THERMAL AND ENVIRONEMENTAL PERFORMANCE OF PRECAST BUILDING SYSTEM

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Degree of Master Science

Department of Civil Engineering

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DECLARATION

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D.S. Munasinghe

The above candidate has carried out research for the Masters Dissertation under our supervision.

……………………………………… Date:

Prof. M.T.R. Jayasinghe

……………………………………… Date:

Prof. (Mrs.) C. Jayasinghe

Abstract

Buildings are the living spaces of human beings that usually get-to-gather for number of times and occasions during a day. Quality standard spaces create more secure, comfort and convenient spaces for its users and can provide many advantages in all processes of the building construction, users as well as other supplementary equipment designers. The precast building systems provide some advantage to design quality standard spaces with more secure, comfort and convenience.

This research had been conducted to study the thermal and environmental performance of buildings which were constructed using Expanded Polystyrene (EPS) based lightweight wall panels and these building performances had been evaluated through testing of thermal material properties and computer simulation of the buildings. ASHRAE standard for comfort condition is used to develop computer modelling.

Testing of small scale model and real scale model were developed under this research study and carried out in locations in Colombo and Tangalle, respectively. Testing is carried out over a two weeks period and observations are discussed in this research study. Another model house, which is located in Jaffna, was evaluated and identified significant variation due to EPS based light weight panel used as walling and celling material.

Building design strategies were considered for design of thermally comfortable houses and ECOTECT and Climate Consultant 6 software were used to simulate and generate the design strategies. Based on these strategies, a new house plan was created as a model house for dry zone of Sri Lanka to be located at Polonnaruwa. The ECOTECT simulation showed that building could achieve a reasonable thermal performance by applying the strategies identified based on Climate Consultant 6.

Key words: EPS based light weight wall panels, Thermal Comfort, Building Performance

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Chapter 1- Introduction

1.1 General

This chapter aims to discuss the research questions and to provide general overview on Sri Lanka's housing sector. Further it discusses the different types of laws and regulations, as applicable to the housing sector. However, these laws and regulations are being practiced only in certain areas of the country.

People are using different types of materials for building construction in various parts of the country and it is hard to estimate the degree of which various forcing factors are being considered for material selection apart from the cost factor.

Thermal performance of the building helps the dwellers to minimize their operational cost of the building. Therefore, there is a need to understand how to develop thermal comfortable buildings.

The initial part of this chapter discusses the above and followed by a discussion on the structure of the thesis.

1.2 Background

Buildings are the living spaces integrated with day to day lives of human beings. The quality and standardised spaces provide more security, comfort and convenience to its users while providing convenience and advantage in processes of the building construction and other equipment designers. Therefore, it can be considered that standardisation of the buildings are essential to the development of the country and its quality of life of its community.

Housing & Town Improvement Ordinance No. 19 of 1915, Town & Country Planning Ordinance No. 13 of 1946 and Urban Development Authority Act No. 41 of 1978 are the prominent legal statute that regulate building construction in the country and were enacted with consideration of British standards at the time. However these legislations had not followed the building standardization regulations. Hence the different types of buildings are being constructed without considering the standards due to this non-obligatory nature of above legislations which had put urban environment at high risk situation in terms of natural hazards, economy, and social aspects.

Building approval process is currently driven by the local authorities i.e. Municipal Council (MC), Urban Councils (UC) and Pradeshiya Sabaha (PS), under the aforementioned building codes. Although MC's and UC's are practicing these building codes to some extent. It is observed that PS's are not enforcing these legislations in areas under their purview relatively. Therefore, building design is largely unstructured and not properly developed in major part of the country. Recent study conducted by National Building Research Organisation (NBRO) provides evidence that nearly 90% of buildings in Badulla District are constructed without being obtaining prior building approvals necessary (NBRO risk profile development programme, 2017) [1].

Different types of building materials are being used to construct buildings and it has resulted in a vast variation of the spectrum building design. Table 1-1 shows the different types of materials used in building construction in Sri Lanka.

Table 1-1: Types of Materials used to Construct Buildings in Sri Lanka

	Wall						
	Brick	Cement block/Stone	Cabook	Soil bricks	Mud	Cadjan/ Palmyrah	Plank/Metal Sheet
Sri Lanka	53.0%	34.0%	2.0%	3.0%	5.0%	1.0%	2.0%
Dry Zone	72.3%	14.0%	0.1%	0.9%	6.6%	2.8%	3.2%
Intermediate Zone	73.7%	12.3%	1.1%	6.6%	5.6%	0.2%	0.6%
Wet Zone	42.2%	45.5%	3.5%	2.6%	4.2%	0.1%	1.9%

Source: Census and Statistic Department, 2012

According to the above table, 53% of the buildings were constructed by using bricks. Wall materials differ according to the climatic zones of the country. Large quantities

(72%) of buildings are constructed by using bricks in the dry zone compared to 42% buildings are constructed using bricks in the wet zone.

Building design in the international context is different from the Sri Lanka's context and practices. Buildings in many international, mainly in developed countries are designed and constructed by specialist groups considering all user and stakeholder requirements, safety guidelines, laws and regulations of the area. The building are constructed to withstand and possess prescribed capacities to prevent certain natural hazards. Lightweight building materials had been proven in most cases to develop hazard resilient buildings. Therefore, the constructors are being demanded by both authorities and legislation to use precast building systems which are more profitable, user-friendly and easy for installation.

1.3 Research Questions

Analysis of the precast building systems have three main component and each of the component is mastered in different theses. These components are namely; 1) Structural assessments of the precast building system, 2) life-cycle assessment of the precast building system and 3) thermal performance of the precast building system. This thesis focuses the third component which is "thermal performance of the precast building system".

Following research questions were identified to study the building comfort condition of precast building systems.

- How it could affect the comfort level of buildings?
- How the precast building system utilize for building resilience?
- What is the efficiency of using the precast building systems?
- What are the standards that can be adopted for achieving the building comfort?

Most buildings are constructed without having professional support or advice. Building Research Institute has found that there are gaps between engineering techniques and actual construction. [2]

Thermal performance and environmental impacts had been identified as two main thematic areas to be studied based on above research questions and objectives of the study were derived from these thematic areas.

1.4 Objectives of the Study

Objectives of the study are;

1. Identifying and minimising the environmental impacts of the proposed building system and,
2. Determining thermal performance of the proposed pre-cast building system

1.4.1 Objective 1: Identifying and minimising the environmental impacts of the proposed building system

Buildings are the habitable place of people which are utilised for different activities such as residential, commercial, recreational, and industrial etc. These buildings are therefore required to construct ensuring safety of its users to utilise for their needs. Building safety is mainly affected by disasters of the environment in which buildings are constructed and these disasters may occur in two different categories; man-made disasters and natural disasters. Natural disasters such as floods, landslides, cyclones, lightning, etc., occurred due to natural phenomenon and may have triggered and degree of impact can be varied due to unplanned man-made activities. Therefore, it can be understood that planned construction could minimise the natural hazard impacts. As an example raising the foundation beyond flood level where buildings constructed in flood prone area can minimise the impact of floods to the buildings.

The proposed building system should support to achieve the safer condition with limited alteration. The complete system was analysed based on external area conditions to achieve safer building.

1.4.2 Objective 2: Determining thermal performance of the proposed pre-cast building system

Thermal performance of buildings has not being widely discussed on the building construction despite building systems should be providing support for dwellers. The common benefit of a building with better thermal performance comes from reducing the operational cost of having Heat Ventilation, Air condition (HVAC) system. In the long term, such buildings can also be benefited by recognising as the most comfortable location for the identified activities.

This objective will be analysed in-depth on the thesis to identify the process for development of comfortable building system.

1.5 Structure of the thesis

The thesis is comprised of (5) chapters and objectives of each chapter was discussed below.

Introduction to the thesis, general status of the building system, research questions and objectives of the research study had been discussed in the Chapter 1.

Literature review of the thesis, including basic calculations, theories and methods have been discussed in Chapter 2.

Testing of thermal properties of the material and the computer simulation model has been discussed in detailed in Chapter 3 followed by discussion of how thermal comfort conditions had been changed due to building design.

Application of precast building materials for construction of precast buildings has been discussed and evaluated in Chapter 4. Further it has been discussed different design strategies for thermal comfort of building construction in dry and wet zones.

Conclusion and future considerations were elaborated in Chapter 5.

Chapter 2- Literature Review

2.1 General

This chapter aims to develop literature background for the study. According to the objective of the research, a methodology is required to determine the thermal performance of buildings.

Literature had been primarily collected from scientific journals and conference papers are quoted and referenced accordingly.

2.2 Introduction

The literature review was elaborated by using mind mapping tools which revealed the linkages to different concepts and theories to achieve the objectives of the study. The start and end points were identified based on the research questions and objectives discussed in Chapter 1.

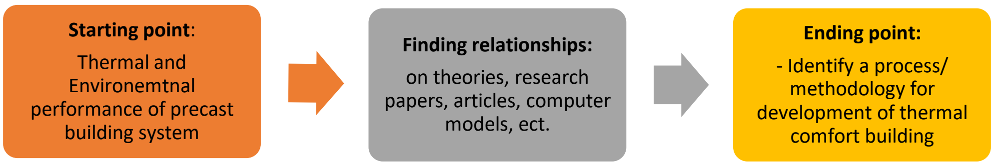


Figure 2-1 – Input and Output of Research

The starting point of the thesis has been identified as the requirement to develop thermal and environmental performance of the precast building system. The ending point of the thesis has been understood as identification of a process/ methodology to develop thermally comfortable building system. Identification and development of relationship between start and end points had been given greater emphasis on this literature review through secondary information. Each secondary information was plotted as connection diagram where a relationship had been identified on the different paths to reach the ending point Figure 2-2 shows the skeleton of mind map that was developed under the research study.

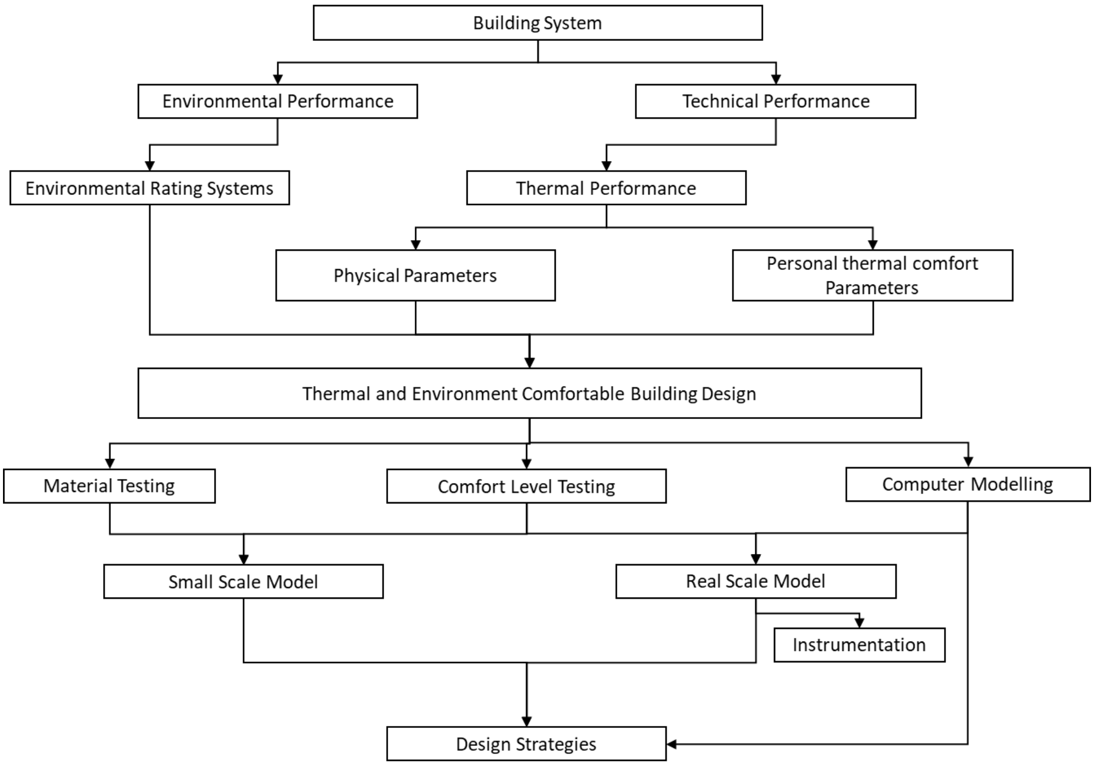


Figure 2-2: Mind Map of Research Study

This research study has been carried out by subdividing the study into three main parts after considering its' subjects viz. 1) Environmental performance of the building, 2) Thermal performance of the building and 3) Precast Building System. Each subject is provided adequate theoretical background for designing the thermal and environmental performance of the precast building system. Each subject is discussed in following sections in detail.

2.3 Building Performance

Building performance can be depended on many aspects of the building itself. The aspects of the performance analysis can be categorised as follows [3];

1. Technical Performance (Heat Insulation, Fire)
2. Functional Performance (Functionality, Applicability, Adaptability)
3. Social Performance (Comfort, Health, Safety)
4. Economic Performance (Life-Cycle cost, Cash flow, Market value)
5. Environmental Performance (Energy uses, Material use)

Out of different categories that forwarded above—technical performance, functional performance and indoor environmental performance had been found appropriate for assessing both technical and social aspects for meeting the demand of reducing risk to buildings—Performance-Risk Indicator - PRI [3]. Table 2-1 shows the PRI indicators that were used to assess the buildings.

Table 2-1: PRI Indicators for Building Assessment [3]

Indicators		
Technical Performance	Functional Performance	Indoor Environmental Performance
• Design of building fittings • Structural stability • Information technology system operation • Electrical services • Plumbing services • Fire prevention services • Materials & internal finishes • Roof • Lift	• Spaces • Orientation • Infrastructure • Access/ Entrance • Circulation area • Ergonomic building facilities • Adequacy of building signature • Emergency exits • Building related illness/ sick building syndrome • Amenities	• Cooling (Thermal Comfort) • Artificial lighting (Visual Comfort) • Natural lighting (Visual Comfort) • Waste reduction • Building ventilation • Acoustic comfort (Noise) • Level of cleanness

2.4 Environmental Performance of the Building

Environmental performance had proven to be a useful tool for building assessments. The most common environmental performance tool is understood as green building rating systems—which currently practiced to assess building to determine the current standards of HVAC systems. A useful method of categorizing green design tools were first proposed by Gowri—knowledge-based methods, rating schema and performance-based tools. [4]. Knowledge based tools can be usually understood as such tools user manuals, guidelines, or other reference materials such as EnergyStar or green building advisor. Building rating schema often comprise of checklists, frameworks, and calculations are used to quantify a building's sustainability profile. These include popular tools like leadership in energy and environmental Design (LEED), Building Research Establishment Environment Assessment Method (BREEAM) and National Australian Building Environmental Rating System (NABERS) [4]. Green SL® rating system for assessing the environmental performance of the buildings had been also been developed by Green Building Council of Sri Lanka (GBSL). The performance-based tools include life cycle assessment methods and energy simulation tools for calculating building energy consumption and environmental emission such as SimaPro and GaBi [4].

2.5 Thermal Performance of a building

Thermal performance of a building links to thermal physics [5]. Thermal comfort of a building can be understood as the condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

Two main parameters are adopted to evaluate thermal performance—personal parameters and environmental parameters. Personal choice; activities and clothing pattern can be considered as Personal parameters while Building envelope and HVAC; air temperature, mean radiant temperature, air speed and humidity are understood as Environmental parameters.

The design background for the particular building is often provided by thermal physics theories and thermal performance is calculated through the computer modelling and software programmes due to its complexity.

Thermal performance assessment tool are primarily aimed to 1) Identify and mitigate the environmental impacts of the proposed building system and 2. Determine thermal performance of the proposed precast building system.

The basis of thermal physics for building design is discussed below to provide the basic understanding of the subject area. The thermal performance of the building can have different understandings such as [6];

- Thermal comfort
- Psychrometric chart
- Optimising energy use of thermal comfort
- Climate
- Internal loads
- Building heat transfer
- Mass (air) transfer
- Passive strategies
- Active strategies

In addition to thermal performance, some literature had discussed the visual performance of the building as well. According to the USAID, INDIA ECO III project, visual performance of the building characteristics are as follows; [6]

- Light basics
- Visual Comfort
- Optimizing energy use for visual comfort
- Passive strategies
- Active strategies

2.6 Personal Thermal Comfort Parameters

Activity and clothing are discussed under the personal thermal comfort parameter section. Human activities are measured as Metabolic rate (M) which can be understood as the rate of transformation of chemical energy into heat and mechanical works by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface or met units.

1 met = 58.2 W/m^2

(Which is equal to the energy produced per unit surface area of an average person, seated at rest) (ANSI/ASHRAE standard 55-2004) [7]

Table 2-2 shows a few metabolic rates for identifying activities;

Table 2-2: Metabolic Rates for Different Activities [7]

Activity	**Metabolic rate**	
	Met Unit	**W/m^2**
Sleeping	0.7	40
Standing, relaxed	1.2	70
Car driving	1.2 - 2.0	60- 115
Walking at 0.9 m/s	2.0	115
Cooking	1.6-2.0	95- 115
Playing basketball	5.0- 7.6	290 - 440

(Source: ANSI/ ASHRAE Standard 55-2004)

Clothing insulation can also be adopted as measure for thermal comfort analysis of the building. According to the ANSI/ ASHRAE Standard 55-2004 [7] mentioned some of clothing insulations as follows (Table 2-3);

Table 2-3: Cloth values [7]

Ensemble Description	**Clo**	**W/m^2**
Trousers + short-sleeved shirt	0.57	0.08835
Long sleeved coveralls + t-shirt	0.72	0.1116
Sweat pants+ sweat shirt	0.74	0.1147
Trousers + long sleeved shirt+ suit jacket	0.96	0.1488
Insulated overalls + long sleeved thermal underwear (+bottoms)	1.37	0.21235

(1 Clo = 0.155 m2.K/W

Source: ANSI/ASHRAE Standard 55-2004, Thermal Environmental Condition for Human Occupancy

2.6.1 Heat Exchange

1.1.1.1 Radiation exchange

The heat transfers as the radiant is described as follows (Equation (1));

$$\theta \approx \frac{\sum \theta^i A^i}{\sum A} \qquad \text{Equation (1)}$$

Here; θ means the radiant temperature and A is the area of the surface.

