.
Shading Strategy: Ventilated screens wrap around the building.
Climatic Issues: Tropical climate.
Ventilation Strategy: "Breathing" external wall allowing air flow right up through the building.
Rainwater dispersal: Flat roofs.
Technology Level: low.
Materials: Reinforced concrete frame building with concrete ventilation and shading screens..
Cyclone resistance: High.
Relevance to Mauritius: High - Through the correct use of shading devices and an understanding of the natural stack effect the benefits of lifting the whole building up a storey allow cool air from below to be circulated throughout the building.


The "Breathing" wall

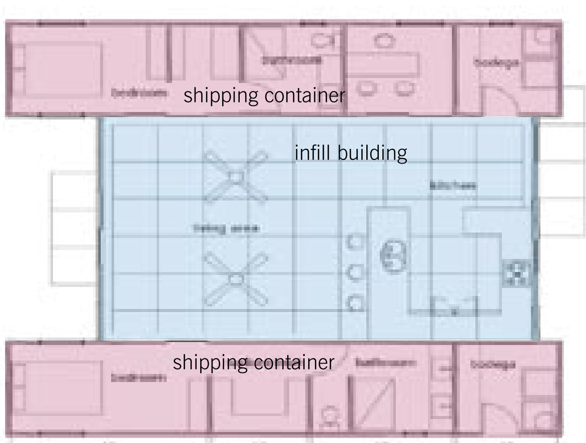

Ground floor view


Elevation of Bishop's College

5.0 International Best Practice - Materials

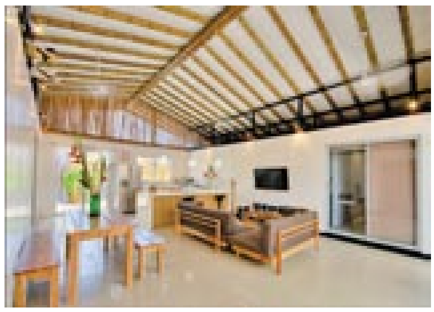
5.1 Bamboo Groove - Inventive re-use of materials.

Description: Bamboo-Groove is an American company that have looked at the many ways in which shipping containers can be re-used as part of a system to provide affordable, sustainable modern housing. The strategy is to re-fit shipping containers and span a new roof between the containers to provide additional living space. The new roofs are formed from steel and often Bamboo.
Architect: Bamboo-Groove.
Year: Ongoing.
Location: Worldwide.
Income Level: Middle to high.
Shading Strategy: Large pitched overhanging roof with external veranda to provide shade.
Climatic Issues: High humidity and high temperatures.
Ventilation Strategy: Natural ventilation through openable windows and doors but supplemented with air conditioning units.
Rainwater dispersal: Pitched roof.
Technology Level: Low to medium.
Materials: Recycled shipping containers with a steel and bamboo roof.
Cyclone resistance: Low
Relevance to Mauritius: The use of recycled materials in the shipping containers may be applicable to Mauritius. Unfortunately these houses have been fitted with air conditioning units to provide additional cooling.



Bamboo-Groove plan


Bamboo-Groove exterior


Bamboo-Groove interior


Bamboo-Groove interior

5.2 Ecopet 21, 90km north of Mexico City, Mexico.

Description: Ecopet 21 is an innovative sustainable construction system aimed at the development of ecological sustainable communities, particularly in tropical regions. Ecopet refers to the plastic Polyethylene terephalate from which the vast majority of plastic drinks bottles are manufactured. A building system has been developed using the bottles together with perimeter steel frames and wires to enclose the bottles to enable walls to be constructed. These panels have a basic module of 2.4m high x 1.2m wide with a sand-mortar plaster applied to both sides.

Mexico is the second world consumer of soda beverages which are mainly housed in PET bottles as well as consuming large quantities of bottles water. There is therefore a very large amount of PET bottles available. A new build house of 90m2 constructed using PET integrated into modular panels equates to between 9000 and 12,000 PET bottles per house built. Taking into account the total annual production of empty bottles in Mexico, about 1.8 million houses could be built using this building system every year.
Architect: Jose Roberto Garcia Chavez
Year: 2006
Location: 90km north of Mexico City.
Income Level: Low.
Shading Strategy: None.
Climatic Issues: High humidity and high temperatures.
Ventilation Strategy: Natural ventilation through openable windows.
Rainwater dispersal: Pitched roof.
Technology Level: Low.
Materials: PET bottles with a sand-mortar plaster. The vast majority of the building materials for the house are recycled.
Cyclone resistance: Low.
Relevance to Mauritius: The use of recycled materials goes a long way in reducing the energy associated with the construction of the houses but it does not tackle the issue of energy efficiency in use.

