Chapter 5

THERMALLY COMFORTABLE PASSIVE HOUSES FOR TROPICAL UPLANDS

5.1 General

In many countries located close to the equator, such as India, Sri Lanka, Myanmar, Thailand, Malaysia, Indonesia, part of Africa and South America, certain regions could be considered as tropical uplands. In such regions, the cold discomfort that occurs during the night and warm discomfort that occurs during the daytime could become a problem unless the houses are planned with careful consideration. It is shown using computer simulation case studies carried out for the climatic data pertaining to tropical uplands of Sri Lanka that the adverse climatic effects could be minimised by carefully planning the houses so that occupants could adjust to the prevailing conditions. The result of this study is also presented as a set of rules with an example of a conceptual house so that designers could easily include such rules at the conceptual design stage of planning the houses.

The main objective of the study is to develop the guidelines for designing passive houses for tropical uplands, so that the need to use energy consuming active means for thermal comfort could be minimised. For this study, the following methodology was adopted:

1. A comfort zone presented in Section 4.3 was used as the guidance to determine the desirable conditions.

2. The passive features that could be included are established on a qualitative basis.

3. The usefulness of such passive features was found using computer simulations.

4. The results are presented as a set of guidelines, along with a conceptual house suitable for tropical uplands, which could be adopted by the house designers.

5.2 Passive houses for tropical uplands

Since the weather patterns in tropical uplands change from day to day, it is practically not possible to ensure that passive houses will remain between 22^0C – 26^0C everyday. However, it is useful to determine the desirable features that could be of assistance to reach thermally comfortable conditions.

Therefore, the passive elements should keep the house warm during night while preventing overheating during daytime. To maintain adequate temperature during the cold night, it should gain sufficient solar radiation during the daytime, especially in the afternoon. It should also minimise the heat losses during the night.

1. Minimise heat losses due to air circulation during the night
2. Maximise the heat gains through the windows.
3. Maximise heat gains through the walls using desirable colours such as those with higher absorptance.

5.3 The case study for tropical uplands

In order to determine desirable passive features that should be adopted for a house in tropical uplands, computer simulations were carried out for a general case using the average climatic data given in Table 4.1 in Chapter 4. For this part of the research also, DEROB-LTH was used. DEROB-LTH is one of the best thermal software tools that can be used for analysis the thermal performance of buildings. Since the climatic data are average values, the results of computer simulations are useful only to predict the trends, but not the actual temperatures. In this case, DEROB-LTH was used to predict the operative temperatures (Operative temperature is defined as the average of mean radiant temperature and ambient air temperature, weighted by their respective heat transfer co-efficient). Since, it is considered as a better indication than the average indoor air temperatures. An indepth introduction and the validation of DEROB-LTH for tropical uplands were given in Chapter 3.

5.3.1 Details of the case study

In multi-storey houses, top floor is sheltered by the roof. Other floors are protected by the upper floors. Therefore, for the case study, a two-storey house was selected. In order to determine the effect of sun movement, four volumes were selected at each floor level as shown in Figure 5.1. The ridge was arranged in East-west direction. For countries located close to the equator, direct solar radiation could penetrate through both north and south facing windows. Therefore, for the base case, windows were considered facing north and south. Since, glass could be a main source for heat gain and losses, the effect of placing additional windows facing east and west was also investigated as shown in Figure 5.2. The 3D model used for computer simulations is given in figure 5.3.