1.1.1.2 Air Speed

The average speed of the air to which the body is exposed can be measured. A certain minimum desirable wind speed is needed for achieving thermal comfort at different temperatures and relative humidity values. Table 2-4 describes the wind speed (m/s) for achieving the thermal comfort condition of the building.

Table 2-4: Wind speed need for different indoor temperatures [7]

	Relative Humidity (Percentage)						
Dry Bulb Temperature	30%	40%	50%	60%	70%	80%	90%
28°C	*	*	*	*	*	*	*
29°C	*	*	*	*	*	0.06	0.19
30°C	*	*	*	0.06	0.24	0.53	0.85
31°C	*	0.06	0.24	0.53	1.04	1.47	2.10
32°C	0.2	0.46	0.94	1.59	2.26	3.04	**
33°C	0.77	1.36	2.12	3.00	**	**	**
34°C	1.85	2.72	**	**	**	**	**
35°C	3.2	**	**	**	**	**	**

Source: ANSI/ASHRAE standard 55-2004/ National Building Code of India 2005

2.6.2 Humidity

Humidity is a measure of the moisture content of the air which is expressed in several variables; vapour pressure, dew point temperature, relative humidity and humidity ratio.

2.7 Thermal Comfort Indices

People make many alterations to their lifestyles and to the building to achieve a more comfort condition of inhabiting. Changing clothing patterns, activities, and air movement are the short term activities, while redesign of the building, and landscaping can be understood as long term activities to achieve a comfort condition of the buildings. As per the ASHRAE standards 55-2004 an equation (Equation (2)) for determining the comfort temperature of the building is;

$$t_{oc} = 18.9 + 0.255 \times t_{out} \qquad \text{Equation (2)}$$

In here;

t_{oc} = Operative Comfort Temperature

t_{out} =mean outside temperature of the month (℃)

As an example, if the mean outside temperature of the month is 30℃; then the comfort temperate of the building is 26.55℃.

In addition to temperature, moisture content is directly evolved to ensure the thermal comfort condition of the building; this can be presented on a psychrometric chart.

Olesen, B.W. [8] described a set of recommended values of the indoor temperature in the design of buildings. [8] In his paper, buildings were categorised into four groups which can be described in Table 2-5.

Table 2-5:Building Categories on thermal comfort [8]

Category	**Explanation**
I	High level of expectation and is recommended for spaces occupied by varying sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.
II	Normal Level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

The recommended temperatures were defined based on above categories in Table 2-6; the temperature was listed for winter season and summer seasons.

Table 2-6:Recommended temperature for activities [8]

Type of building/ Space	Winter season (Heating)	Summer season (Cooling)
Residential building; living spaces (Bed rooms, drawing room, kitchen, etc), Sedentary ~1.2 met	21 – 18 °C	25.5 – 27 °C
Residential building: other spaces (storages, halls, etc), standing/walking ~1.6 met	18-14 °C	
Single and landscaped office conference room, auditorium, sedentary ~1.2 met	21-19 °C	25-27 °C
Cafeteria/restaurant, sedentary ~1.2 met	21-19 °C	25.5-27 °C
Classroom, sedentary ~1.2 met	21-19 °C	25-27 °C
Kindergarten, standing/walking ~1.4 met	19-16.5 °C	24.5-26 °C
Department Store, standing/ walking ~1.6 met	17.5-15 °C	24-26 °C

2.7.1 Psychrometric Charts

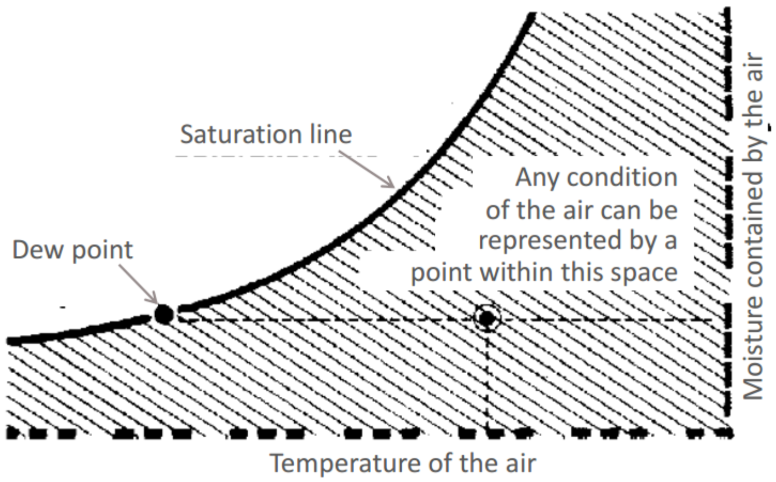


Figure 2-3: Sample Psychrometric Chart

Moisture contents of the air with reference to atmospheric temperature can be understood by referring the psychrometric charts. The wet bulb temperature and dry bulb temperature are measured to locate the moisture content of the air. The example of psychrometric chart can be shown in Figure 2-3.

2.8 Indoor air quality and Ventilation rates

Not only temperature but also the ventilation rate is an essential requirement to achieve the thermal comfort level of a building. The ventilation system is designed by considering the required ventilation to achieve the thermal comfort levels. The ASHRAE standard 62.1 for ventilation and indoor air quality has a basis using ventilation level for adapting persons. [8] Olesen B.W. discusses one method for calculating the required ventilation for room as follows (Equation (3));

$$q_{tot} = nq_p + Aq_B \qquad \text{Equation (3)}$$

Where $q_{tot}$is the total rate of the room, n is the design value for the number of the persons in the room, $q_p$is the ventilation rate for occupancy per person, A is the room floor area (m2), $q_B$is the ventilation rate of emissions from buildings. [8] The basic required ventilation rates for diluting emissions from people in different categories are shown in Table 2-7;

Table 2-7:Ventilation rates of diluting emissions [8]

Category	Expected Percentage Dissatisfied	People Component ($\boldsymbol{q_p}$)	Building component ($\boldsymbol{q_B}$)		
			Very Low Polluting	Low Polluting	Not Low Polluting
I	15	10	0.5	1.0	2.0
II	20	7	0.35	0.7	1.4
III	30	4	0.2	0.4	0.8
IV	>30	<4	<0.2	<0.4	<0.8

2.9 Manual Calculation of thermal Performance

As it is necessary to understand the application of theories to the real world, manual calculation of thermal performance was done for a model which can described as follows. A model house plan was developed for the calculation as in Figure 2-4.

However, the manual calculation can be easily used only for steady state condition. Total heat gain under steady state condition can be written on (Equation (4))

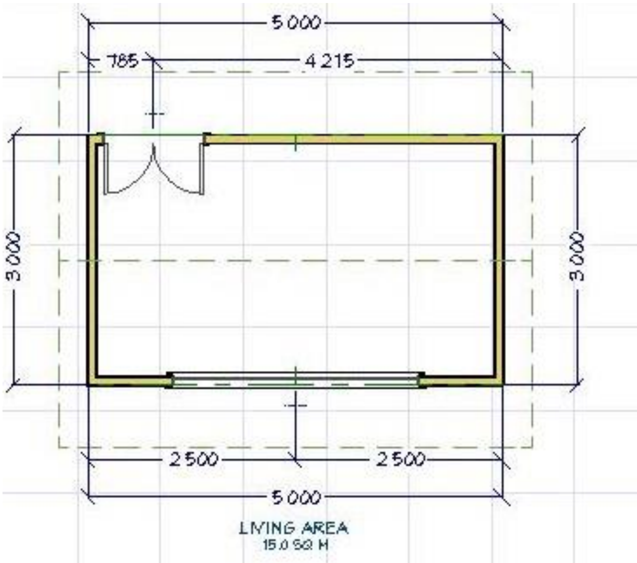
$$Qtot = Qc + Qs + Qi + Qv \qquad \text{Equation (4)}$$

Qc- Heat Conduction

Qs- Solar Heat Gain

Qi- Internal Gain

Qv-Evaporation



Building size: 5m x 3m

Height : 3m

Window: 1.5m x 3m (On south wall)

Door: 2m x 1.2m (on North wall)

Figure 2-4:Computer Simulation Model

Following data was assumed for the calculation purpose.

Ventilation Rate	0.5	h^{-1}
Artificial light	100	W
Occupancy	2	Persons
Window Area	4.5	m^2
Door	1.2	m^2

The following meteorological data also assumed for the model.

Daily Av. Outside Temperature	30	°C
Absorption of external wall surfaces	0.6	

Outside heat transfer coefficient	22.7	W/m^2K
Inside design temp	27	°C
Daily Av. Solar Radiation on south wall	111.3	W/m^2
Daily Av. Solar Radiation on east wall	158.2	W/m^2
Daily Av. Solar Radiation on north wall	101.1	W/m^2
Daily Av. Solar Radiation on west wall	155.2	W/m^2
Daily Av. Solar Radiation on Roof wall	303.1	W/m^2
Daily Av. Solar Radiation on window wall	111.3	W/m^2
Mean absorptivity of space	0.6	
Transmissivity of window	0.86	
Absorptivity of glazing for solar radiation	0.06	
Absorptivity of wood for solar radiation	0	
Different between longwave and surface (roof)	63	W/m^2
Density of Air	1.20	kg/m^3
Specific heat of air	1,005.00	J/kg-K
U value of Glazing	5.77	W/m^2-K
U value of Wall	2.86	W/m^2-K

In the steady state, solar air temperature around the building can be calculated by using the following formula. Based on the formula, temperatures were calculated as follows (Equation 5).

$$Sol - Air\ temperature = (Daily\ Av.Outside\ Temp + \frac{[Mean\ absoptivity\ of\ space * Daily\ Av.Solar\ Radiation]}{Outside\ heat\ transfer\ coiefficent}) \quad \text{Equation 5)}$$

Sol-air temperature South	32.94	°C
Sol-air temperature east	34.18	°C
Sol-air temperature North	32.67	°C
Sol-air temperature West	34.10	°C

Sol-air temperature Roof	36.35	°C
Sol-air temperature Window	32.94	°C
Sol-air temperature Door	30.02	°C

Apply the heat conduction formula for heat conduction calculate (Equation (6)).

$$Qc = \sum_{i=1}^{Nc} A_i U_i \Delta T_i \qquad \text{Equation (6)}$$

Where; i= Building element

Nc= number of components

A= Surface Area

U= Thermal Transmittance

ΔT= Temperature difference between inside and outside air (K)

Conduction	Qc	
Qc (South wall)	255.14	W
Qc (East wall)	308.37	W
Qc (North wall) with window	170.50	W
Qc(West) with Door	280.57	W
Qc (Window)	154.28	W
Qc (Door)	11.51	W
Qc(Roof)	539.75	W
Total Qc	1,720.12	W

Calculation of heat gain from transparent elements could be calculated by using following formula (Equation (7));

$$Q_s = \alpha_s \sum_{i=1}^{M} A_i S_{gi} \tau_i \quad \text{Equation (7)}$$

Where; α_s = mean absorptivity of the space

A_i = Area of transparent element

S_{gi} = Daily average of value of solar radiation on the transparent element

τ_i = Transmissivity of the transparent element.

M= Number of transparent elements

Solar Heat gain by transparent element	**Qs**	
Qs (window)	234.75	W
Qs (Door)	111.74	W
Total Qs	346.50	W

Calculation of internal gain: This includes personal gain and artificial lighting. Which could be illustrated as follows (Equation (8));

$$Q_i = ((\text{No of people x Heat output rate}) + \text{Rated Wattage Lamps} + \text{Appliance load}) \quad \text{Equation (8)}$$

Internal Gain	**Qi**	
Qi	300.00	W

Evaporation rate could be calculated by using following formula (Equation (9));

$$Q_v = \rho V_r C \Delta T \qquad \text{Equation (9)}$$

Where; ρ = Density of Air

V_r= Ventilation rate

C= Specific heat of air

ΔT= Temperature difference

Evaporation	**Qv**	
Qv	37.69	W

Total gain under the steady state can be written as (Equation (4));

$$Qtot = Qc + Qs + Qi + Qv$$

Q total		
Q t	2,404.30	W

This mean of 2.4kW generated at the room and room designer's duty to find the strategies to transform this energy for ensuring the comfort condition.

For actual performance, it has to be dynamic assessments under varying conditions for which computer simulations are needed.

2.10 Computer modelling of thermal Performance

Different types of models have been used for simulating the thermal comfort level of buildings and by using such computer modeling, designers and architects can design the buildings in energy efficient manner. It has following advantages to users; [9]

- Help to work with façade panels or any other kind of modular systems that includes assemblages and combinations of building construction information.
- Visualize the results and change the building accordingly.
- Thermal calculation assists the design guidelines.
- Control heating and cooling effects

There are different types of computer based thermal performance packages such as Autodesk Ecotect, Design Builder, Open Studio, Autodesk CFD, Autodesk Revit, etc. According to Shi, X et al [10], out of these numerical simulation packages three important and commonly used packages such as Ecotect, Energy Plus and Radiance were integrated to Rhinoceros/ Grasshopper to establish the workflows. Further, Shi, X et al. [10] elaborated the workflow of performance driven approach as follows (Figure 2-5).

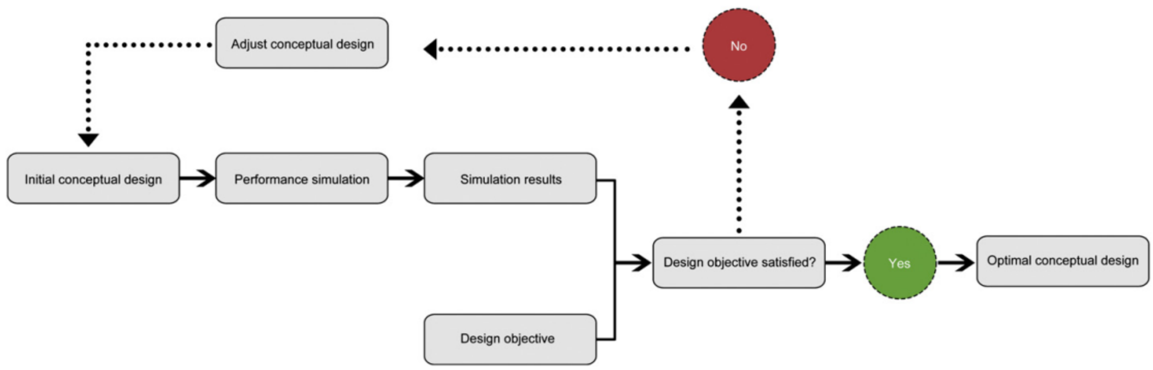


Figure 2-5: Workflow of Performance Driven Approach by Shi, X.

Therefore, for this research study Ecotect tool had been used to simulate the building performance and it has been also identified the following limitations. [10]

- Data availability and quality for the early design phases are limited when detailed energy-use models have not been created. [10]

- Ecotect is composed of simplified energy modelling tools that are based on more complex simulation engines and thus cannot be used for meeting codes or regulations. [10]
- Programming take long time for simulating.

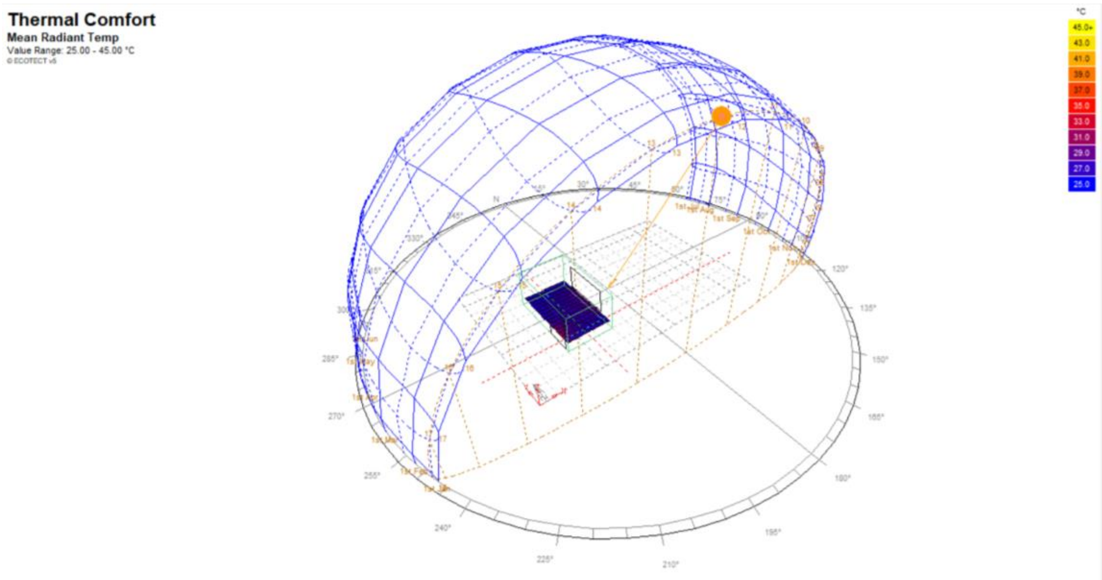


Figure 2-6: Sun path

Weather information was collected from Energyplus [11] and modified with Meteorological department data. Figure 2-6 shows the sun path location over the one-year period. The computer simulation was conducted for an annum on monthly basis (1st day of the month at 12.00pm). Ecotect can give similar results analysis for the same house. The thermal comfort conditions are as follows (Figure 2-7);

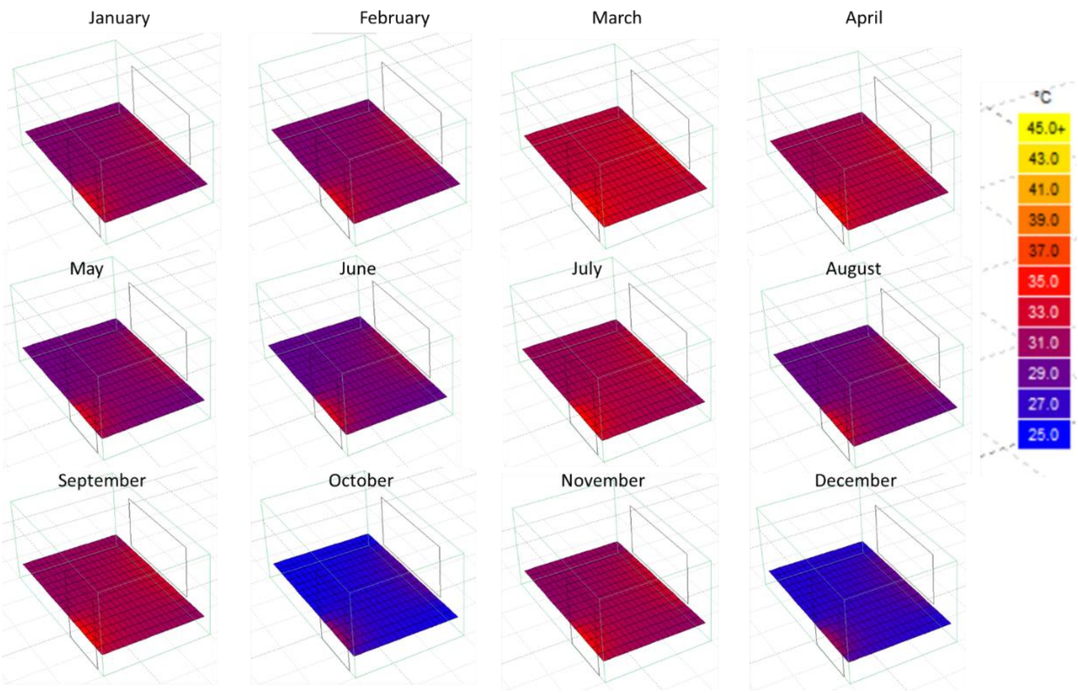


Figure 2-7: Monthly thermal comfort levels

2.11 Computer Simulation Software

2.11.1 Climate Consultant 6

The Climate Consultant Simulation Software was developed by Department of Architecture and Urban Design, University of California. This software provides the graphic-based computer programme that helps to architects, planners, engineers, contractor, builders and students to understand their local climate conditions. There are different types of data charts available in this software. Psychrometric chart generates automatically based on the available of predefined weather data file. Also it provides the different 16 design strategies [12];

1. **Comfort Zone**: "It is assumed to enclose the number of hours when the occupants of a space are thermally comfortable whether in indoor or outdoor conditions".
2. **Sun shading zone**: "The sun shading is particularly effective in outdoor spaces to control radiant temperatures, and on windows to help prevent indoor dry bulb temperatures from climbing above ambient temperature".