House plan

Bottles used in the construction of the ceiling

Wall panels being constructed

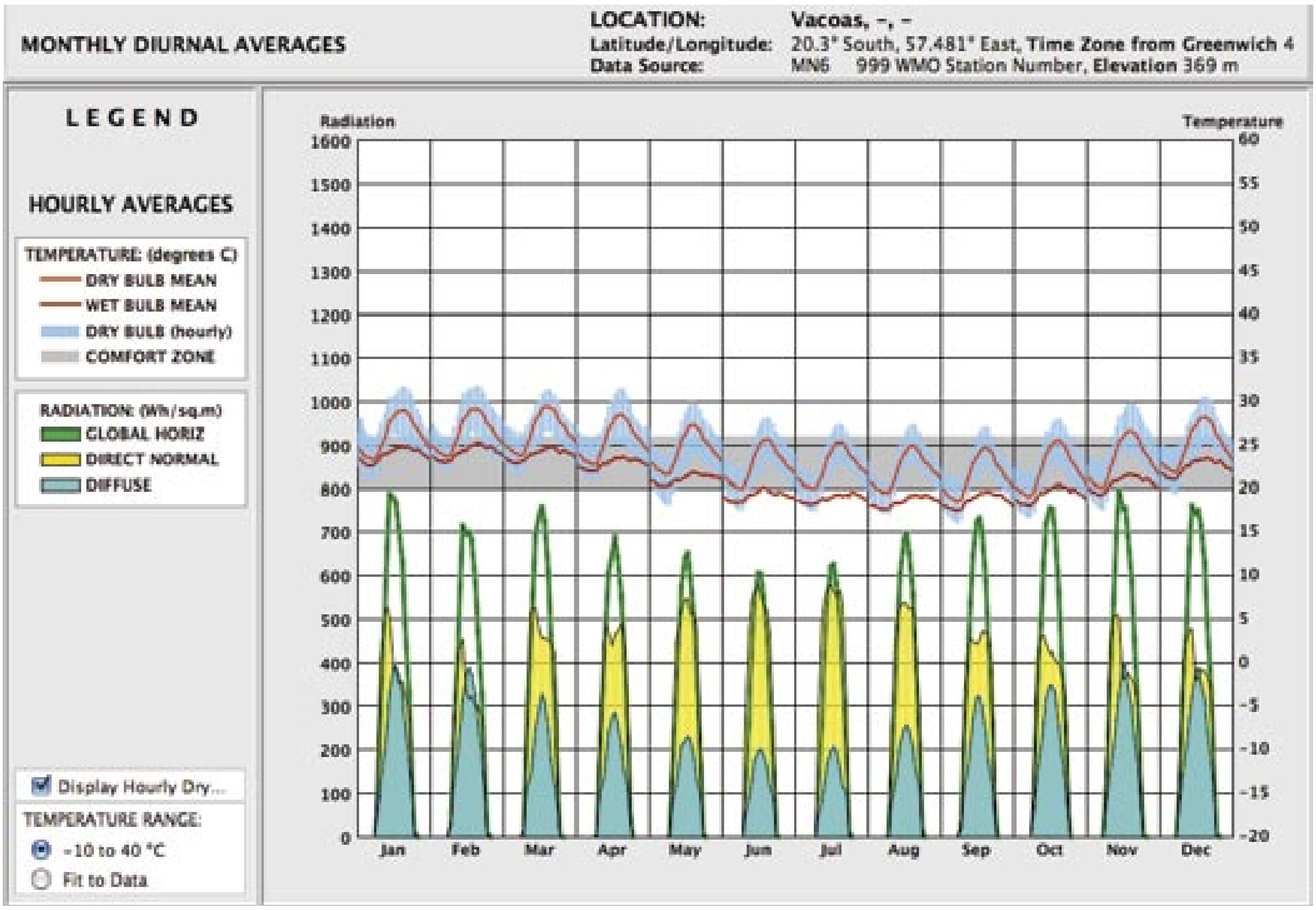
6.0 Climatic Conditions - International Comparisions