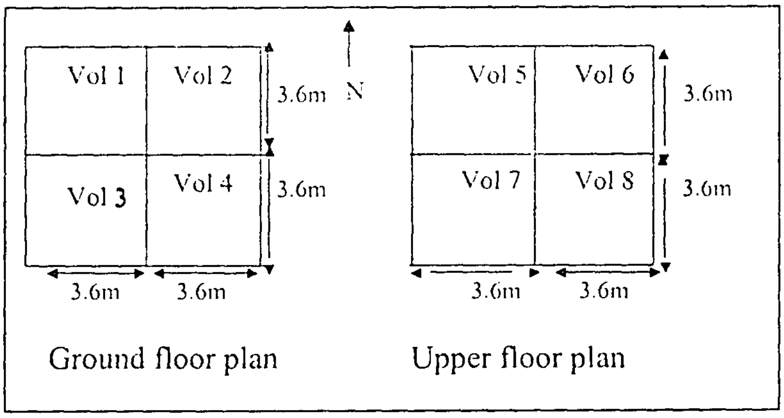


Figure 5.1: Floor plans of the model house

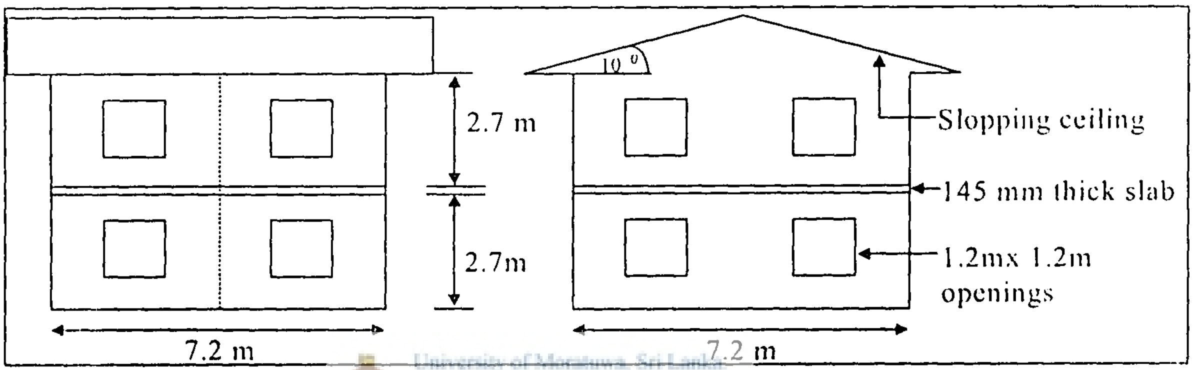


Figure 5.2: Front and side elevations of the model house

For the main computer simulations, March was selected (21st March). It can be seen from Table 4.1 that the minimum outdoor is 14.5 ^{0}C and the maximum is 25.5 ^{0}C. The range is 11 ^{0}C. This minimum is much lower than the minimum required for thermal comfort. The maximum temperature is high enough to cause overheating for undesirable passive features.

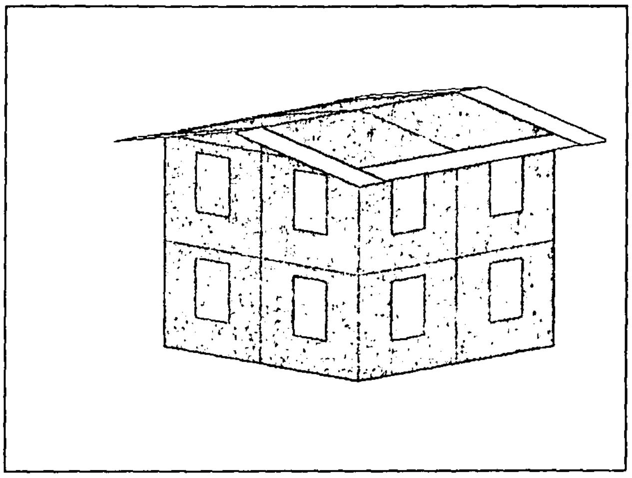


Figure 5.3: The 3D model used for the simulations.

5.3.2 Data and variables used for simulations

The model used for the computer simulations is shown in Figure 5.3. The roof is considered as of cement fibre sheets. Since these sheet will become blackish two or three years of installation in tropical climates, an absoptance of 75% was considered for the roof (Nayak et al., 1999). The walls were considered as plastered brickwork of one brick thickness. The colour of the walls were considered as dark and light for two different cases since it was reported by Bansal et al.,(1992) that colour can affect the indoor temperature. The reinforced concrete floor slab was considered to have an overall thickness of 145 mm with the finishes. For houses in tropical uplands, infiltration of air through the windows could be undesirable, specially during the cold nights. Therefore, generally, the windows would be kept closed during the night. The number of air changes could be a low value, such of 0.5–1 ach. During the daytime, few windows would be opened which could increase the number of air changes to about 2–3 ach. Generally, this would be from about 11.00 hours to 17.00 hours since the out door temperature remains at lower values at other times. Therefore, the simulations were carried out for three cases.

1. The windows were kept closed during day and night. This could give rise to overheating during daytime although such a strategy could be advantageous during night-time (Z1– 1 ach throughout the day).

2. Some windows were kept open from 11.00 – 17.00 hours so that the benefit of daytime high temperatures could be obtained while avoiding the overheating (Z2- 3 ach from 11.00-17.00, other times- 1ach).

3. Another possibility is a poorly constructed house where the number of air changes can be high as 3 during day and night.(Z3– 3 ach throughout the day).