3. **High thermal mass zone**: "In hot dry climates using high thermal mass on the interior is a good cooling design strategy. This counts on the thermal storage and time lag and dumping effects of the mass. Thus high daily outdoor temperature swings will become low daily indoor temperature swings, thus the building will be closed up and 'coast' through high daytime temperature".
4. **High thermal mass with night flushing zone**: "In hot dry climates using high thermal mass on the interior is a good cooling design strategy, especially when either natural ventilation or a whole house fan is used to bring in a lot of cool night time air and then the building is closed up during the heat of the day. This counts on the thermal storage and time lag and damping effects of the mass, thus the building will 'coast' through high daytime temperatures. Thus high daily outdoor temperature swings will become low daily indoor temperature swings".
5. **Direct evaporation cooling zone**: "Evaporative cooling takes place when water is changed from liquid water to gas (taking on the latent heat of fusion), thus the air becomes cooler but more humid".
6. **Two stage evaporative cooling zone**: "It is the same as the Direct Evaporative Cooler except that the angle of the upper boundary is increased in proportion to the percent efficiency of the Indirect Phase. The first stage uses evaporation to cool the outside of a heat exchanger, through which incoming air is drawn into the second stage where it is cooled by direct evaporation".
7. **Natural ventilation cooling zone**: "In hot humid climates air motion is one of the few ways to produce a cooling effect on the human body. It does this by increasing the rate of sweat evaporation and giving the psychological sense of cooling (note that ventilation does not actually reduce the dry bulb temperature)".
8. **Fan forced ventilation cooling zone**: "It is assumed that when ventilation cooling is needed, fan forced air motion can be created by centralized mechanical fans or ceiling fans or even small local fans on a desk or table. In hot humid climates air motion is one of the few ways to produce a cooling effect on the human body. It does this by increasing the rate of sweat

evaporation and giving the psychological sense of cooling (note that ventilation does not actually reduce the dry bulb temperature)".

9. **Internal heat gain zone**: "It represents a rough estimate of the amount of heat that is added to a building by internal loads such as lights, people, and equipment."
10. **Passive solar direct gain low mass zone**: "it can only be a rough estimate because it is very much a function of building design. If the building has the right amount of sun-facing glass, then passive solar heating can raise internal temperatures. Also this zone assumes a relatively low Thermal Time Lag for Low Mass Buildings, on the order of 3 hours, which means that the radiation is measured 3 hours previous to the current hour. A given hour is assumed to be inside this zone if the temperature rise that radiation produces reaches the minimum Comfort temperature."
11. **Passive solar direct high mass zone**: "This zone also assumes a relatively long Thermal Time Lag for High Mass Buildings on the order of 12 or more hours, which means that the radiation is measured 12 hours previous to the current hour. A given hour is assumed to be inside this zone if the indoor temperature rise that radiation produces reaches the minimum Comfort temperature."
12. **Wind protection of outdoor spaces**: "In very cold weather it represents the hours when cold winds are uncomfortable in outdoor spaces, and in very hot weather it represents the hours when hot winds are uncomfortable in outdoor spaces."
13. **Humidification zone**: "It represents the case where indoor air is within the dry bulb comfort range but is too dry and so would need to have moisture added."
14. **Dehumidification zone**: "It represents the case where the indoor air is within the dry bulb comfort range but is too humid and so would need to have moisture removed."
15. **Cooling zone (and dehumidification if needed)**: "On any hour when outdoor temperature is above the comfort range and is not in any other cooling strategy zone, by default that hour falls into the zone where some type of artificial cooling is necessary to create a comfortable indoor temperature"

16. **Heating zone (and humidification if necessary)**: “When outdoor temperature is below the comfort range and is not in any other heating zones, by default that hour falls into the zone where some type of artificial heating is necessary to create comfortable indoor temperatures”

The design principles were generated based on above 16 strategies and which could be shown in Annexure 01.

2.11.2 Ecotect

Ecotect simulation software was developed under Autodesk suite. This simulation software used to analysis the spatial variation of thermal comfort conditions in the building. Different spatial zones could be created from the software and could be analysed each zones in periodically.

Thermal properties could be insert and thermal condition was changed accordingly. Clothing pattern and activity pattern could be used as input parameters and also it could be input as weekly, monthly, yearly schedules.

2.12 Precast Building Systems

Precast building system relates to industrial building systems (IBS). The IBS has characteristics of a prefabricated system, mass production, design using modular coordination, standardized components and off-site production. Due to such production process and component characteristics, precast building systems possess the number of advantages compared to the conventional building systems;

- Control of human resources and costs; the precast building system was developed based pre-engineered construction phases and users can easily place the precast building system with less human resources.
- Shorten construction Period and increase the quality of building; Prefabrication system believes to have the potential for better environmental performance (e.g. Sanders and Phillipson [13]; Gorgolewski, [14])
- Enhance occupational health and safety [15];)

- Reduce construction waste ([16]; [17]; [18]); It was proved that; Jaillon et al. [16] average wastage reduction level through the implementation of IBS is about 52% [18]

Wu, et al., [19] describes that by applying the lean concept of a production line, 9 to 6.5 people (labour waste), 12% space (equipment waste) and 10% material waste can be reduced. It has been further understood that lean concept may have benefits in reducing carbon emissions in precast concrete factories by improving site layout design and supply chain by adding Non-value adding (NVA) activities.

IBS/ Precast building systems provides better opportunities to make sustainable built environment through proper planning and strategies. Sustainability in construction developments must have an outcome of responsible maintenance of a healthy built environment based on ecological principles, and by means of an efficient use of resources. ([20]; [18].

These precast building systems also can be used to construct prefabricated buildings for disaster victim communities. [21] These systems can be installed within a shorter period in a place and after the land clearance, the system can remove and it can be reused for permanent structures subsequently. Johnson, C. [22] mentioned that there are advantages of using precast system/ prefabricated system for creating of temporary shelters.

- Rapidly available
- Draw on local supplier
- Meet local level standards and comfort
- Efficient long-term plan

2.12.1 EPS based light weight panels

This EPS based light weight panel creates cement fiber boards filled with EPS based lightweight concrete mix with a density in the rage of 600-700 kg/m^3 with 50% of the EPS content being replaced with mechanically recycled EPS [23]. Different thickness is available on this panels; 75mm, 100 mm and 150 mm. Size of the panel is 8’ x 2’.

2.13 Environmental Performance of the building

Environmental performance of a building has different meanings. One argument of environmental performance is that it could be related to resilience to hazards. Global average sea level has risen since 1960 at an average rate of 1.8 mm/y, and since 1993 at 3.1 mm/y [24]. Similarly, frequency of hazard and its magnitude are increasing with the climate change. Therefore, it is understood as resilience to hazard as one variable for assessing the environmental performance of the building.

Environmental performance of the building can be also understood through the point of its Life cycle energy. According to the United Nations Environment Programme [25], the life cycle energy consumption in the building can be divided into five phases; a) Embodied energy, b) Transport construction materials, c) Building construction energy, d) Operation and e) Demolition and recycling.

Building are the largest consumer of energy and the greatest contributor to climate change in the United States consuming approximately 49% of primary energy and contributing 47% of greenhouse gases emitted annually. (United States Energy Information Administration, Annual Energy review) [26]. Studies show that earlier environmental and/or energy assessments can prevail greater potential to effectively influence the life cycle performance of the building. [27]

Therefore, it is understood the necessity of the tools to assess the environmental performance of the building and a useful method of categorizing green design tools were proposed; 1) knowledge-based methods, 2) Rating schema, and 3) Performance-based tools [28]. Manuals, guild lines, or other reference materials such as Energy Star or Green Building Advisor can be considered as the knowledge-based tools. Designed checklists, frameworks, and calculators used to quantify a building's sustainability profile are considered as Building rating schema. These include popular tools like leadership in Energy and environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and National Australian Building Environmental Rating System (NABERS).

As with environmental performance, sustainable environment also has many definitions. One definition elaborated sustainability as balancing of Environmental, Economic and Social aspects of the area. However, Green building council of Sri Lanka forwarded that sustainable environment as balance of built environment, natural environment and theoretical environment. Built environment is understood as buildings, roads and other physical constructions while theoretical environment is the balance of theories and concepts that developed for management of society.

Life cycle assessment methods and energy simulation tools for calculating building energy consumption and environmental emission such as SimaPro and GaBi can be considered as Performance-based tools to assess environmental performance of buildings.

Sanders and Philipson, [13]; Gorgolewski, [14]; explained that the need of the prefabrication system for the environmental performance analysis. Prefabrication system believes to have the potential for better environmental performance.

2.14 Thermal and Environment Comfortable Building Design

It is required to have a building design guideline for construction of thermal and environmental performed buildings in the area. Guidance is based on existing research studies, standards and other regulations. Khalil, N. et al. [3] ranking of the indicators for building performance and developed performance risk index (PRI). These indicators may varied according to the climatic zones and therefore it is required to identify the relevant zonal climate parameters before designing the building.

The building envelop is one of the key aspect to determine the comfort condition of the building. Envelop is a separation of indoor environment and outdoor weather conditions. The decision of envelop design is based on several aspects [28];

- Heat flow control
- Air flow control
- Water vapor flow control
- Rain penetration control
- Light, solar and other radiation control
- Noise control
- Fire safety

- Structural Control
- Durability
- Aesthetic control
- Cost
- Buildability
- Maintainability
- Special Considerations

These aspects are varied from place to place and therefore it is required to understand the context of application before designing the building. It is also required to develop different alternatives for selection of the envelop. This can be categorized as [28];

1. Establishing the design context
2. Specification of design objective
3. Generation of alternatives
4. Prediction of alternative performance
5. Evaluation and selection of alternative materials

2.15 Summery

There are numerous studies that have been carried out related to achieving the thermal performance in various building systems. Such amendments help to improve the usage of materials to minimise the energy usages. In the study presented in this thesis, a detailed study has been carried out for models and a house constructed using EPS based light weight panels which is a newly manufactured product in Sri Lanka.

Chapter 3- Testing of Properties of the Building Material

3.1 General

Testing of properties is essential in determining the thermal comfort condition. It helps to determine thermal properties of selected building materials. Additionally, it helps to the designers to know the thermal parameters and their variances across the day and night when choosing proper technique of building design. Therefore, it is a vital requirement to develop and test the material in different aspects, in different environmental conditions to understand the behavior of the material.

3.2 Introduction

Thermal properties of a material were tested at different levels; laboratory, scale model and realistic scale models. Testing procedures and methods for each case are elaborated under this chapter.

3.3 Thermal Conductivity

Thermal conductivity of the material is one of the critical factors for determining the thermal comfort condition of the building. Different methods had been proposed to determine the thermal conductivity of the material. “Guarded Hot Plate Method” can be understood as a basic concept in this regard which the sample is pasted in between cold plate and hot plate and temperatures are monitored until becoming a steady state. This method takes considerable time to achieve the steady state and thermal conductivity is calculated by using following formula (Equation (10)).

$$Q = Q/A = \frac{\Delta T}{\frac{\Delta X}{k}} \qquad \text{Equation (10)}$$

Where, k = thermal conductivity of the test specimen (W/mK),

Q,Q/A= Heat flow per unit area or the heat flux (W/m2)

ΔX= Thickness of the test specimen (m)

ΔT = temperature difference across the test specimen (K)

This method is useful to define thermal conductivity of super insulation materials like high performance insulation boards. However the method had not been proven to be useful in measuring liquids or high thermal conductivity materials like copper, lead, gold, silver, aluminum, etc.

“Laser flash diffusivity” can be adopted as another method which materials are tested using most extreme temperatures where thermal diffusivity is measured and later it is converted to the thermal conductivity. This technique is used to measure the dense ceramic, metals and aerospace. Complexity and limited sample band the wider use of the technique. The “transient plane source” is another method to use for measure the thermal conductivity. The sensor is located center of two samples and sensor generate heat and it will monitor through the sensor. Temperature with time are measured and equation helps to calculate the thermal conductivity of the material.

Guarded Hot Plate Method was used to test the sandwich wall panel with following the ASTM C236: Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box [29]. (Figure 3-1, Figure 3-2)

Following procedure was followed to test the sample;

3.3.1 Testing Procedure

- Size of the test piece is 150 x150 mm and thickness; 75 mm
- Attached the Thermal Sensors to test piece
- Place the test specimen into the apparatus and Adjust the thermal intensity (750 W, 1300 W)
- Monitor the temperature while, it came to steady state levels
- Cooled plate (4 °C – 150 mm dia.)
- Hot plate (1300 w – 150 mm dia. Max 200 °C)
- Testing time: 5 hours
- Temperature recorded every 5min interval

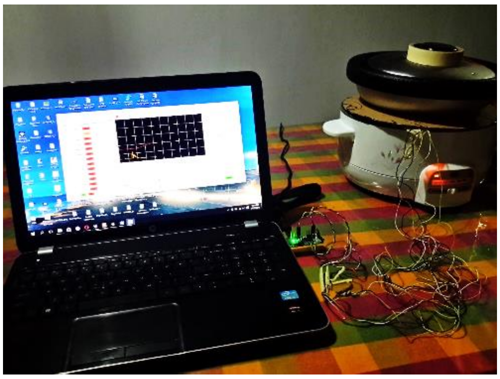


Figure 3-1: Thermal Conductivity Testing

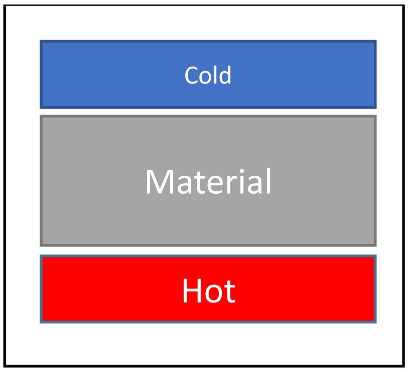


Figure 3-2: Guarded Hot Plate Method

The thermal conductivity was measured by using the Equation (11);

$$\lambda = \frac{QL}{A(\Delta t)}$$ Equation (11)

Where;

λ = Thermal conductivity (W/m.K)

Q = Time rate of heat flow (W)

L = Length of path of heat flow, (m)

Δt = Area weighted average temp. of hot surface – Cold surface (K)

Based on the recorded data, thermal conductivity value varied as following Figure 3-3;

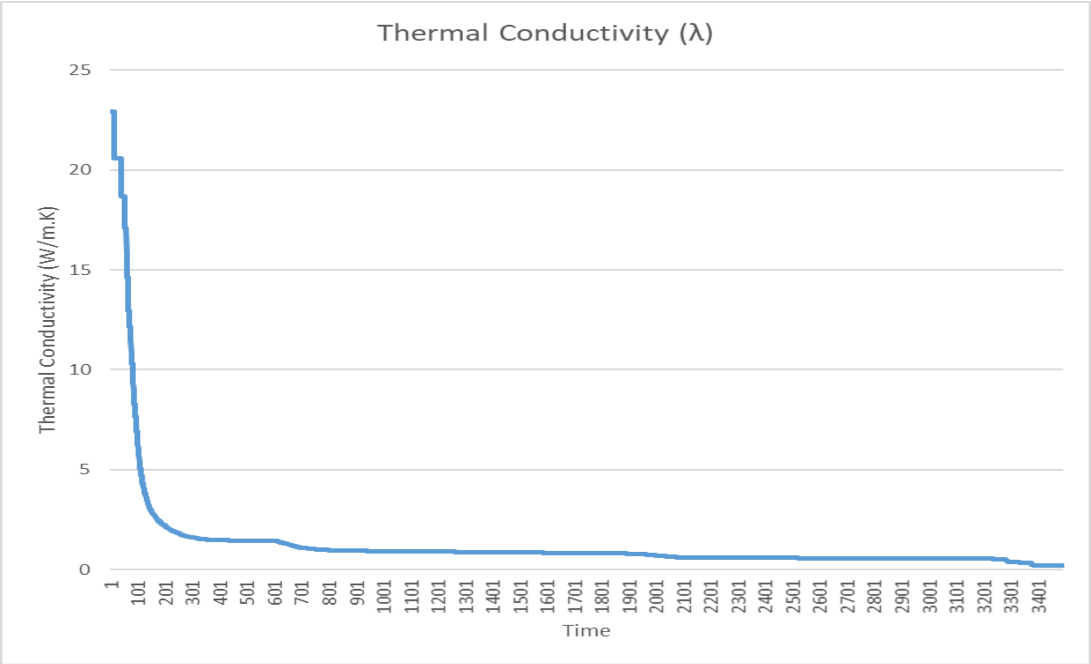


Figure 3-3: Thermal Conductivity

According to the calculation, the steady state thermal conductivity was 0.2147 W/m.K. and density was 741 kg/m^3. Table 3-1 shows the different thermal conductivity values in different materials;

Table 3-1: Thermal Conductivity and Density of Materials

Material	**Density (Kg/m^3)**	**Thermal Conductivity (W/m K)**
Walls (External and Internal)		
Brick (Exposed)	1,750	0.77
Brick (Protected)	1,700	0.56
Dense Concrete block (Exposed)	2,300	1.87
Mortar (Exposed)	1,900	0.94
Mortar (Protected)	1,900	0.88
Surface Finishers		
Plaster (Dense)	1,300	0.57
Plaster (Light-weight)	600	0.18
Insulation		
Expanded Polystyrene (EPS) slab	15	0.040

3.4 Testing of real scale model

There were three real buildings monitored for thermal variation constructed with light weight precast panels.