6.1 Mauritius, climate

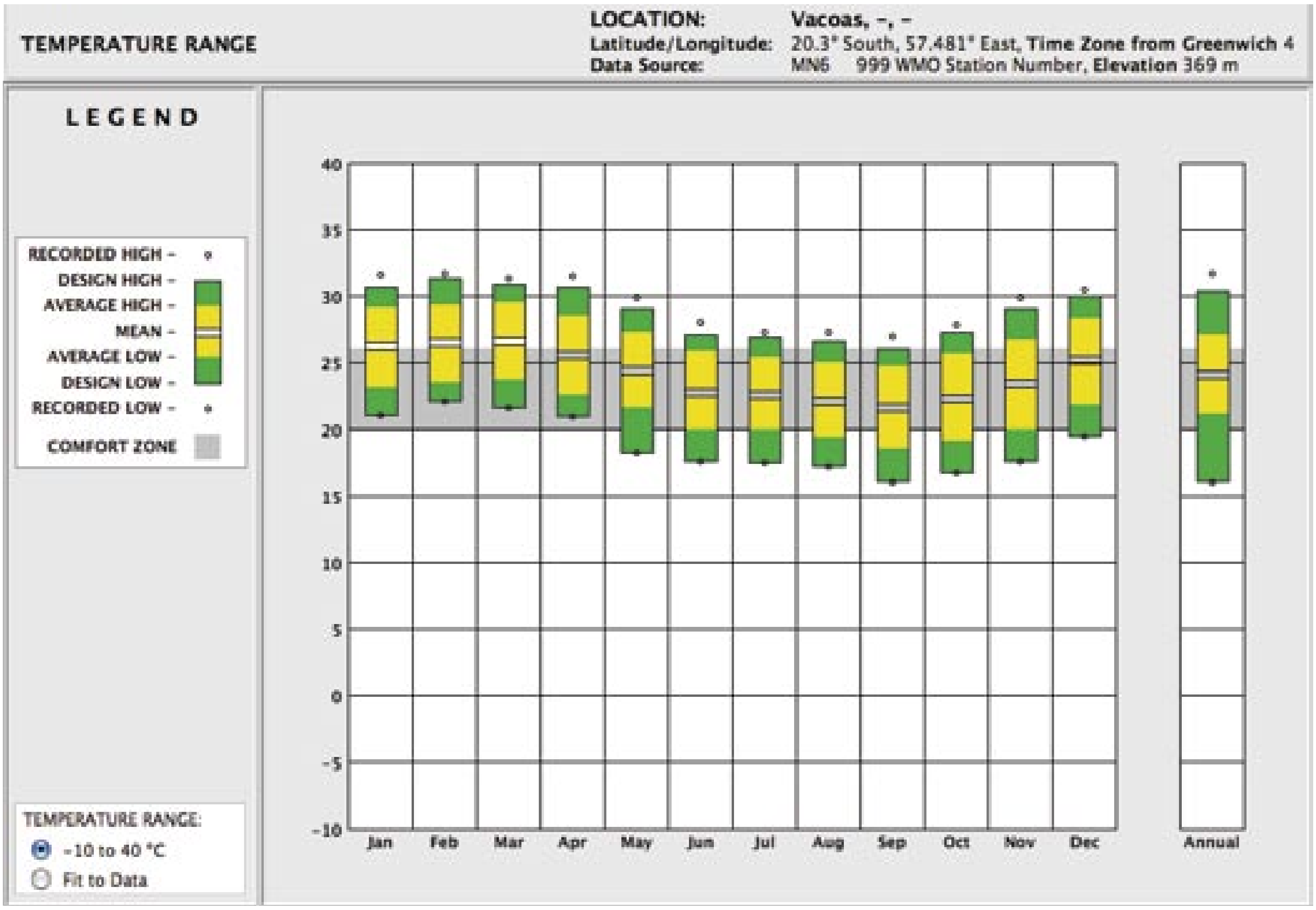
In order to compare best practice of energy efficient buildings from other parts of the world, we need to understand the significant features of their climatic zones and how and why they are similar to Mauritius. This will help us to assess key design strategies and whether or not they are applicable to the Mauritian context.

Although the climate of Mauritius can be broadly described as “tropical”, there are separate micro-climatic zones on the island that create local characteristics that need to be considered. These micro-climatic zones are created through the islands topography, and the way that changes in elevation/altitude affect the way that moist air from the trade winds is pushed around the island. The difference in air temperature, humidity, wind is particularly noticeable on leeward and windward sides of the island. Sunlight is less affected, as this is more about air movement and precipitation.