To determine the effect of the important variables discussed above, the following cases were considered.

1. The Base case with windows facing north and south (W1). The walls were also considered as of dark colour (C1). The roof was also of dark colours (R1). For this Base case, three possible air changes were considered as given in Table 5.1. Those are Z1, Z2 and Z3 cases.

2. The effect of placing additional windows facing east or west was considered with W2 and W3.

3. The effect of neglecting the desirable features was investigated by having a house with light colours for walls (C2) and roof (R2).

	Parameter simulated	*The identification*	*Case selected for further simulation*
The thermal performance of the house with passive features during March	The effect of air changes on the indoor temperatures- Z1,Z2 and Z3	MC1R1W1Z1 MC1R1W1Z2 MC1R1W1Z3	Z1 and Z2 gave similar results. Z2 was selected since it is the practically more likely case.
	The effect of having additional windows facing east and west	MC1R1W1Z2 MC1R1W2Z2 MC1R1W3Z2	W2 case was selected since it is desirable to have some direct solar radiation penetrating during the cool morning
	The effect of neglecting the desirable features. This can be compared with MC1R1W1Z2	MC2R2W1Z2	
The thermal performance of the house with passive features during July	The data for July was used to compare with MC1R1W2Z2	JC1R1W2Z2	

Table 5.1: Computer simulations conducted

These simulations were carried out for March (M) where the sun path is almost above the house. The effect of having the sun in extreme locations was investigated with a few selected cases. For this, July was selected (21st July). It can be seen from Table 4.1 in Chapter 4, for July that the minimum outdoor temperature is 16.7 ^{0}C and the maximum outdoor temperature is 25.8 ^{0}C. The range is 9.1 ^{0}C. Number of sunshine hours was 6.6.

The important properties of the building materials used for the simulations are given in Table 5.2. These were obtained from (BRE 1984), Evans (1980) and Nayak et al., (1999). The constituent materials and overall properties as calculated by DEROB-LTH are given in Table 5.3.

Material type	*Conductivity W/mK*	*Specific heat Wh/kgK*	*Density kg/m3*
Earth	1.4	0.22	1300
Plain concrete	1.7	0.25	2300
Hand moulded bricks	0.82	0.24	1850
Cement plaster	0.72	0.24	1800
Cement fibre sheets	0.22	0.25	1600
Air space	0.024	0.28	1.201

Table 5.2: Properties of the materials used for the simulations.

Item	Constituent materials from front to back as defined for DEROB-LTH		Dynamic Attenuation	Time lag (hours)
	Material	Thickness		
Concrete floor	Earth Plain concrete Cement Plaster	500 mm 50 mm 20 mm	0.258	10.43
External or internal wall with 240 mm brickwork	Cement plaster Hand moulded Brick Cement plaster	15 mm 210 mm 15mm	0.569	6.134
Cement fibre roof with cement fibre sloping ceiling	Cement Fibre sheet Air gap Cement Fibre sheet	8 mm 250mm 6 mm	0.999	0.217
Concrete floor slab	Concrete slab	145 mm	0.861	2.73

Table 5.3: Constituent material properties.

In order to simulate the different colours of the wall and roof surfaces, the following values of absorptances and emittances in Table 5.4 were used.

Item	Surface colour	Absorptance (%)	Emittance (%)
Walls- brickwork	Light colour-off white	30	90
Walls- brickwork	Dark colours-green, blue, red	60	60
Cement fibre sheets of roof	Blackish grey	75	95
Cement fibre sheets of roof	Ash	50	50

Table 5.4: Absoptance and Emitance used for materials

5.4 The result and discussion

Since March climatic data was used for simulations, the results for south or north facing volumes indicate only a marginal difference as sun is almost above the building. Therefore, south facing volumes were considered for comparison purposes. For convenience in referring to the volumes, the following code was employed, when referring to the volumes.

Ground floor, U: Upper floor, N: Northern volumes, S: Southern volumes, E: volume with an east-facing wall, W: volume with a west-facing wall.