1. Negambo Hospital
2. Model House at Yayawatta, Tangalle
3. House at Jaffna

The newly constructed building at Negambo Hospital has been constructed by using straw based panels are considered in this section. This straw-based panel has been used for wall, roof and different precast slabs are available for constructing the building as a system. The newly construct temporary buildings (3 Nos.) were constructed under this technology and initial measurements were taken based on the buildings.

The comfort levels were measured through the wet-dry bulb and plotted the values in psychrometric chart (Figure 3-4). Wind speed was also measured inside the building and outside the building. Operation theaters, wards were the main proposed activities of that building. The building floor area was divided into 10x 10ft grid and measurement were taken in each grid. The measurement was taken continuously in a day and plotted the results in psychometric chart. Green color points were the outside the building and red color points were inside of the building.

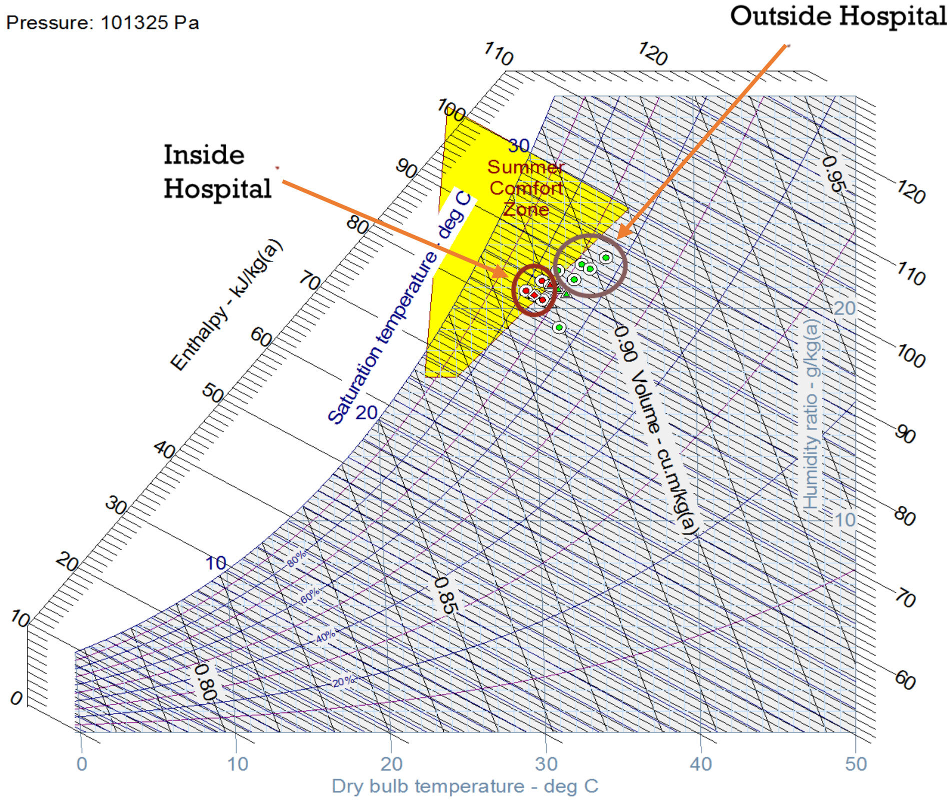


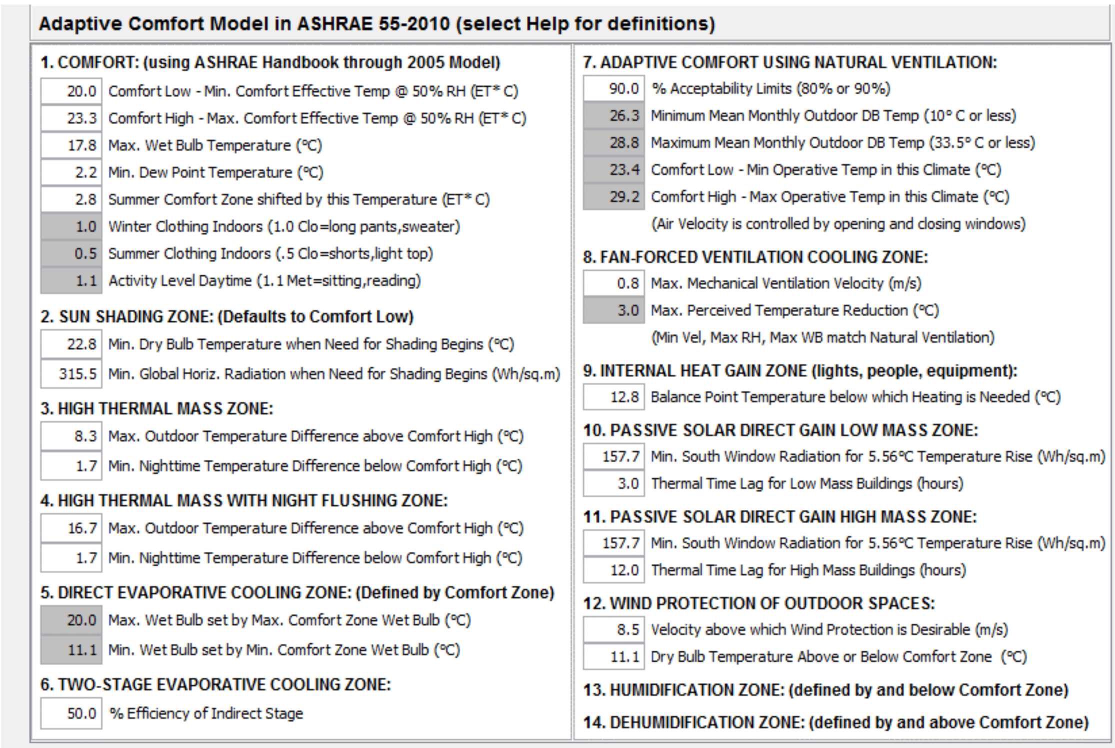
Figure 3-4:Psychrometric Chart of Negambo Hospital

Katunayake was the nearest weather station for the site where the site is located and comfort conditions were analyzed by considering the Climate Consultant Software [12]. Adaptive comfort model in ASHRAE standard 55-2005 was selected to proceed the model and it described as follows;

“In naturally ventilated spaces where occupants can open and close windows, their thermal response will depend in part on the outdoor climate and may have a wider comfort range than in buildings with centralized HVAC systems. This model assumes occupants adapt their clothing to thermal conditions and are sedentary (1.0 to 1.3 met). There must be no mechanical Cooling System, but this method does not apply if a Mechanical Heating System is in operation.” [12]

The parameters assigned in to adaptive comfort model are presented in Figure 3-5;

For Negambo, the standard climate file has been run with climate consultant simulation software to obtain the effects of variance strategies available for improving the thermal conductivity.


Adaptive Comfort Model in ASHRAE 55-2010 (select Help for definitions)

1. COMFORT: (using ASHRAE Handbook through 2005 Model)
20.0 Comfort Low - Min. Comfort Effective Temp @ 50% RH (ET* C)
23.3 Comfort High - Max. Comfort Effective Temp @ 50% RH (ET* C)
17.8 Max. Wet Bulb Temperature (°C)
2.2 Min. Dew Point Temperature (°C)
2.8 Summer Comfort Zone shifted by this Temperature (ET* C)
1.0 Winter Clothing Indoors (1.0 Clo=long pants,sweater)
0.5 Summer Clothing Indoors (.5 Clo=shorts,light top)
1.1 Activity Level Daytime (1.1 Met=sitting,reading)

2. SUN SHADING ZONE: (Defaults to Comfort Low)
22.8 Min. Dry Bulb Temperature when Need for Shading Begins (°C)
315.5 Min. Global Horiz. Radiation when Need for Shading Begins (Wh/sq.m)

3. HIGH THERMAL MASS ZONE:
8.3 Max. Outdoor Temperature Difference above Comfort High (°C)
1.7 Min. Nighttime Temperature Difference below Comfort High (°C)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:
16.7 Max. Outdoor Temperature Difference above Comfort High (°C)
1.7 Min. Nighttime Temperature Difference below Comfort High (°C)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)
20.0 Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°C)
11.1 Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°C)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:
50.0 % Efficiency of Indirect Stage

7. ADAPTIVE COMFORT USING NATURAL VENTILATION:
90.0 % Acceptability Limits (80% or 90%)
26.3 Minimum Mean Monthly Outdoor DB Temp (10° C or less)
28.8 Maximum Mean Monthly Outdoor DB Temp (33.5° C or less)
23.4 Comfort Low - Min Operative Temp in this Climate (°C)
29.2 Comfort High - Max Operative Temp in this Climate (°C)
(Air Velocity is controlled by opening and closing windows)

8. FAN-FORCED VENTILATION COOLING ZONE:
0.8 Max. Mechanical Ventilation Velocity (m/s)
3.0 Max. Perceived Temperature Reduction (°C)
(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE (lights, people, equipment):
12.8 Balance Point Temperature below which Heating is Needed (°C)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:
157.7 Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
3.0 Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:
157.7 Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
12.0 Thermal Time Lag for High Mass Buildings (hours)

12. WIND PROTECTION OF OUTDOOR SPACES:
8.5 Velocity above which Wind Protection is Desirable (m/s)
11.1 Dry Bulb Temperature Above or Below Comfort Zone (°C)

13. HUMIDIFICATION ZONE: (defined by and below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (defined by and above Comfort Zone)

Figure 3-5: Assigned parameters to adaptive comfort model

According to the calculation only 1.5% of total hours will fit to comfort range and 62% of total hours will fit to adaptive comfort ventilation. Therefore, only 63.2% of total hours will belongs to comfortable hours. Figure 3-6 shows the psychrometric chart of dry-wet bulb temperature, which includes comfort zone and adaptive comfort ventilation zone.

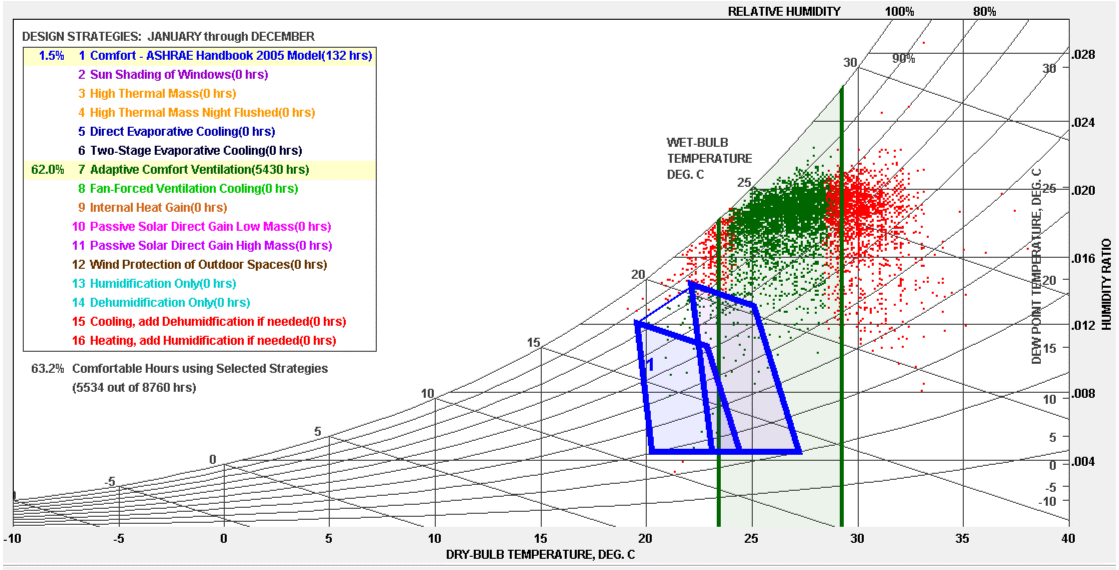


Figure 3-6: Design Strategies with psychrometric chart

Different strategies can be considered for enhancing the comfort range. Table 3-2 indicates the percentages of comfort level changes by applying of design strategies for the building.

Table 3-2: Level of impacts from design strategies

No	Design Strategy	Level of impact
1	High thermal mass	0.1%
2	High thermal mass night flushed	0.3%
3	Direct evaporative cooling	0.1%
4	Two-stage evaporative cooling	0.4%
5	Fan forced ventilation cooling	1.9%
6	Dehumidification only	5.3%
7	Cooling, add dehumidification if needed	31.4%

The observations of dry-wet bulb temperature points in the hospital building are located in closer to the comfort zone. It is required to apply "Cooling, add dehumidification if needed" design strategies to achieve the comfort level of the building.

3.5 Small scale model testing

A small scale model was developed to study the comparison of typical building material and EPS panel building material. The model was constructed near Civil Engineering Department, University of Moratuwa. The model size was designed, LWH, 820 mm x 800 mm x 1000 mm. Two models were constructed; one is cement block with asbestos sheet and second one is EPS wall panel with asbestos. 75 mm thick EPS walls were used to construct the model. Following figures illustrate the construction stage (Figure 3-7) and after the construction (Figure 3-8) of the models.

Construction of Model No 2.
Wall material: EPS Panels
Roof: Asbestos.

Figure 3-7: Construction of Model

After the construction of two models.

Figure 3-8: Model after the construction

The following figures illustrate the different stages of model construction (Figure 3-9, Figure 3-10, Figure 3-11, Figure 3-12, Figure 3-13, Figure 3-14);

Figure 3-9: Reshaping the wall panels.

Figure 3-10:Reshaping the roof

Figure 3-11:Initialize the wall panels

Figure 3-12:Completed model

Figure 3-13: Installing the data loggers & connections

Figure 3-14: Model is ready for collecting data

After completing the models, data logger was installed to measure the temperature variations of the different walls. Figure 3-15 shows the locations where measurement of two models were taken.

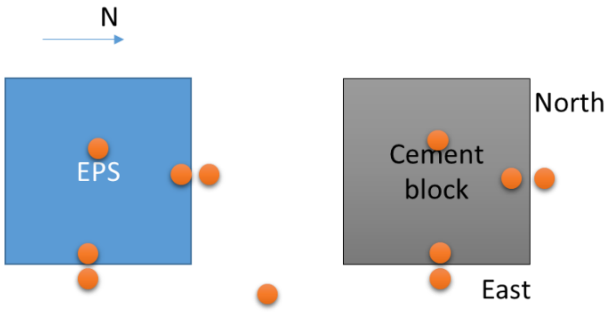


Figure 3-15: thermocouples locations of model

Measurement locations:

- North Inner and Outer walls
- East Inner and Outer walls
- Center of the model
- Outside the models

Temperature measurements were taken 18 days from 9th April to 27th April, 2016 at 5-minute intervals. During this period, total rainfall was recorded as 93 mm, highest temperature was 42°C and lowest temperature was 25°C. Figure 3-16 shows the rainfall variation during this period. [30]

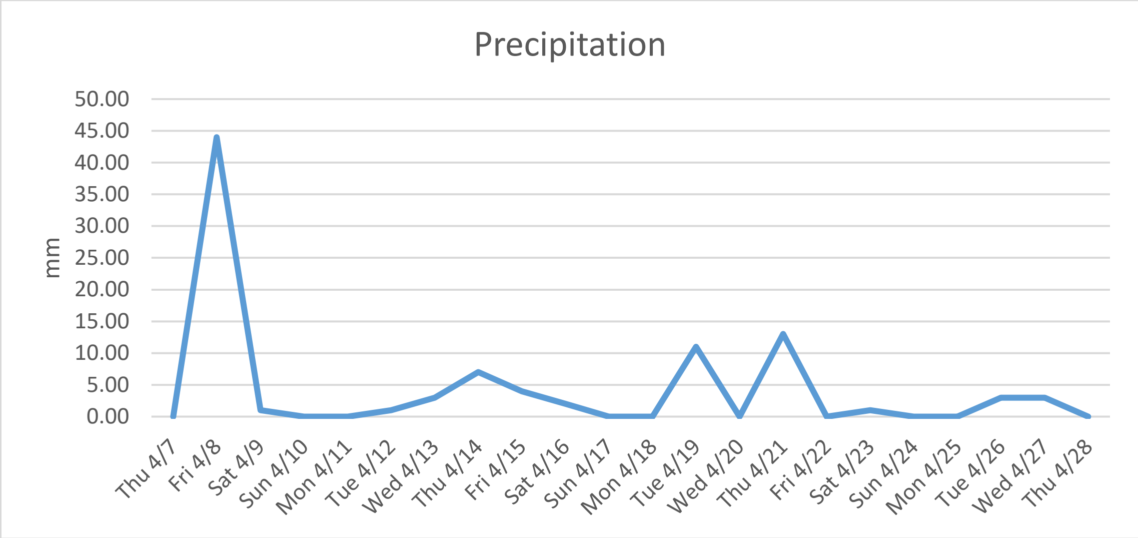


Figure 3-16: Precipitation levels during testing period

3.5.1 Temperature Variation over day at the center of Each Models

The temperature variation in the center of the models was analyzed and data were plotted as hourly variation and to plot the trend lines of each data category (Figure 3-17). Three data sources were used for analysis of this variation;

- Center of EPS model temperature (CenterEPS) – T1
- Center of Cement block model temperature (CenterCement) – T2
- Surrounding environment temperature (Envi) – T3