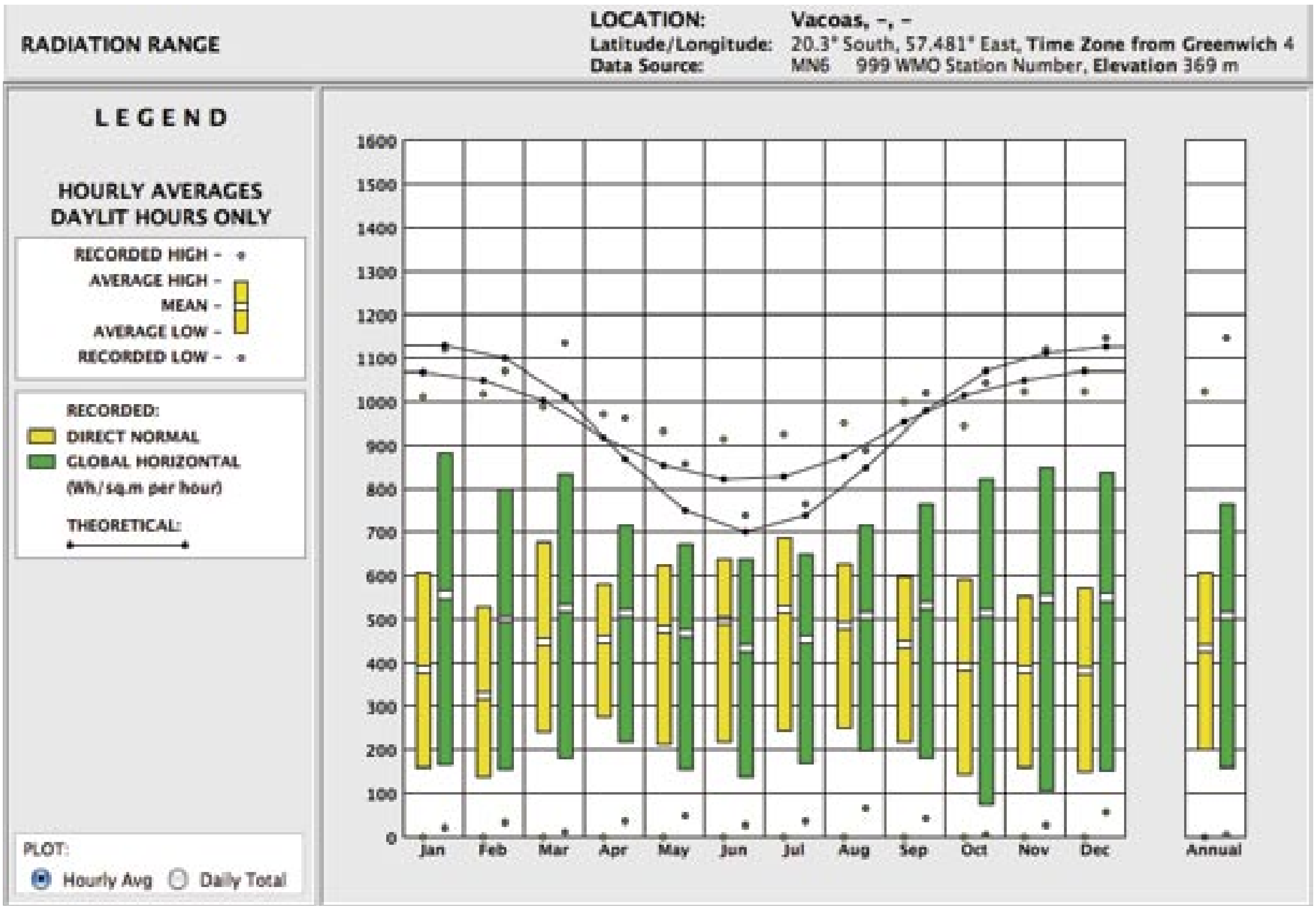
For the purpose of our study, we have defined two climatic zones, for Vacoas (cooler, central plateau) and Plaisance (warm, coastal). The meteorological services of Mauritius are providing us with climatic data for Vacoas and we shall use simulated data generated by Meteonorm for Plaisance. Typical data for Vacoas is as follows:



Monthly Diurnal Averages for Vacoas



Temperature range for Vacoas



Radiation range for Vacoas

6.2 Comparisons

As the climate of Mauritius is varied for a relatively small landmass, it provides the opportunity to compare its climate with different zones around the world.

There are some common factors that are included with the climatic comparisons. These are as follows:
- Humidity – is common across Mauritius; the relative humidity is typically between 70-95% for most of the year. The high peak of humidity is normally in the morning with the effects of the sun reducing humdity throughout the day before the humidity level rises again in the evening, once the sun has set.
- Sunshine hours – these are common across the island;

These factors have led us to consider the climatic zones referred to in our comparisons here as primarily humid, sunny and tropical climates.

6.3 Orientation

Our standard designs will look at the best orientation for buildings in relation to the compass points and the prevailing wind direction in Mauritius.