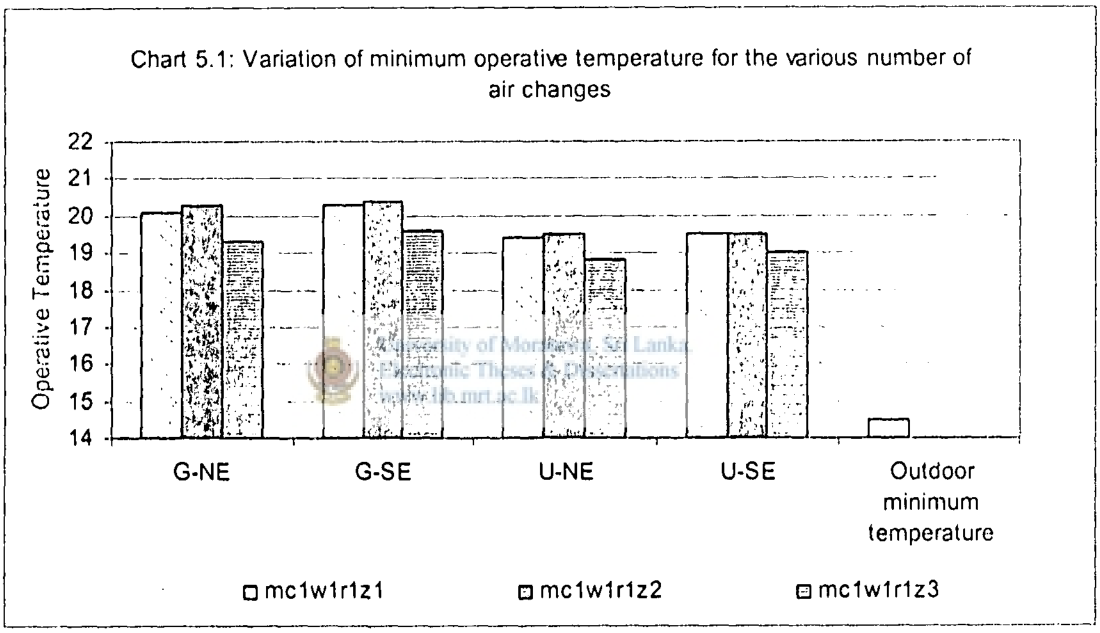
G-NE means ground floor volume facing north with an east facing wall.

The simulation results are discussed under the following topics:

1. Minimise heat losses due to air circulation during the night.
2. Maximise the heat gains through the windows.
3. Maximise heat gains through the walls using desirable colours such as those with higher absorptance.

ASHRAE defines the operative temperature as the average of the mean radiant and ambient air temperature, weighted by their respective heat transfer co-efficient. Therefore, it could be said operative temperatures is a better indication than the average indoor air temperature to represent indoor thermal comfort conditions. Therefore, for the analysis operative temperature was considered.

5.4.1 Effect of the number of air changes



The infiltration of outside air could give rise to a certain number of air changes. The maximum and minimum operative temperatures for the three combinations of air changes are presented in Charts 5.1 and 5.2.

Chart 5.1 indicates that the minimum operative temperature has remained much above the out door temperature for all the cases considered. The case of having a poor construction with a lot of infiltration during the night (Z3) has given a lower operative minimum temperature than Z1 and Z2 cases. This is because high infiltration allowed to cold air come in to the house. Warm air is passed through stack ventilation. Thus, the indoor temperature is reduced. Thus, having some of the windows open when the outdoor temperature is high (Z2) has no significant effect when compared with low infiltration throughout the day (Z1).

Thus, for tropical uplands, it is important to ensure that infiltration of cold air is as minimised as possible during the night. This conclusion tallies with the physical observation by Malama and Sharples (1997) done in a traditional house in Zambia located at an altitude of about 1300m above sea level. Chart 5.1 also indicates that the upper floor records a lower minimum operative temperature than the ground floor. This shows that the ground floor bedrooms of a two-storey house would have a lesser degree of cold discomfort than a upper floor bed room. With computer simulations it can be identified that the room in the upper floor of two storey house could experience a lower temperature in the night and higher temperature in the daytime than the room at a ground floor level. This means that generally upper floor rooms could be better during daytime since these could experience temperatures close to the outdoor. However, there is some possibility for overheating in quite warm days. The lower fluctuation of temperature and also higher temperature during the nighttime of ground floor bed rooms indicate that these could be better during the night.

The results indicate that the highest value of minimum operative temperature has occurred for Z2 case for both upper floor and ground floor. This indicates that the opening of windows during the daytime has a distinct advantage while closing them as the outdoor cools down. Similarly, the highest maximum operative temperature also has occurred for this case. This could indicate that allowing adequate ventilation when outdoors in warmer is a good strategy. Therefore, houses should be planned so that such ventilation in possible.