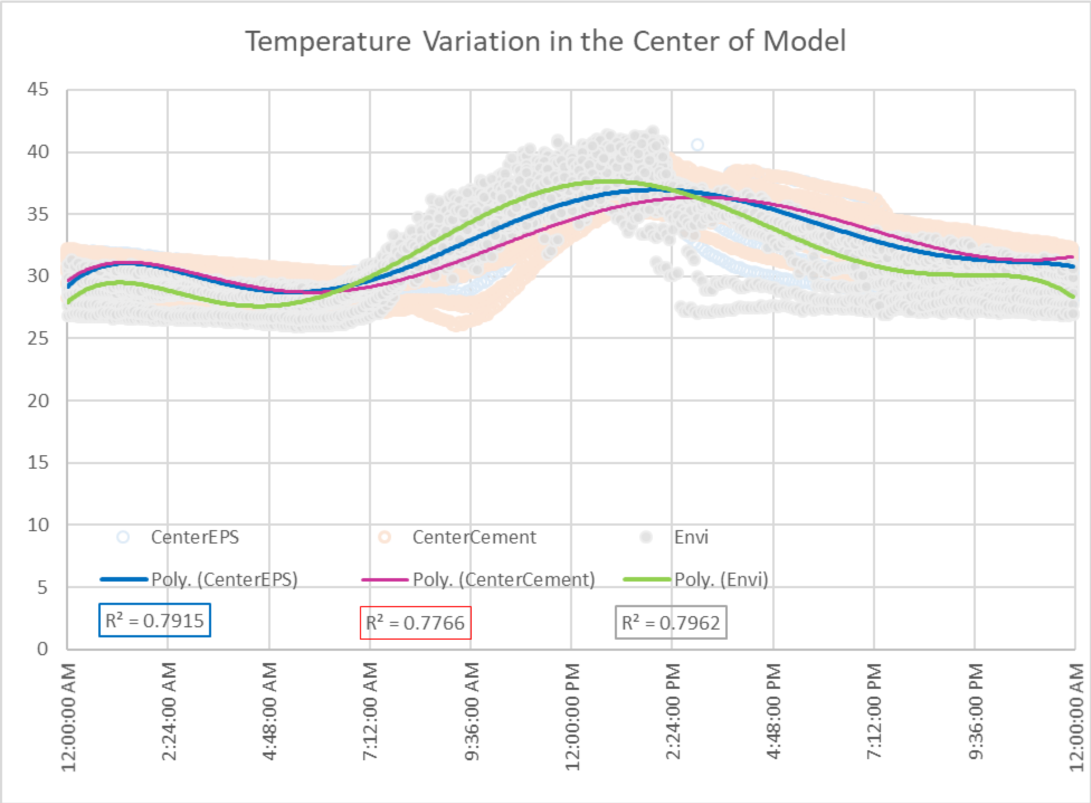


Figure 3-17: Temperature Variation over day at the center of Each Models

The trend lines of the data represent around 80% data and following observations can be made based on data.

- Before the sunrise, EPS model center temperature and Cement Model center temperature were equal; T1=T2
- With the sunrise, the temperature was increasing in the surrounding environment and EPS center temperature was increased than the Cement Model Center temperature; T1>T2
- With the sunset, the temperature is decreasing in the surrounding environment and EPS center temperature was decreased than the Cement Model Center Temperature; T1<T2

3.5.2 Temperature variation over a day in North & East Direction Wall Inner temperature variation

Temperature variation of the North and East direction walls in EPS Model were analyzed. Data was plotted as hourly variation and get the trend lines of each data (Figure 3-18). Three data sources were used for analysis this variation;

- East Inner Wall EPS model temperature (EastEPSInner) – T4
- North Inner Wall EPS model temperature (NorthEPSInner) – T5
- Surrounding environment temperature (Envi) – T3

Trend lines were developed and 80% of data were represented on these trend lines. Figure 3-18 illustrate the values of North & East Direction Walls inner temperature variations and trend lines.

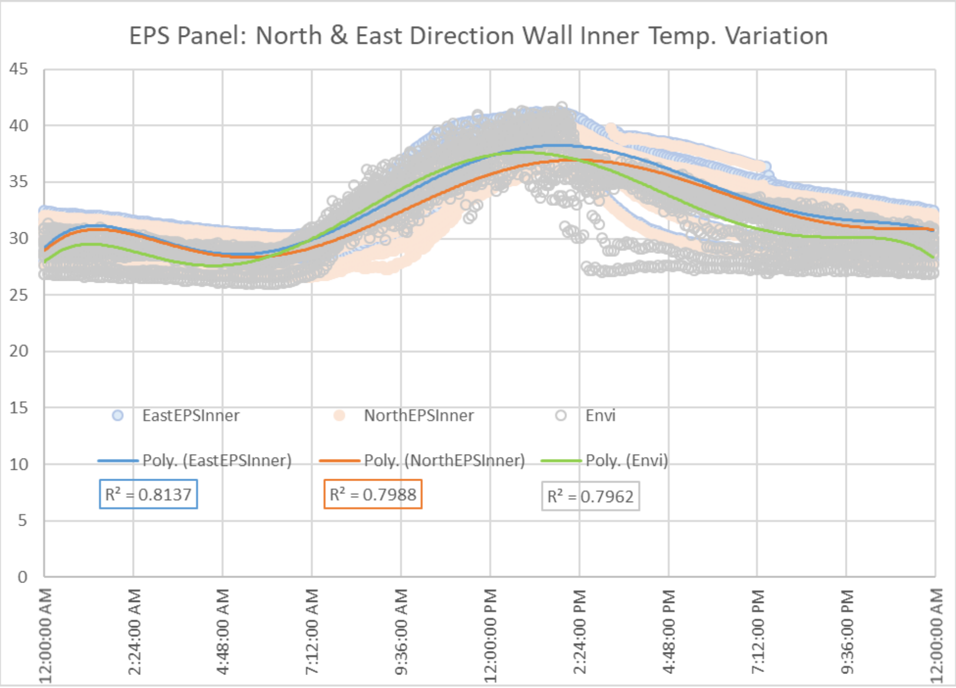


Figure 3-18: Temperature variation over a day in North & East Direction Wall Inner temperature variation

The following observations can be made by considering the above figure.

- Before the sunrise, EPS model East & North wall temperature were almost equal; T4=T5

- With sunrise, the temperature was increasing in the surrounding environment and EPS East Inner wall temperature was increased than EPS North wall Inner temperature; T4>T5
- With the sunset, the temperature is decreasing in surrounding environment and EPS East Inner Wall temperature was decreasing and it will be equal to EPS North Inner wall temperature;

3.5.3 Temperature variation over a day in East Direction Inner Walls temperature variation of EPS & Cement Models

Temperature variation of East direction walls in EPS Model and Cement Model were analyzed. Data was plotted as hourly variation and get the trend lines of each data (Figure 3-19). Three data sources were used for analysis of this variation;

- East Inner Wall EPS model temperature (EastEPSInner) – T4
- East Inner Wall Cement model temperature (EastCementInner) – T6
- Surrounding environment temperature (Envi) – T3

Trend lines were developed and 80% of data were represented on these trend lines. Figure 3-19 illustrate the values of East Direction Walls inner temperature variations and trend lines.

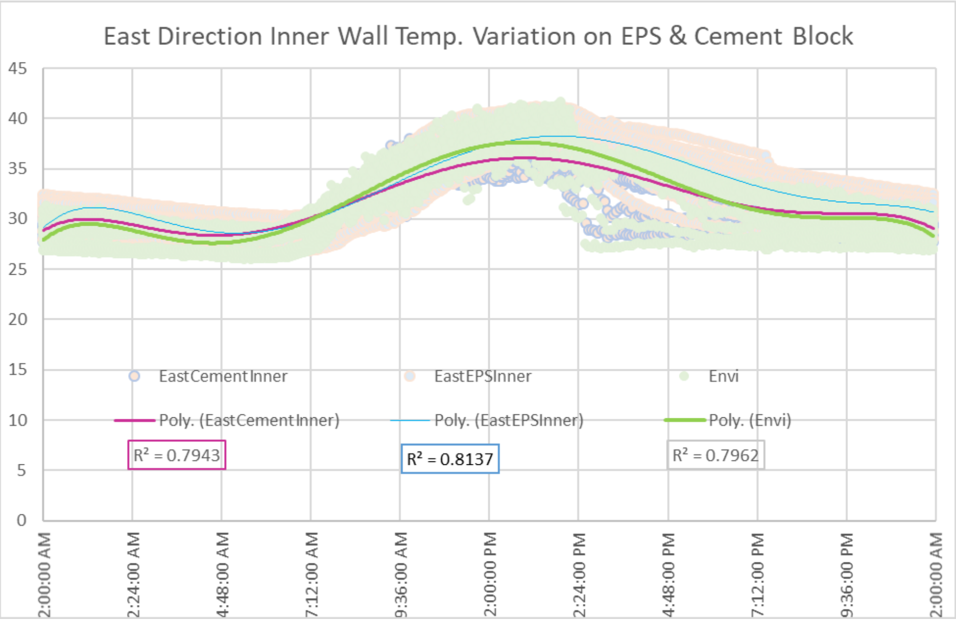


Figure 3-19: Temperature variation over a day in East Direction Inner Walls temperature variation of EPS & Cement Models

The following observations can be made by considering the Figure 3-19.

- Before the sunrise, EPS model East Inner wall temperature was higher than Cement Model East Inner wall temperature; T4>T5
- With sunrise, the temperature was increasing in the surrounding environment and EPS East Inner wall temperature was increased than Cement Model East Inner wall temperature; T4>T5
- With the sunset, the temperature is decreasing in surrounding environment and EPS East Inner Wall temperature was decreasing, but it is higher than the Cement Model East Inner temperature; T4>T5

3.6 Thermal imaging

Fixing the thermocouples can only provide the point reading. However thermal imaging can be used to capture the temperature variations of the entire wall. Thermal cameras can be used to determine the building thermal performance [31]. The building performance also varied with surrounding environments which changes with land use pattern of the area [32].

Thermal camera was used to capture the images (Figure 3-20, Figure 3-21) and it can be used to clearly identify the outside temperature variation of the models. The image was taken around 4.45 pm. At that time, outside temperature of the brick wall is higher than EPS model.

Figure 3-20:Testing Models

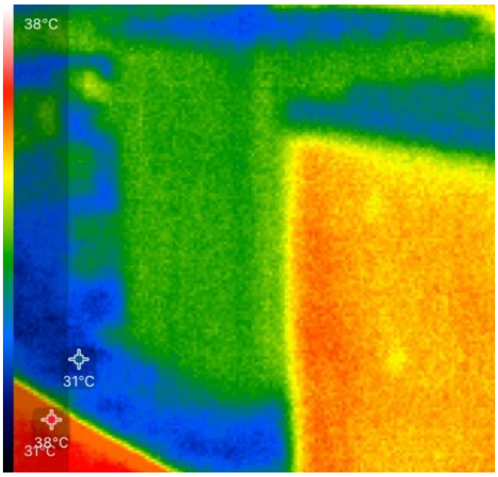


Figure 3-21: Thermal Image of model

3.7 Instrumentation

3.7.1 Seek Thermal Camera

Figure 3-22: Seek Thermal Camera

The above camera (Figure 3-22) was used to capture the thermal images of the models and buildings. It can detect temperature variations of -40 to 626 °C and the accuracy of the camera is 0.04 °C [33]. The above equipment had been purchased to NBRO under this research study.

3.7.2 Arduino based data logger system

A simple data logger system had been developed by using Arduino tools and temperature sensors were developed by using thermal detecting sensors, LM35 IC which has 0.4°C accuracy at ambient temperature. Figure 3-23 shows the Arduino tool that was used to convert signals into the record. Figure 3-24 indicates the result that can be obtained on a computer screen as a series of graphical output. These voltage results can be converted to corresponding temperature values. The main advantage is the relatively low cost which would be less than Rs. 5,000/=.

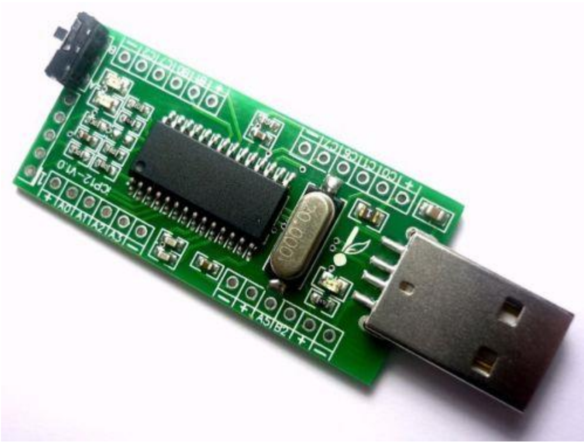


Figure 3-23: USB Data Logger (Arduino)

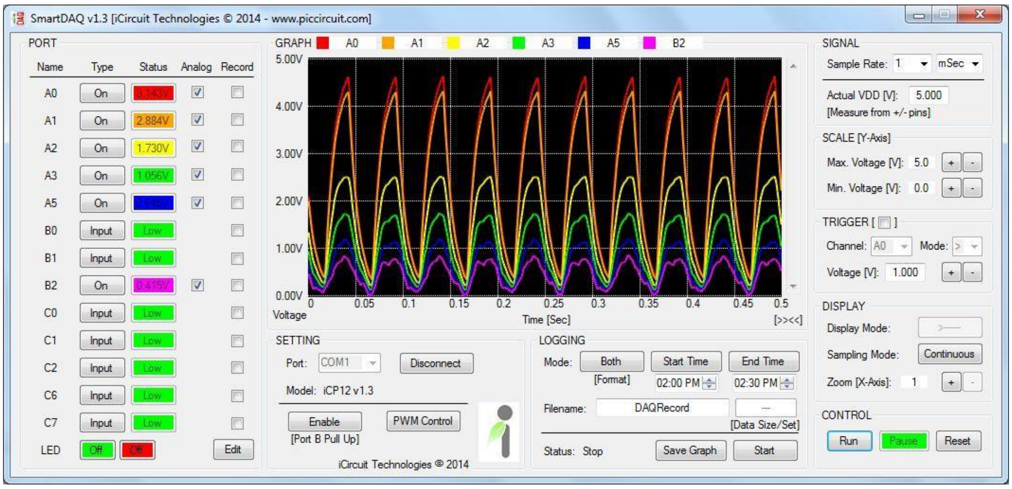


Figure 3-24: Data Capturing Application

3.8 Summery

The result of the experimental studies, and studies carried out using small scale model for thermal performance have been presented in this chapter.

Chapter 4- Applying of Wall Panels to Construction

4.1 General

It is necessary to conduct the application of the wall panels into a realistic model to understand the concept on more practical scenario of construction of houses. Two case studies were discussed under this chapter—case study 1 represents the model house construction which constructed under this research study at Yayawatta, Tangalle area, and case study 2 represents the evaluation of thermal performance of the building which constructed by using EPS panels at Jaffna.

Design strategies which can be used achieve the thermal comfort condition in different locations that developed under ASHRAE standards is being discussed at the end of this chapter.

4.2 Case Study 1: Real Scale Model House Construction (Tangalle)

A real scale model house had been constructed at Yayawatta, Tangalle area by using three different wall materials—EPS, Fly ash cement block and rammed earth materials. The building is located at 6.054 N, 80.829 E to promote disaster resilient concepts for withstand tsunami & high wind hazards. Figure 4-1 illustrates the plan of the model house. Walls which consist of EPS has been marked in orange color.

Rubble foundation was constructed in the building and wall materials were transported from the manufacturing yard. 38 numbers of 75mm width wall panel were used to construct the room (130 sqft). Panels were arranged vertically and a ring beam was constructed at 10ft height to enforce disaster resilient features of the building. The following Figure 4-2 depicts the wall panel arrangements. Wall panels can be pasted with interlocking with adjacent panel and it can be raised up to 15~20ft.

Phasing of the panel is quite simple and easy. High performance concrete was used as a paste for fixing the panels. Un-skill labour were used to construct above model house and they completed the model house within 1.5 days.

However, following challenges were faced during construction;

- Transporting the Panels to the site: - Panels had to be transported to the site with care. Beside cement sheets, panel corners can be damaged while transporting and could result to paste "putty" for finishing.
- Cutting and reshaping the panels: a machine was required for cutting the panels for right sizes. This can be avoided by designing the building with reference to the size of the panels. It is essential to use water while cutting the panels to avoid the dust.
- Applying pre-designed window and door frames: Concrete door and window frames were applied to the building. Drilling was necessary to insert hooks while fixing these concrete door and windows.

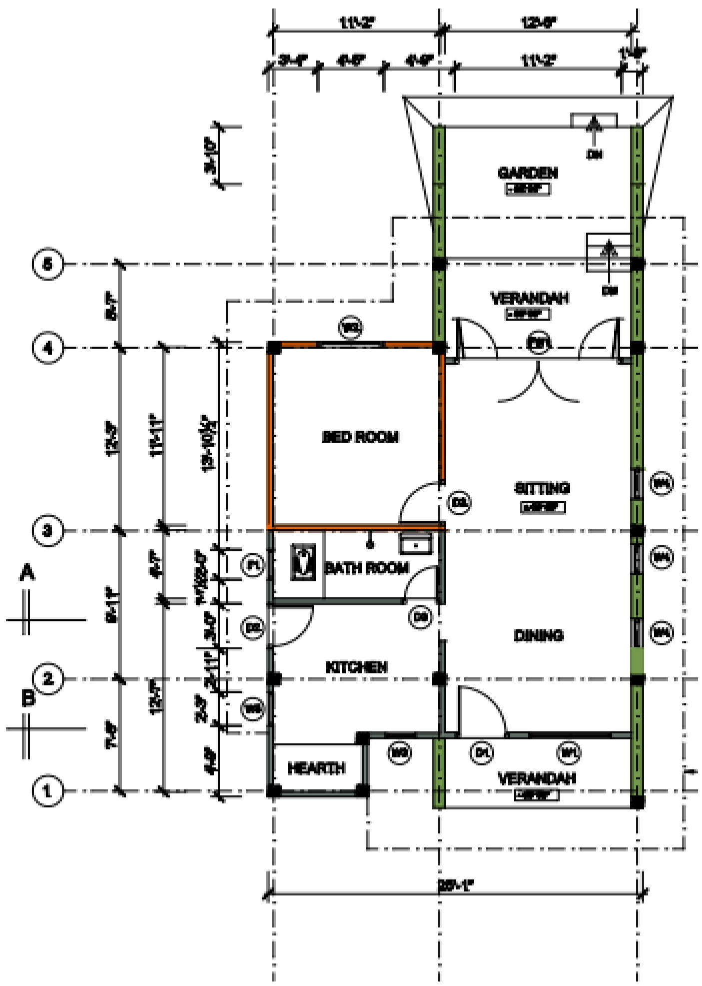


Figure 4-1: Real Scale Model at Yayawatta, Tangalle

4.2.1 Wall panel arrangements

There had been few difficulties with wall arrangement in the model house. A ring beam has to construct around the walls to increase the safety of the model house. Therefore, the wall panels were arranged differently than usual arrangement. Firstly panels were vertically arranged and at the top ring beam was constructed. After the beam, 6’ wall panels were located. Figure 4-2 shows the wall panel arrangements in the room. The roof was built with cement fiber sheets.