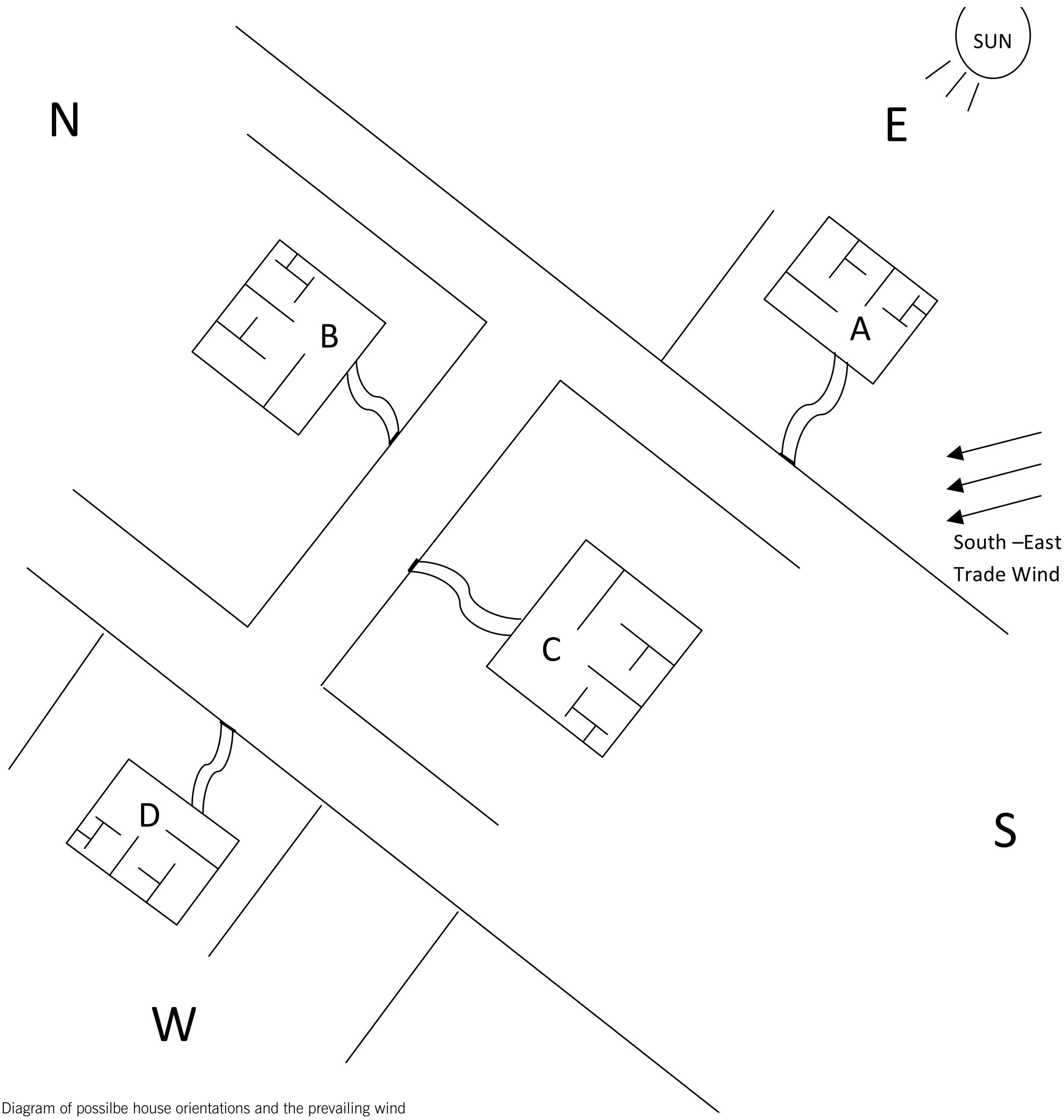


Diagram of possilbe house orientations and the prevailing wind direction

7.0 Family Structure & Size in Mauritius

7.1 The Shrinking family

Household size is decreasing in Mauritius. It currently stands at 3.7 people per household. Projected decreases are as follows:

Year	2000	2005	2010	2015	2020
Household size	3.93	3.77	3.59	3.47	3.34

7.2 Family Structure

- 60.6% of families consist of a couple with unmarried children (52.6%) or a single parent with unmarried children (8%). Unmarried children usually range in age from 0-29 years. This is referred to as the Nuclear family.
- 22.1% of households consist of newly married couples living with their in-laws or households constituting three generations of a single family e.g. Grandparents, parents and children.
- 10.4% of households consist of couples without children such as newly married couples or retired couples
- 6.9% of households are constituted of single member households.

7.3 Changes to household types

Family Type	% Year	
	2001/02	2006/07
Nuclear family	63.0	60.6
Single parent	7.8	8.0
Extended family	23.3	22.1
Couple without children	8.7	10.4
Single member	5.2	6.9

There is a marked shift from family living units to single member households as well as the increase in households constituted of couples without children, this may be partly explained by the increase in the age of the population of Mauritius.

7.4 Ageing Population

Mauritius has an ageing population for which there is projected a significant increase in the over 65's. As of 2009 7.8% of the population were over 65 years old. It is projected that by 2049 this will rise to 13.8%. This near doubling of the over 65 age group will have significant effects on the housing provision required in Mauritius as well as emphasizing the shift from "nuclear" family units to single member and non-children household units.

7.5 Estimation of Housing Needs: (source 2000 Housing and population Census)

According to the projections the overall number of households will grow by over 40% over the next 20 years. This represents an annual growth rate of 1.7%. This is approximately equivalent to 5000 new households per year (based on the total number of households in 2000). This level of new household provision has an effect on the amount of land that is required for development of housing and as estimated by the revised National Physical Development Plan (NPDP) some 3240 hectares of land over the next 20 year period will be required. This is approximately equivalent to 1.6% of the total area of Mauritius.

7.6 Demographics

The ethnic composition of Mauritius is:

Indo-Mauritian	68%
Creole	27%
Sino-Mauritian	3%
Franco-Mauritian	2%

The religious composition of Mauritius (and compared with the UK) is:

	Mauritius	UK
Hindu	48%	1.17%
Roman Catholic	23.6%	-
Muslim	16.6%	3.28%
Other Christian	8.6%	71% (all Christian)
Other	2.5%	0.29%
Unspecified	0.3%	7.76%
None	0.2%	14.98%
Buddhist	-	0.29%
Sikh	-	0.70%
Jewish	-	0.54%

8.0 Establishing Appropriate Design Targets

8.1 Energy use per Year

The standard designs will be benchmarked against international best practice for energy efficiency. Typically these figures are broken down into annual energy use (kWh/m2/yr) for the following:

- Thermal energy (heating, domestic hot water and cooling);
- Electrical energy (small power loads, lighting and appliances).