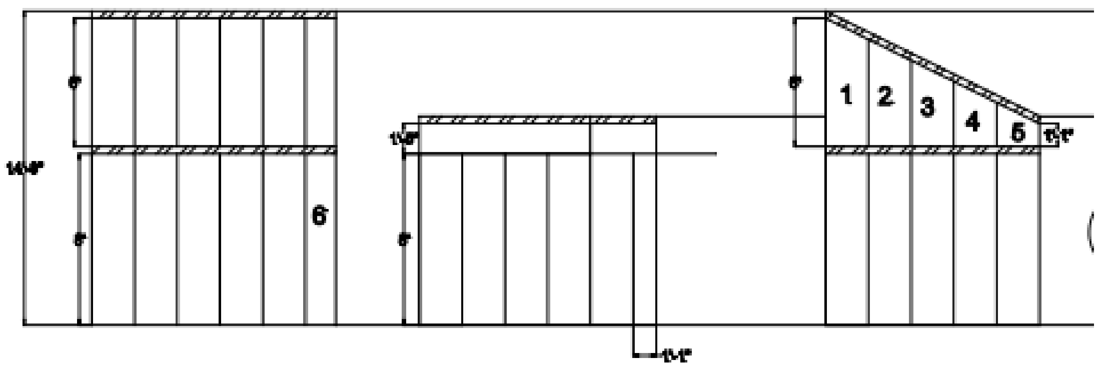


Figure 4-2: Wall Panel Arrangements

Building construction process using wall panels was observed carefully and the same procedures were used to fix the wall panels to the house. The following steps were taken to fix the wall panels to the building.

1. Level the floor before applying the wall panels and constructed the columns, corner of the rooms. This is a pre-requirement of resilient model house.
2. Used 4mm metal for fixed the panels together and apply tile adhesive between panels to fix each other. The panels were tied on top and bottom of the wall panels.
3. Putty was used to finishing the gaps.
4. Concrete door and window frames were fixed using adhesive and metal hooks.

The following figures were illustrated in the different construction phases of the building (Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6, Figure 4-7, Figure 4-8, Figure 4-9, Figure 4-10).

Figure 4-3: Planned Model house to be completed.

Figure 4-4: Completion of the foundation

Figure 4-5: Similar house constructed by using wall panels.

Figure 4-6: Similar house constructed by using wall panels.

Figure 4-7: Construction Phase at Yayawatta, Tangalle

Figure 4-8: Construction phase: the model house has three different materials

Figure 4-9: Construction phase.

Figure 4-10: Model house: without plastering.

Few challenges had been encountered during the construction of this real scale model house which can be discussed under following topics;

1. Standardization: The building design was not standardized which means, panels were needed to cut into vary small sections to be fit which created more complexity. The wall panel width is 2’-0” but walls of the real scale model house were 13’ and 11’ respectively. The window and door frames are also in different dimensions and it has taken considerable amount of time to resize the wall panels to fit around.
2. Transportation of materials: Materials were not available in the local market; and therefore, logistic arrangement had been made from Colombo to Tangalle to transport materials to the site location.
3. Finding labor: the contractor did not have experience with using of these kind of wall panels. However, instruction had been given on how to use these panels and how to join these panels.

4.2.2 Comparison of three different materials for thermal performance

Three different enclosed spaces (Room, Kitchen and Living) with different materials were used to measure the indoor temperature in the center of house. Temperature measurements of each enclosed space was taken continuously in 10 min interval and plotted the temperature variation over a period of 24 Hrs period. Figure 4-11 shows the temperature variation of EPS, Fly ash block, Rammed earth wall and ambient temperature.

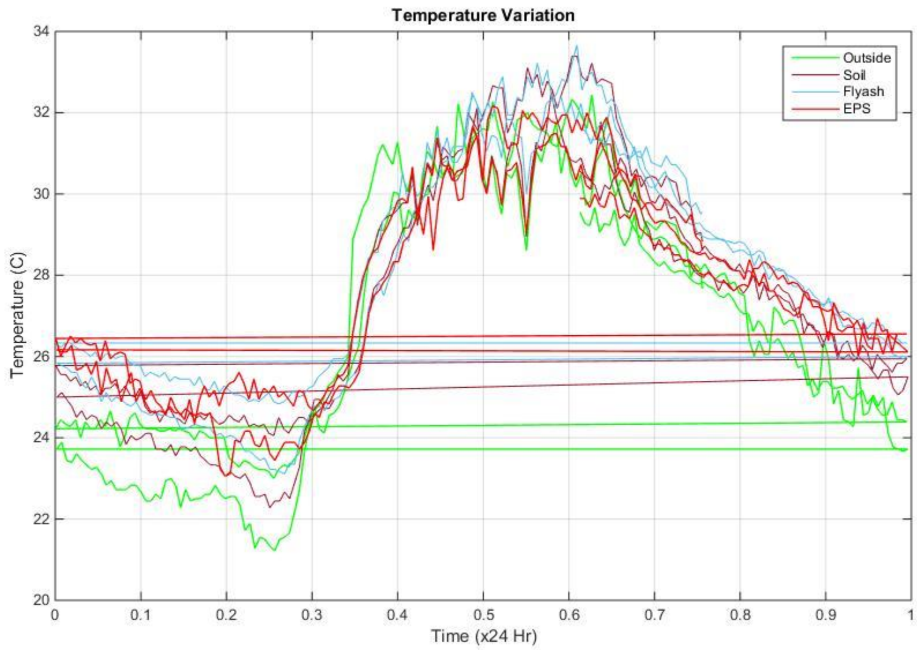


Figure 4-11: Thermal Measurements of Yayawatta Model house

According to the figure, higher temperatures than ambient temperature were observed on EPS during morning hours. After sunrise (after 6.30am), the EPS temperature was increasing according to the ambient temperature but around 12.00 pm, EPS had shown low temperature than the ambient temperature. After 12.00 pm the ambient temperature had shown to have decreasing trend and it had been observed that temperature decreasing gradient is lower than the ambient temperature curve.

Behaviour of the rammed earth material had been observed to have much similar and closer line to ambient temperature. The range of temperature variation had been calculated and it can be illustrated in Figure 4-12. First column of the graph represent the EPS, second column represent the Fly ash, third column represent the Rammed Earth and final column represent the Ambient Temperature.

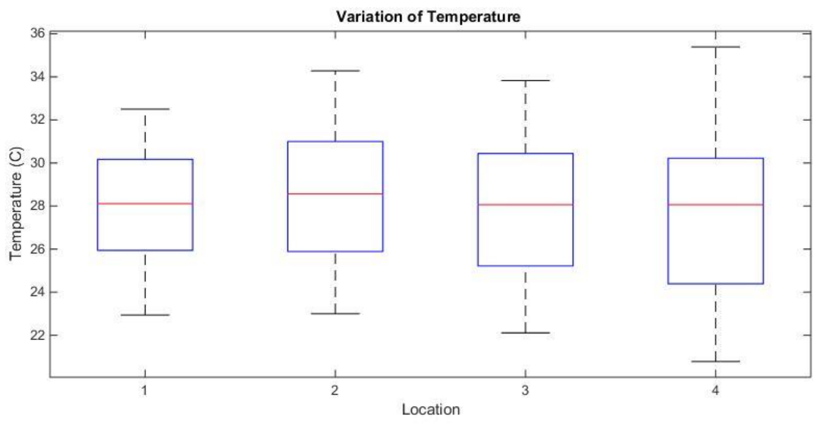


Figure 4-12: Temperature Variation of Different Wall Material (1. EPS, 2. Fly ash, 3, Rammed earth, 4. Ambient Temperature)

The EPS material has the lowest temperature variation compared to other materials. Rammed earth had shown similar behavior pattern to ambient temperature.

Inside temperature to outside temperature was plotted and results were compared against the ASHRAE standards. The results were shown in Figure 4-13. According to the results, EPS based precast panels have demonstrated a comparable comfort condition compared to the rammed earth and brickwork made out of fly ash.

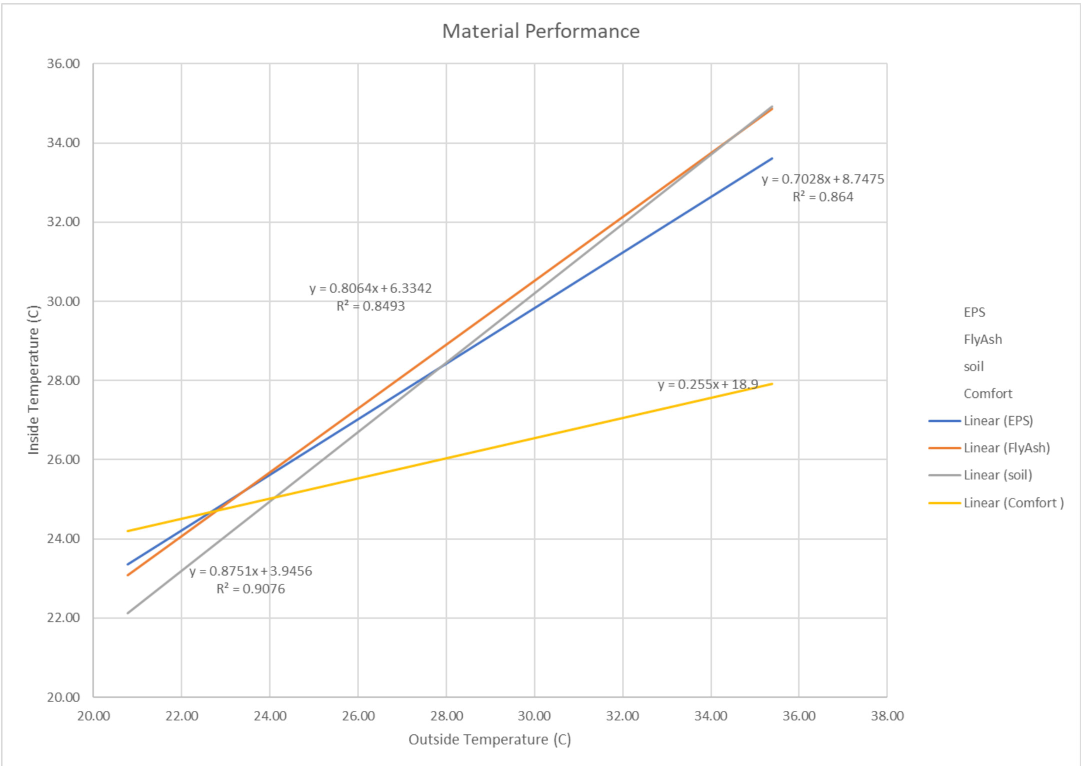


Figure 4-13: Thermal Performance of Different Materials

4.2.3 Thermal Images of Real Scale Model

Thermal images were captured inside and outside of the model house and can be described as follows. East wall of the building was exposed to direct sunlight where outside wall temperature had been observed higher and rising. Outside wall temperature was measured, 40°C (Figure 4-14, Figure 4-15), although the inside temperature was measured, 27°C (Figure 4-16, Figure 4-17). Additionally, outside and inside concrete frame temperature was measured, 38°C and 29 °C respectively (Figure 4-15, Figure 4-17). The concrete frame and ring beam is acting as a thermal bridge to the room. In the EPS based precast panel, a thermal gradient was observed with cooler indoor temperature.

A comparison of Figure 4-15: Thermal image of highlighted area (outside) and Figure 4-17: Thermal image of Inside the room, indicates a significant temperature difference. The indoor surface temperature of light weight panel remains 27-29 °C. This is a very significant finding indicating that light weight panel can perform favorably when exposed to direct sun light.

Figure 4-14: Rear side of real scale model house

Actual Image, the red coloured area was captured by thermal camera.

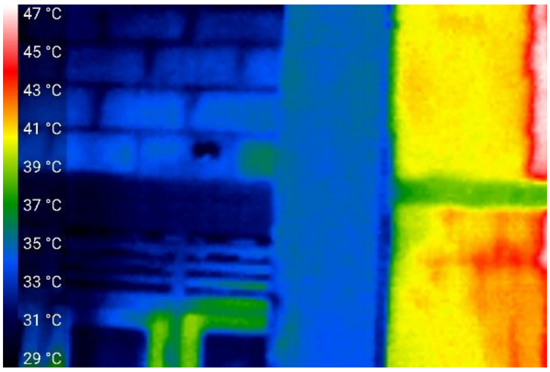


Figure 4-15: Thermal image of highlighted area (outside)

Thermal image of the area. (2017/04/08: 9.00 am): In here we can see higher temperature (41~43 °C) at the outer surface of the material.

Figure 4-16: Inside of the model House

Same location; inside view; Red color area was captured by thermal camera.

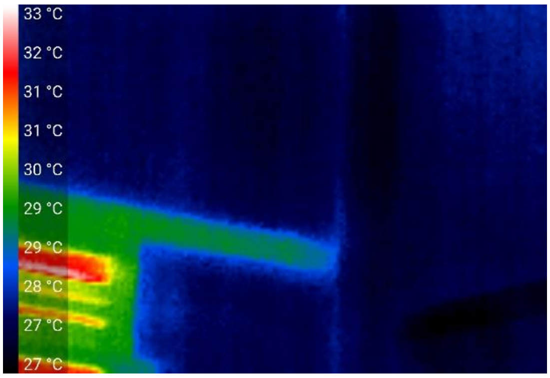


Figure 4-17: Thermal image of Inside the room

Thermal image of inside the room.: Inside wall temperature is 27~29°C, which differ around 10 ~15 °C between outer surface temperature and inner wall temperature.

4.3 Case study 2: Precast Building System in Jaffna

Address : Church Road, Chenkani, Jaffna

GPS : 9°44'46.82"N 79°58'23.09"E (Figure 4-18)

Figure 4-18: Location of Model House

Date of survey : 20/11/2017

Weather condition : Normal

Temperature : 32 °C

Rainfall : 0 mm

Humidity : 70%

4.3.1 Introduction

The model house had been constructed by using EPS panels which were imported from China. Following specifications of the house had been observed during the site visit (Table 4-1),

Table 4-1: Specification of the house

Foundation	Rubble foundation
Floor	Tile
Wall	EPS wall Panels (80 mm thickness)
Celling	EPS Panels (50 mm thickness)
Roof	Non-Asbestos Roofing Sheets
Sq. ft.	580
Types of rooms	2 Bed rooms, Kitchen, Living, Toilets and Verandah
Window Frame	Aluminum
Windows	Aluminum + Glass
Door Frame	Fiber
Door	Fiber

4.3.2 Observations

This single storied model house is located in a 30-perch land with the floor area of 580 sq ft. Building orientation is 103 and wall areas faced to each direction are East-260sqft, West- 260sqft, North-220sqft and south- 220sqft.

The disaster resilient features have been observed and it can be discussed under following principles (Table 4-2);

Table 4-2: Availability of Disaster resilient features

Expected Disaster Resilient Features	**Description of availability**
Increased depth of foundation and raised flow level	2’-6” foundation is constructed as 1’-6” under the ground and raised another 1’ to the floor level. 6” Plinth beam had been constructed and C bars had been layered above plinth beam and anchored through hooks.
Frame structure with reinforced concrete columns	The columns are constructed by using C bars. Reinforced concrete columns cannot be visible at the house.
Wall provided with proper framing	The walls don’t have any additional framing structure, lintel/sill beams.
Wall stiffened at opening using lintel/sill beams	
Good quality building materials used in all components to meet required strength and other properties	The foundation had been constructed by CECB and they gave the certificate for the foundation. Wall panels were imported from China and it has sufficient strength. Roof is constructed with non-asbestos sheets.
Door and window frames properly anchored to structure	Doors and windows are anchored to wall panels through hooks and pasted with high performance cement.
Roof structure properly build and connected to the main structure	C bars are used as roof structure and 50mm thickness EPS sheets are used as finishing celling and properly anchored to the roof structure.
Properly connected gable walls to Structure and Roof to Gable wall	All panels are connected to the C bars and the structure connected with roof.
Roof covering properly connected to roof structure	
Minimum disturbance to ground and supported cuts to retain slopes	The land is flat land and there are no any vertical cuts and slopes.

Although the building is not located in the UDA declared area it has been observed that following the basic guidelines were adhered;

- Minimum internal height = 9ft
- Light angle
- Bathroom opening; floor area< 10% area of opening in toilet
- Bedroom opening; floor area < 7% area of opening in bedroom)
- Land area

However, it is observed that permanent ventilation had not provided to the building.

Indoor air speed is still, airtight and lighting level is equal to office desk/workshop. Sensible gain from lighting and other equipment is 2 W/m^2 (5 x 20W/50 sq. m).

Natural ventilation and fan forced ventilation is activating as HVAC controls of the building. According to the ASHRAE standards, the thermal comfort temperature is 27.06 °C (18.9+0.255*T_{out}) with an outdoor temperature of 32°C.

The landscape pattern is in; West- mango tree with horizontal distance to building 3m, East- mango tree at 10m of horizontal distance, South- Mango and coconut tree in 3m horizontal distance and no plantation at north side of the building. The following figures show the front elevation (Figure 4-19), side elevations (Figure 4-20, Figure 4-21), indoor west wall (Figure 4-23) and indoor east wall (Figure 4-24).

Figure 4-19: Front Elevation (North Side)

Figure 4-20: Side Elevation (West Side)

Figure 4-21: Side Elevation (East side)

Figure 4-22: Sliding Window

Figure 4-23: Living Area (West side wall)

Figure 4-24: Kitchen Area (East Side)

Window frames and door frames were made of aluminum and therefore, thermal bridging can be expected. Floor was constructed with tiles and celling was built with

EPS panels. Cross section of the wall can be illustrated as follows (Figure 4-25);

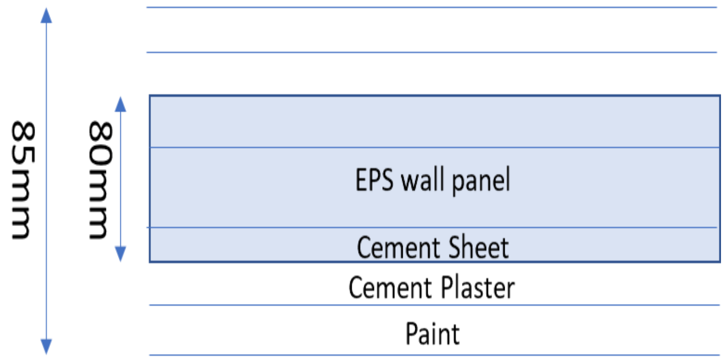


Figure 4-25: Cross section of the wall

4.3.3 Building construction Procedure

Normal rubble foundation had been used and C type steel bars were used to fix EPS panels to the foundation. Columns structure also constructed with C bars. Wall panels were pasted on this C bar and fixed with hooks.

Sliding type windows have used to construct the model house (Figure 4-22) and they have been fixed to wall panel through hooks.

4.3.4 Limitation

The building is not occupied and therefore, social acceptance for the building is not measured.

4.3.5 Analysis

The thermal comfort measurements were taken in 24hr period at room, living area, East (outside), SW(outside) and following observations can be generated based on the temperature data of the building (Figure 4-26).

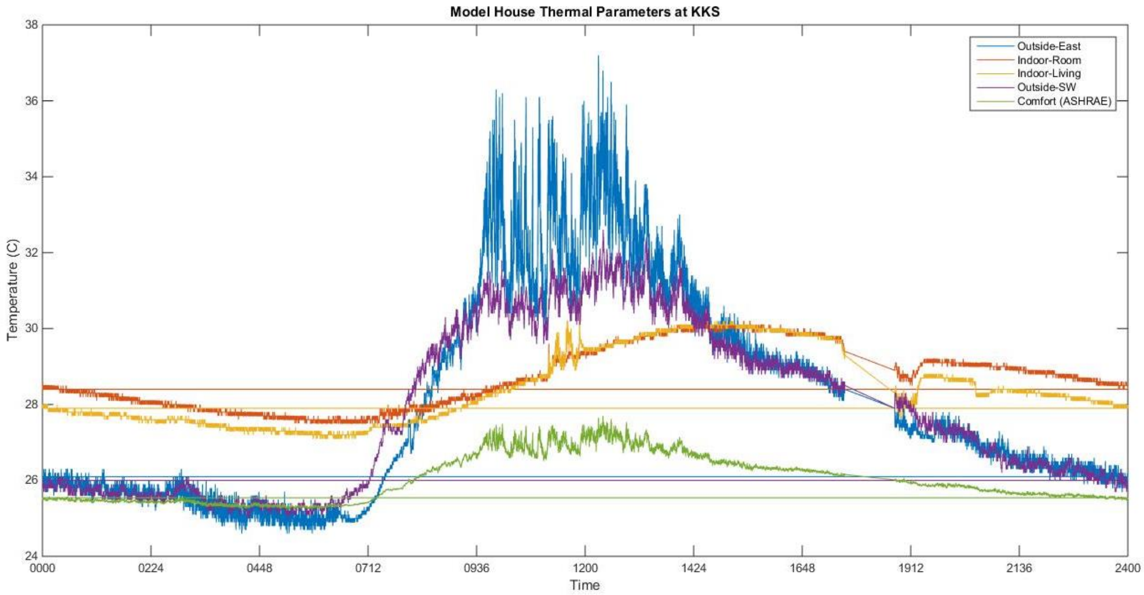


Figure 4-26: Temperature variations in the model house

Outside temperature was almost equal to comfort condition at the morning hours (0000 -0700 hrs). But in the day time, the outside temperature was increased drastically than the comfort temperature. According to the Figure 4-26, the temperature variation outside and inside the house was 8 °C and 3 °C respectively.

In this house, the advantages that can be gained with the EPS based panel could not be realized due to poor layout design and ventilation design.

4.4 Design Aspect

The design of a thermally comfortable house is not simple task since there are a number of principles, theories and practices taken to consideration. The designing of thermal comfort houses is vital for different climatic conditions which can provide many benefits for dwellers. Some design aspects is being discussed below which are relevant to achieve the thermal comfort conditions.

The analysis was done with the available global temperature data and by using of Climate Consultant 6 software [12]. The model has generated the solution through developing of Psychrometric chart for the area (Figure 4-27). Design concept had been illustrated according to ASHRAE standards for these 16 design strategies discussed in section 2.11.1.

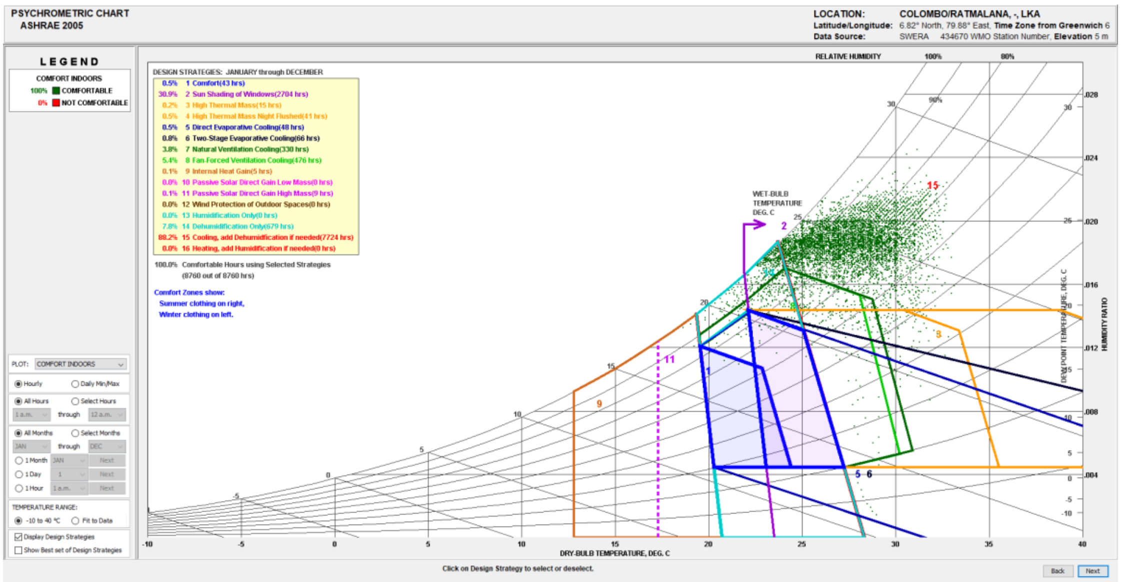


Figure 4-27: Psychrometric Chart and strategies - Climate Consultant 6 Software

Table 4-3 shows the spatial distribution of different building design strategies in the country obtained from Climate Consultant 6 software. Climate data were collected for the following locations in Sri Lanka; Katunayake, Rathmalana, N'Eliya, Hambantota, Batticaloa, Anuradhapura, Trincomalee and Kankasnturei. This is to identify different building strategies to achieve the comfort conditions of the buildings using the software. According to the results, it can be observed that different architectural designs are required to achieve the thermal comfort conditions.

Table 4-3:Different building design strategy varied in different places

District	Strategies															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Batticaloa	0.3	32.6	-	-	0.3	0.4	65.9	5.5	-	-	0.1	-	0.1	2.2	32.0	-
Katunayaka	1.5	31.9	0.2	0.5	0.3	0.8	67.0	6.7	-	-	-	-	-	6.9	30.9	-
Ratmalana	0.5	30.9	0.2	0.5	0.5	0.8	62.6	5.3	0.1	-	0.1	-	-	7.8	29.8	-
Hambantota	0.6	33.1	-	-	0.1	0.2	73.7	8.0	0.1	-	0.1	-	-	4.8	23.2	0.1
KKS	0.6	32.1	-	0.1	0.1	0.3	64.6	8.7	0.1	-	0.1	-	-	3.6	32.4	-
N'Eliya	5	0.2	0.1	0.1	0.2	0.2	3.1	0.1	83.0	23.8	23.9	-	0.2	0.1	0.1	5.2
Puttalam	0.5	32.1	0.1	0.1	0.1	0.2	61.4	4.8	-	-	0.1	-	-	8.4	31.3	-
Tricomalee	0.2	32.5	-	-	0.1	0.2	67.4	7.6	-	-	0.1	-	-	1.9	31.1	0.1

List of Strategies:	
1. Comfort-ASHRAE Handbook 2005 2. Sun Shading of Windows 3. High thermal mass 4. High thermal mass night flushed 5. Direct evaporative cooling 6. Two-stage evaporative cooling 7. Adaptive comfort ventilation 8. Fan-forced ventilation cooling	9. Internal heat gain 10. Passive solar direct gain low mass 11. Passive solar direct gain high mass 12. Wind protection of outdoor spaces 13. Humidification only 14. Dhimmification only 15. Cooling, add dehumidification if needed 16. Heating, add humidification if needed

Different types of architectural practices are needed to achieve thermal comfort strategies. As an example, architectural strategies with reference to ASHRAE standards for two different locations can be listed as follows;

4.4.1 Hot climate condition (Trincomalee):

- Air conditioning of warm weather can be done with good natural ventilation. When the window is shielded from light and the wind blows through
- A long slim building floor plan will help maximize cross draft in a temperate, humid climate
- The shielded basalt and patio provide passive, comfortable cooling by ventilation in warm climates and can prevent insect problems
- To make the ventilation easier, make sure that the doors and windows open on both sides of the building with the wind direction facing up as much as possible
- Traditional passive houses in warm and humid climates used lightweight structures with open walls and a shadow outdoor bag raised to the ground
- Traditional passive houses with warm, humid climate use high ceilings and highly operable (French) windows protected with deep overhangs and porches

4.4.2 Cold Climate Condition (Nuwara Eliya)

- Increased heat from lighting, persons and equipment reduces the need for heating strongly and holds the house (to lower the temperature of the balance)

- A Traditionally passive house, with a cold, clear climate, sealed to provide rapid warmth in the morning,
- For passive solar heating, design the overhang so that most of the southern glass area is completely shaded in summer to maximize winter sunlight
- Provides 2-pane high performance glass (Low-E) in the west, north, east, but it is clear for the South to get maximum passive solar gain
- Low-lying ceiling with wide overhang works well in mild climates

The Annexure 1 shows the detail conceptual designs which can used to achieve thermal comfort conditions. The building which is constructed with these concepts can achieve the thermal comfort easily.

Another model house is planned to construct in Polonnaruwa, where hot climate condition exists similar to Trincomalee. The strategies that can be adopted to achieve thermally comfortable conditions are listed as follows (Table 4-4);

Table 4-4: Design Strategies for Polonnaruwa Model House

Design Strategy	**% of comfort level achievement**
Sun Shading of Windows	31.8%
Direct Evaporative Cooling	0.2%
Fan-Forced Ventilation Cooling	6.4%
Dehumidification only	10.4%
Cooling, and dehumidification if needed	85.9%

The model plan was developed to achieve the thermal comfort by using the following strategies where guidance has been obtained from Climate Consultant 6 simulation.

1. Orientation of the House
2. Increase the permanent ventilation
3. Use low thermal conductivity materials
4. Increase air flows inside the buildings
5. Increase wall heights
6. Sun shadings
7. Landscape planning

The plan of the house developed using the above guidelines in shown in Figure 4-28.

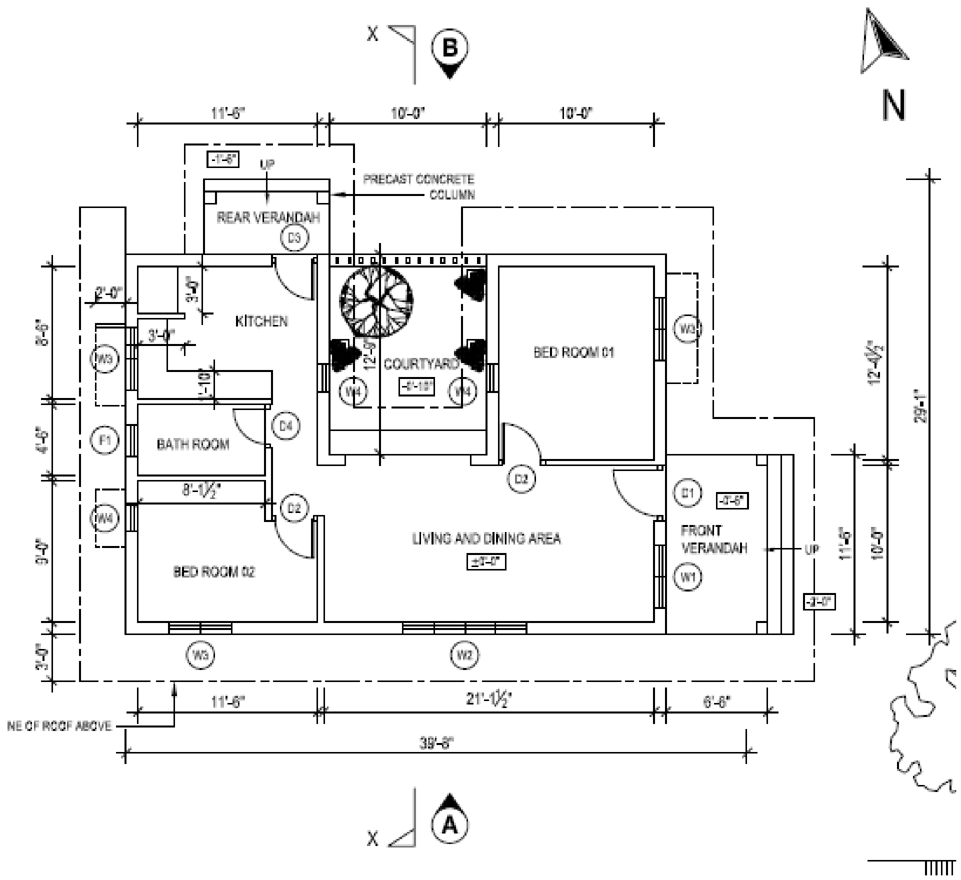


Figure 4-28: Plan of the Polonnaruwa Model House

The walling material for this house have been burnt clay bricks of 125mm thickness. The roof is Calicut tile with insulation. The wall height has been 3.3m. This is a special brick size manufactured in this area. This house has been simulated for thermal comfort in Autodesk Ecotect software. The climate file used was for Trincomalee. The simulation results are indicated in Figure 4-29. It shows that out of the months except two, favorable indoor temperatures could be maintained within the house. If the same house is constructed with 100mm or 150mm thick EPS based panels, a similar favorable result could be expected since the roof also can have 75mm thick EPS based panel insulation.

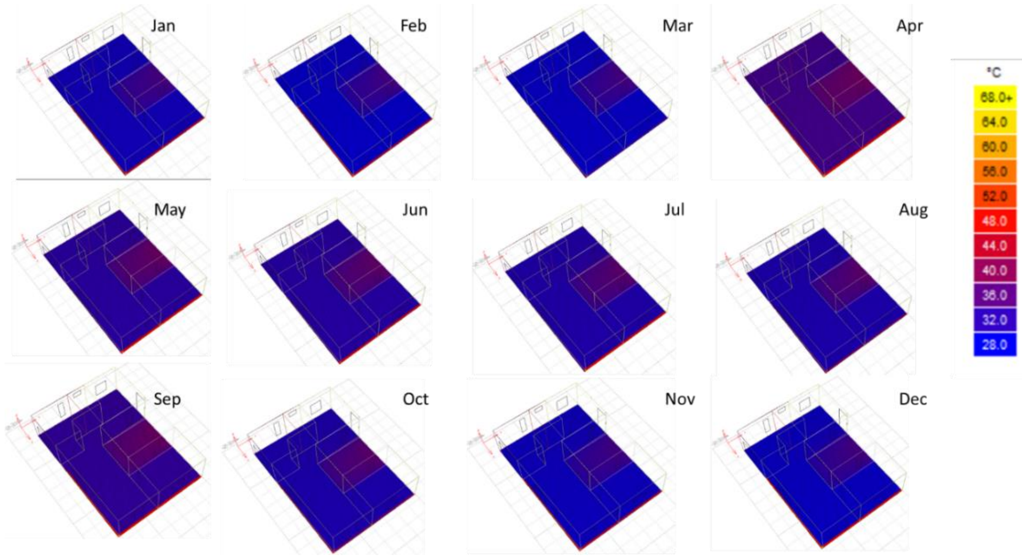


Figure 4-29: Computer Simulation of comfort variation of Polonnaruwa Model House

The average temperature in Polonnaruwa area is around 30 °C.

4.5 Summery

One of the key issues of EPS panels is constructability. It is assessed by using EPS panesl of 2.4m length, 0.6m width and 75mm thickness for an actual house construction at Yayawatta, Tangalle. Few issues have been identified, but could be overcome with proper planning of the layout. The same house has been used to measure the thermal performance. The image taken from Thermal image camera indicates a favorable behavior of EPS based panels when exposed to direct solar radiation. The method that can be successfully used to design a house with thermally acceptable performance also have been highlighted.

Chapter 5- Conclusion

The environmental performance of a building material can be measured with respect to structural performance, durability, thermal performance, life cycle performance and many other similar indicators. In this research focused has been on the thermal performance and constructability of EPS based light weight panel where recycled EPS can be used for manufacturing of the panel.

As the initial step, the thermal properties of light weight panel has been established experimentally. It is shown that the thermal conductivity of light weight panel is significantly lower than the conventional building materials. The values are 0.21 W/m.K and 0.88 W/m.K, respectively. Thus, a reasonably good thermal performance could be expected for the light weight panel though the wall thickness could be relatively low with 75 to 150 mm and also thermal capacity being low due to lower density. The actual performance has been assessed with the physical models. It is shown that the thermal performance in the actual small scale model indicated a comparable performance with a solid cement blocks though some minor variations could be observed. The reason could be the lower wall thickness of light weight panel while having a lower thermal capacity despite having a lower thermal conductivity.