The international case studies have been reviewed to see if comparisons / baselines can be established for both best practice targets and in-use operation information. However, this data has not always been possible to gather at this time.

We are hopeful that as the assignment continues through to the Standard Designs, we will be able to gather information relating to these benchmarks for the building types that we are considering. We will also be researching this information with other partners working in Mauritius, as well as our local Mauritian consultants Pro-Design.

8.2 Water use per Year

The consumption of potable water will also be considered in terms of daily volumes for the following:

- Residential buildings – daily (litres/person/day);
- Non-residential buildings – annually (m3/person/year).

Residential buildings:

The general best practice figure for residential buildings is expressed in terms of volume of potable water used by each person per day. In North America, this figure is often found to be around 280-350 litre/person/day, whereas in Europe the figure is around 150 litres/person/day. We wish to compare with local Mauritius context too in order to ensure that water consumption is benchmarked relative to the local cultural demand.

Non-residential buildings:

The water consumption for the non-residential buildings is generally expressed in terms of annual water consumption – the volume per full time employee (FTE) per year.

In London (UK) the best practice figure proposed under the London Plan is for 4m3/FTE/year.

Again, we wish to compare with local Mauritius context too in order to ensure that water consumption is benchmarked relative to the local cultural demand.

8.3 Goals to Achieve

We propose the following goals for the different building types:

Residential

Thermal energy consumption:	40 kWh/m2/yr
Electrical energy consumption:	20 kWh/m2/yr
Water consumption:	100 litres/person/day

Non-residential

Thermal energy consumption:	60 kWh/m2/yr
Electrical energy consumption:	60 kWh/m2/yr
Water consumption:	4m3/person/yr

8.4 Embodied Energy

According to the Energy Design Guidelines for Tropical Island Climates (2004) the embodied energy of the materials is equal to more than two decades of a school's energy consumption. This is especially true in the tropical island climates, where distance and weather can add time and cost constraints to the school construction process.

However, quantifying the actual net energy figures associated with embodied energy is still prone to some inconsistencies and research and data in this sector is still relatively unfound. Our approach will be to address the overall impacts of energy consumption through the consideration of the energy involved in making each product, transporting the product to the site, and implementing the component into the building.

We will be working with local materials – where possible – that have a lower embodied energy (see below for details).

8.5 Internal Environmental Quality (IEQ)

The local Mauritian expectations of internal environmental quality – temperature, humidity, daylight, fresh air and acoustics – are all factors that have significant impact upon the energy consumption. For example many design guidelines propose that internal comfort is achieved when 21°C and 55% relative humidity experienced.

However, variance from these strict conditions can also create perfectly comfortable spaces, with significantly lower energy consumption. Comfort is subjective – and variable according to culture, climate and expectations. In order to satisfy local comfort requirements, we will seek out advice and research of the local Mauritian context.

8.6 Coordination and collaboration

During the next phase of the project we shall use the skills and expertise of our partners the BRE and the Danish Management Group to further develop and define the most appropriate targets for the evaluation of energy efficiency to be delivered through the standard designs.

9.0 Customs & Observances

9.1 Implications on Design

The religions in Mauritius are Hinduism (52%), Roman Catholicism (31%), Islam (16%) and Buddhism (1%). Many Mauritians from all these different religions have a small area or a room in the house attributed for worship. The house design can cater for this requirement by providing such a space. As prayers usually involve lighting candles, incense sticks or small oil lamps, care should be taken such as these areas are located so as not to present an unnecessary fire risk. The selected place should also be such that it can be used for other purposes in houses where a prayer corner is not needed.

The Mauritian cuisine is also a factor to consider in the house design. The local cuisine is a mixture of Indian, Chinese and Creole cuisines, spicy and involves a lot of frying. In order to prevent odors from the kitchen from spreading to the other rooms, the former must be well ventilated. It is also advisable to locate the kitchen far from the living room and bedrooms.

Mauritians are also lending increasing concern about designing their house according to Vaastu and Feng Shui recommendations for home design. Vaastu is mostly popular among Hindus while Feng Shui recommendations are greatly followed by Sino-Mauritians. Vastu and Feng Shui are concerned with the orientation of key rooms like bedrooms, bathrooms, the kitchen, the dining room and the prayer room. There are also recommendations for the colors to be used for different rooms as well as the location, orientation and number of staircases, doors and windows.