However, a much favourable performances had been obtained with the real scale model when thermal image camera was used to obtain the indoor and outdoor surface temperatures in the house constructed at Yayawatta, Tangalle. When the light weight panel was exposed to direct solar radiation where the outside temperature reached 40 °C and the inside surface temperature remained on 27-29 °C. The light weight panel can have favourable constructability with the rapid construction. However, to have the full advantage, the house plan has to be adjusted to have favourable dimensions.

With respect to constructability and thermal performance, EPS light weight panel can be considered as a viable alternative to conventional walling materials. Further studies on durability and fire resistance can further strengthen the feasibility of EPS based light weight panel.

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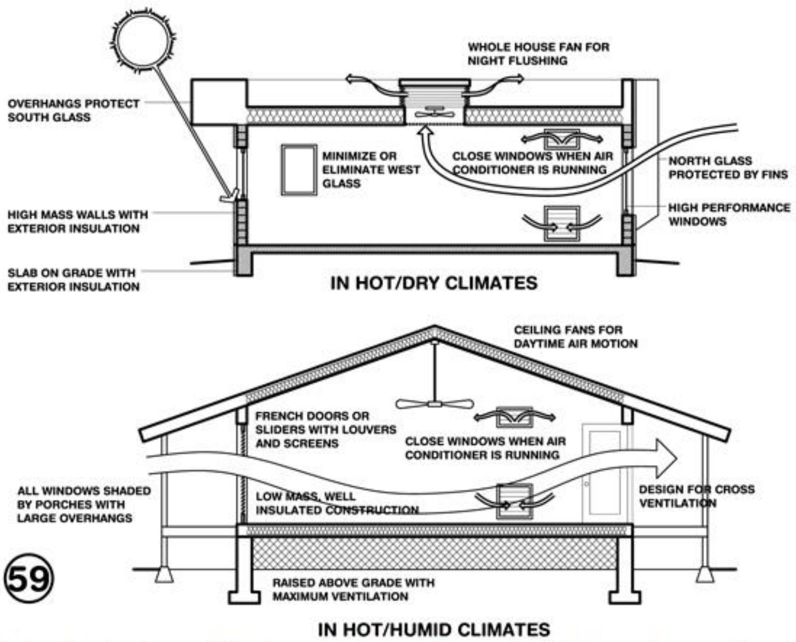
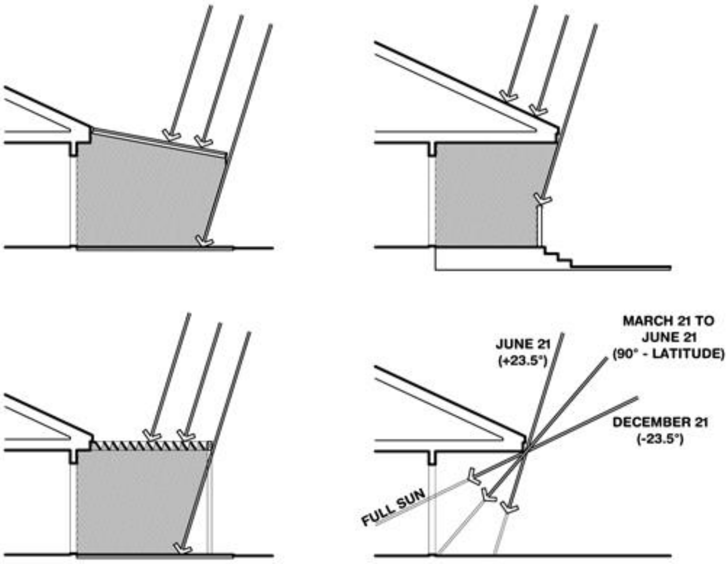
Chapter 7- Annexures

7.1 Annexure 01: Concepts for achieve thermal comfort

Source: University of California



In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating

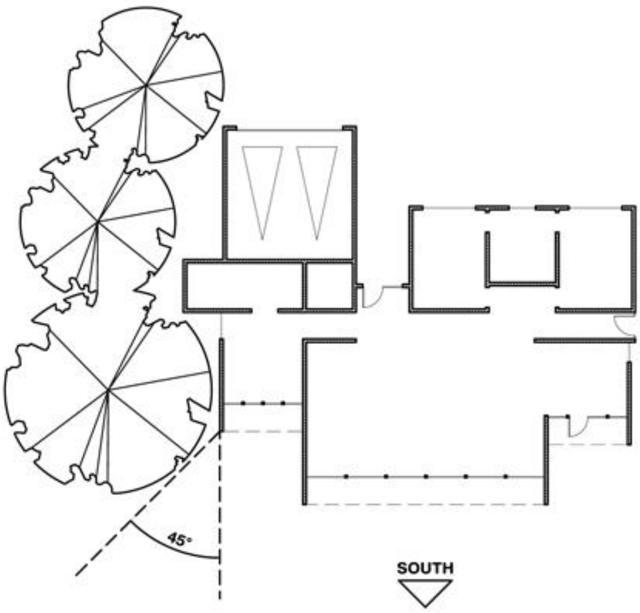


37

Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning

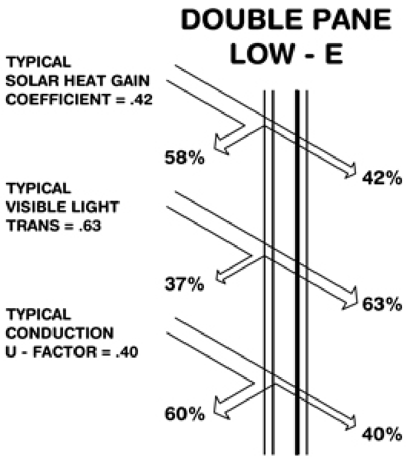
65

Traditional passive homes in warm humid climates used high ceilings and tall operable (French) windows protected by deep overhangs and verandahs



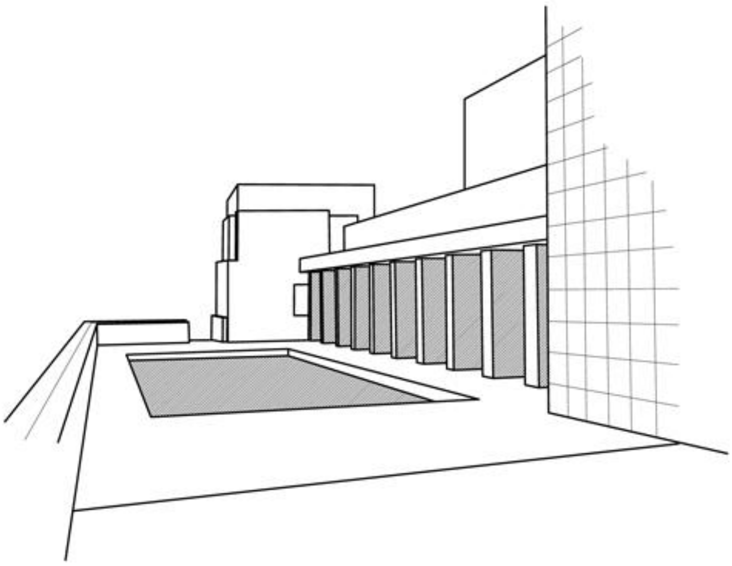
17

Use plant materials (bushes, trees, ivy-covered walls) especially on the west to minimize heat gain (if summer rains support native plant growth)



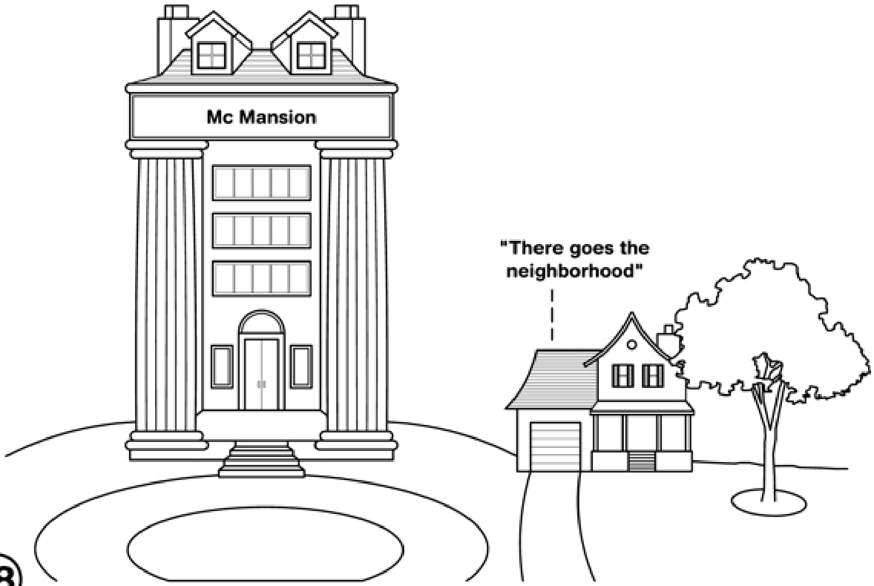
30

High performance glazing on all orientations should prove cost effective (Low-E, insulated frames) in hot clear summers or dark overcast winters



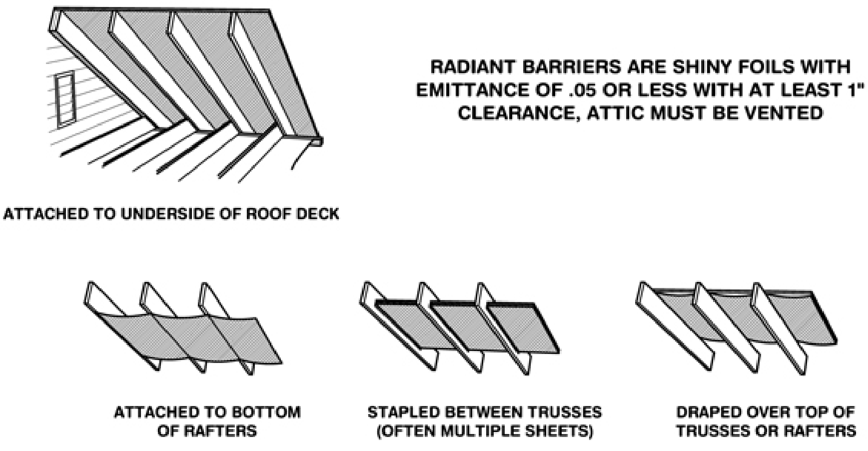
57

Orient most of the glass to the north, shaded by vertical fins, in very hot climates, because there are essentially no passive solar needs



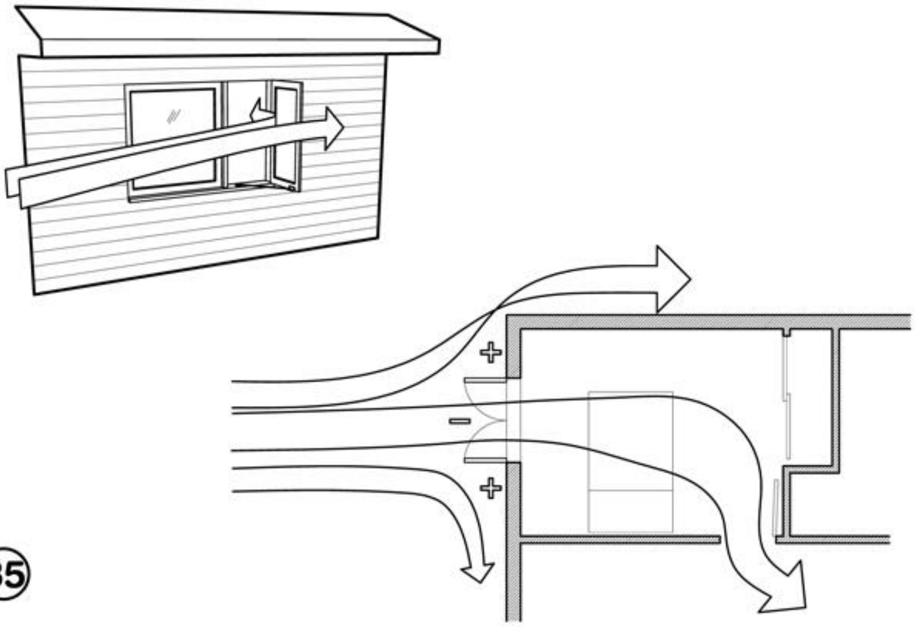
18

Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy



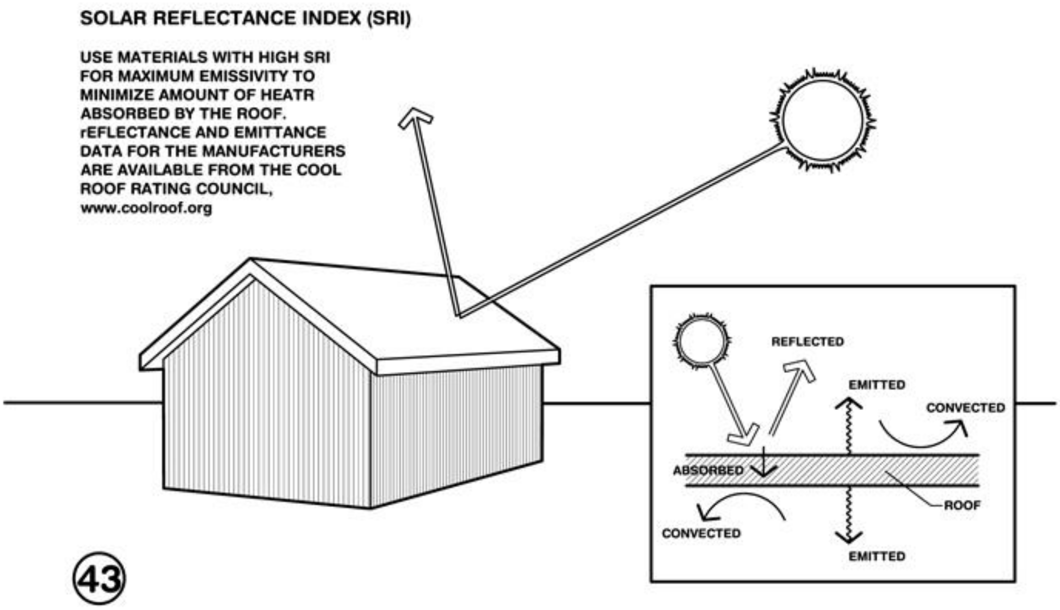
26

A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates



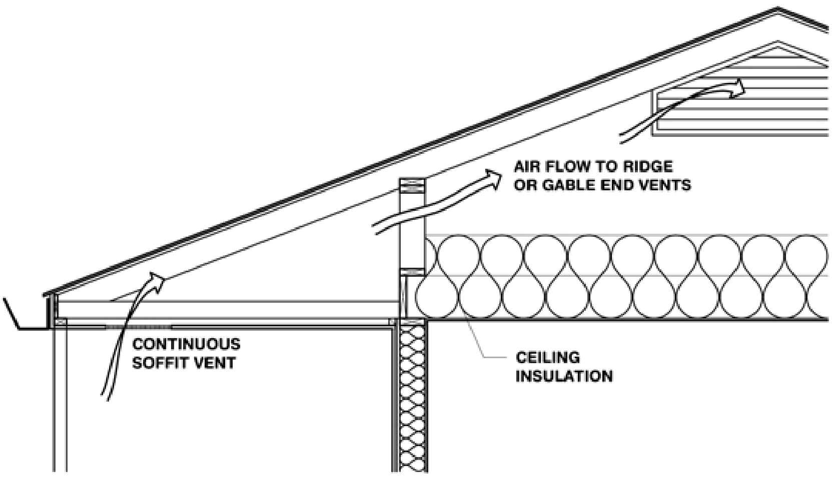
35

Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes



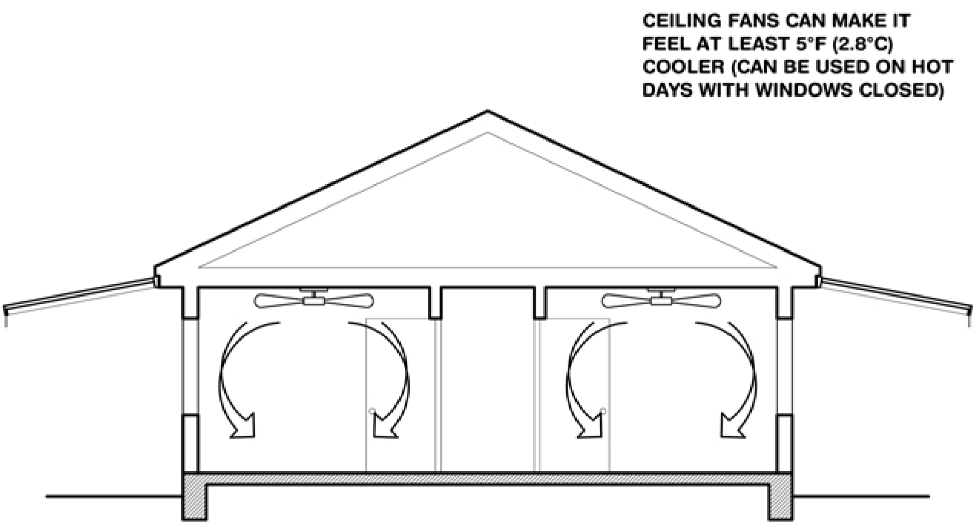
43

Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain



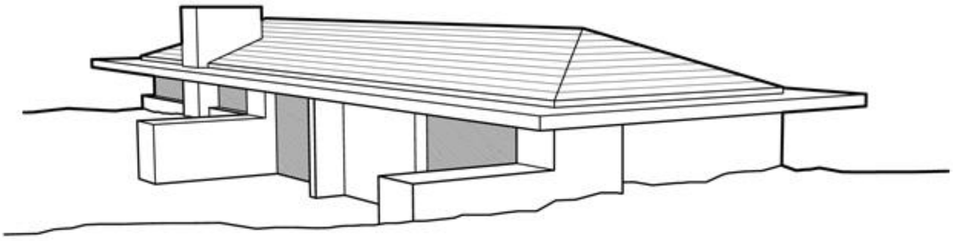
25

In wet climates well ventilated attics with pitched roofs work well to shed rain and can be extended to protect entries, porches, verandas, outdoor work areas



42

On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed



60

Earth sheltering, occupied basements, or earth tubes reduce heat loads in very hot dry climates because the earth stays near average annual temperature