According to Vaastu recommendations, the kitchen must be ideally located towards the south-east or else in the north-west direction. The prayer room should be located in the north-east direction, the main bedroom in the south, the dining room in the west and the bathroom in the east. According to Feng Shui, the main bedroom must be far from the main entrance while the dining room must be close to the kitchen. Feng Shui is also concern with good ventilation and lighting.

Mauritians of all cultural background would love to have a garden in the backward if they can afford such a place where they could plant herbs (e.g. coriander and curry leaf) as well as flowers. Related to religious practice and having an external space for worship, Hindus typically have a small compartment made of concrete, increasingly purchased as a cast structure as opposed to cast in-situ, if not a small temple. This space is located in the east direction of rising sun.

10.0 Geotechnical Considerations & Topography

10.1 Geotechnical Implications

Our research into the effects of geotechnical and topographical conditions has shown that the main considerations here are as follows:

- Potential for earth coupling;
- Cross ventilation from leeward/windward hillsides

We are also interested in hillside development, and whether this is allowable or encouraged or discouraged. If it is allowed, we need to know which of the climatic zones is it most popular with.

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10.2 Topographical Implications

The wind conditions affect many factors in relation to the potential for passive design measures in buildings. For example, a building that is orientated to capture the prevailing winds will perform well in natural cooling through cross ventilation. However, at the same time, the louvers/windows need to be designed to withstand airflow when high air-change rate ventilation in unfavorable (during winter, or cyclone seasons).

Our design strategies will address these issues in relation to the effect that topographical conditions have upon the potential for passive building design.

Mauritius - Not to scale

11.0 Procurement Systems, Contracting Methods & Skills

11.1 Procurement Systems

The main type of procurement system used in Mauritius is the traditional method from the separated and cooperative category in which design consultants are hired at the start of a project (usually via a tendering process) to design according to the owner's/client's brief and provide detailed design documents and bill of quantities together with specifications of equipment to be installed and workmanship to be adopted. This information is provided in a tender document, which contractors use to quote their prices for the different services equipment and materials listed.

From the bids given by the potential contractors, the design consultant assesses the different bids, selects the best package and recommends to the client the Main Contractor to be appointed. The Main Contractor is responsible for all civil and structural works, and specialist sub-contractors are appointed by the Main Contractor to carry out the various M&E works. Therefore, the Main Contractor is responsible for procuring materials and products associated with erecting the building and construction works including external road, pathways, patios, landscaping and digging of pits and trenches. The respective M&E sub-contractors procure the products and materials they need to complete their work. The Main Contractor and the sub-contractor prepare construction documents in line with the detailed design plans provided by the design consultant team in the tender documents.

The conditions of the procurement system, although based on this traditional method, differ in procedure depending on whether it is a private or public project. The Public Procurement Act (PPA) 2006 is adhered to for public projects. The FIDIC procurement system has also been applied for public projects where it has been deemed to be more suitable. For example, upon consultation with the MPI, they reported that all state secondary schools have used the Public Procurement Act 2006 while there are projects for which the FIDIC procurement system has been used. The private sector uses the FIDIC and East African conditions of contract, depending on which system the Main Contractor prefers to work with.

The traditional method would be applied for projects of high value, both residential (mostly high-rise) and non-residential. On the other hand, the procurement system for the construction of stand-alone, one-off houses by individuals follow two distinct routes; either a contractor is hired by the individual and the contractor provides all the materials and workmanship needed or the owner manages the construction work. In both approaches, the owner is charged per square feet of the house. When a contractor is hired, he provides the materials and equipment and charges the owner, either on a per square feet basis or for the different equipment separately. The contractor finishes the house in terms of painting, flooring, plumbing, electrical and lighting. This option is generally perceived as more costly and with less control on expenditures. The second approach is the method of choice for the construction of middle and low income houses. A mason is appointed to construct the house, normally based on a price per square feet, excluding any materials and finishing (except rendering). The mason completes the work by hiring assistants and other masons, using materials purchased by the owner. The slab is normally cast at the additional cost of the owner, for which a separate team or company is hired just for this purpose, although the mason is present on the day the slab is cast. At suitable phases of the construction, the owner hires specialist sub-contractors for other works, e.g. installation of doors and windows, lighting, electrical and water installation, painting and laying of tiles.

12.0 Structural Methods & Materiality Availability

12.1 Structural Methods

Typically, structural methods used for small scale non-residential and residential buildings are based on the same principle, namely medium-weight blockwork with columns and beams made of concrete and steel rods with a concrete roof/ceiling. Non-residential buildings as well as high-rise residential buildings can also make use of pre-cast structures made of concrete and steel rods. These high rise buildings typically make use of 200mm (8 inch) blocks for external walls whereas common houses are made of 150mm (6 inch) blocks. For high rise buildings and newer developments, steel frames are also used to complement the conventional structural methods. Some buildings such as the State Bank Tower in Port-Louis have only a steel frame skeleton. As with residential buildings, wood is the most commonly used material for formworks in non-residential buildings.

An important consideration when designing high rise building in Mauritius, is that the structure has to be able to withstand strong cyclonic gusts with a speed of at least 300 km/h.
For the foundation of any type of building the legal requirements are:
1. The foundation should be on solid ground.
2. If the ground is unstable, either use piles or a foundation with a width such that pressure on the ground per unit wall length is less than half ton per square foot.

12.2 Material Availability

The common building materials used are:
Ready mixed concrete (supplied by local companies).

- Aggregates:
    - 14 – 20 mm.
    - 10 – 14 mm.
    - 6 – 10 mm.
    - 20 – 25 mm.
- Crusher run:
    - 0 – 20 mm.
    - 0 – 30 mm.
- Spall:
    - 0 – 150 mm.
    - Rock sand:
    - Washed: 0 – 4 mm.
    - Washed: 0 – 2 mm.
    - Unwashed: 0 – 6 mm.
- Blocks:
    - 100 mm.
    - 150 mm.
    - 200 mm.
- Cement.
    - Steel bars.
    - Wood (for formwork).

With the exception of cement, steel and wood, all the other building materials used are extracted locally.

13.0 Next Steps

13.1 Mauritian context and available materials

We are aware of the current limitations of the available resources for construction in Mauritius. This combined with the need to provide buildings which are cyclone resistant manifests itself in the use of concrete block and reinforced concrete for the majority of current housing and that built over the recent past.

Although it will be challenging to use alternative materials and we understand that the use of concrete and concrete block is currently embedded in the culture we want to use this report to explore the potential of alternatives. The examples provided on the previous pages have been selected as a range of approaches employing different construction materials and techniques. The unifying theme is that they all aim to use the earth's resources in an economic manner and therefore aid energy efficiency.

We understand that change is not an easy process nor is it usually a quick one therefore the standard designs that we will present in the guidebooks will look at the best ways of increasing energy efficiency whilst building with concrete block and reinforced concrete. We shall be providing recommendations which address the following issues:

- Correct solar orientation.
- Appropriate use of thermal mass.
- Solar shading via low tech means e.g. appropriate planting, external louvers.
- Passive stack ventilation strategies.
- Cross ventilation - to control humidity and expel warm air.
- Solar water heaters.
- Rainwater harvesting.
- Possible local insulation materials.

13.2 Establishing Local Industries

In order to explore different material alternatives to concrete block and reinforced concrete the market sectors for different industries need to be developed. For example the climatic conditions in Mauritius are conducive to the production of timber. Mauritian grown timber would obviously provide a sustainable and therefore energy efficient building material.

Locally produced insulation material such as Bagasse, a by-product of the sugarcane crushing process. although we do recognise that the majority of Bagasse is currently burnt at the power stations. The production of this type of material in Mauritius would go a long way in reducing the environmental and economic impact of having to import insulation products. We note that insulation is locally manufactured on Reunion.

There are obvious challenges in establishing new industries but in order to address the long term issues arising from climate change and the reliance upon concrete Mauritius needs to look to a wider and more sustainable sourced and manufactured range of building materials.

13.3 Distinction between Low and Middle income

Our standard designs will show a clear distinction between low and middle income house and flat types.

There has been some discussion about the possible stigma of the titles “low” and “middle” income. It would seem wise that in order to avoid any possible reasons why people would feel unable to adopt the standard designs the title of the designs should be changed to something less prescriptive. At a meeting held at the Ministry on the 15th April this was discussed and revised title of “Standard Designs for Dwellings less than 500m2” was proposed.

13.4 Regulations and Guidance

To ensure that our standard designs are finely tuned to Mauritius they will take into account and comply with where necessary the following guidelines:

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

13.5 Safety and Security

We recognise that there are likely to be some issues of security, ease of operations and maintenance and the standard designs we propose. We are committed to working through these issues as the standard designs for residential and non-residential buildings develop.

13.6 Standard Designs

The next step for the project is to take the knowledge that we have collected through the formation of this report and now apply it to the specific standard designs for low and middle income housing, schools and other building needs.

This report has allowed us to do the following:

- Establish targets for energy efficiency for our standard designs.
- Compare and contrast the best of international practice, allowing us to equip ourselves with a series of worked examples, some historical, some employing different levels of technology, assess the projects and understand their relevance to the Mauritian context.
- Further understand the demographic and cultural issues surrounding residential and non-residential buildings in Mauritius.
- Establish some of the limitations for the standard designs in regard to available materials, procurement methods and construction techniques.
- Further understand the specifics of the Mauritian climate with regard to the two climatic zones we will be considering for the standard designs.

Upon completion of this report we shall now begin the standard designs with a view to present and review the first steps of this process to the stakeholders in the second week in April 2011.

14.0 Disclaimer

It should be noted that our team does not include a structural engineer. Any recommendations made that relate to structual engineering issues will have to be externally checked and varifyed to be safe by a suitably qualified structural engineer. We do not accept any responsibility or liability for the strucutal integrity of structures proposed.

It should be further noted that a strucutural engineer was never a requirement of the terms of reference of the project.