Chart 5.2: Variation of maximum operative temperature for the various number of air changes

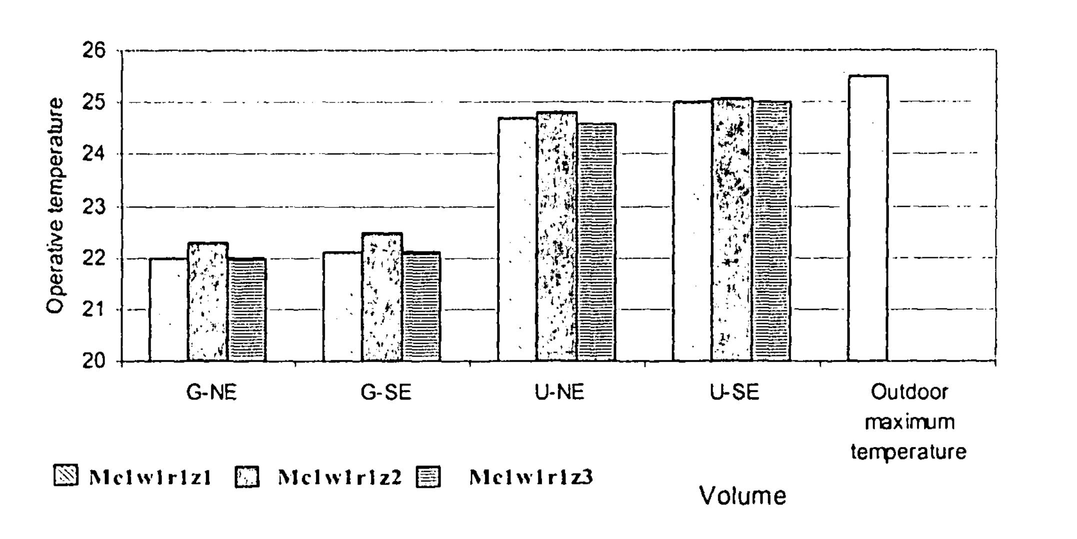


Chart 5.2 indicates that the infiltration has only a marginal effect on the indoor maximum operative temperature. The maximum temperature recorded by the ground floor is less than the upper floor. This may indicate that the upper floor areas could be better during the daytime as far as cold discomfort is concerned, except in days where hot discomfort will

become a problem. When windows are closed through out the day, the solar radiation in to the house through glazing is high. Thus, over heating may occur.

5.4.2 Effect of orientation of windows

Chart 5.3 and 5.4 indicates that having extra windows either facing east or west could have only a marginal effect on the operative temperature. However, east-facing windows would be of an advantage during cold mornings since the direct solar radiation could be used by the occupants in upper floor to have plenty of daylight. Thus, provision of additional west facing openings as well as east facing openings results in the most desirable conditions.

Chart 5.3: Variation of minimum operative temperature for the various window orientations

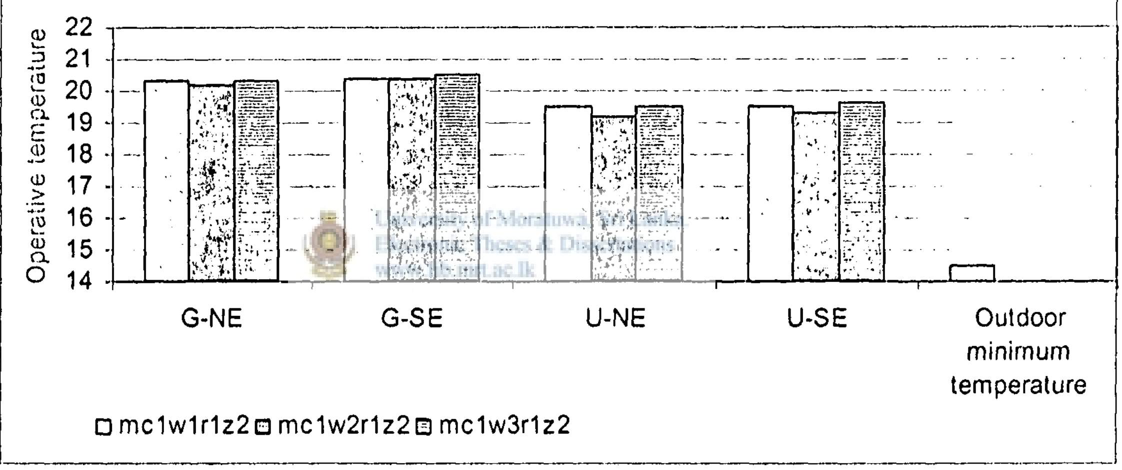
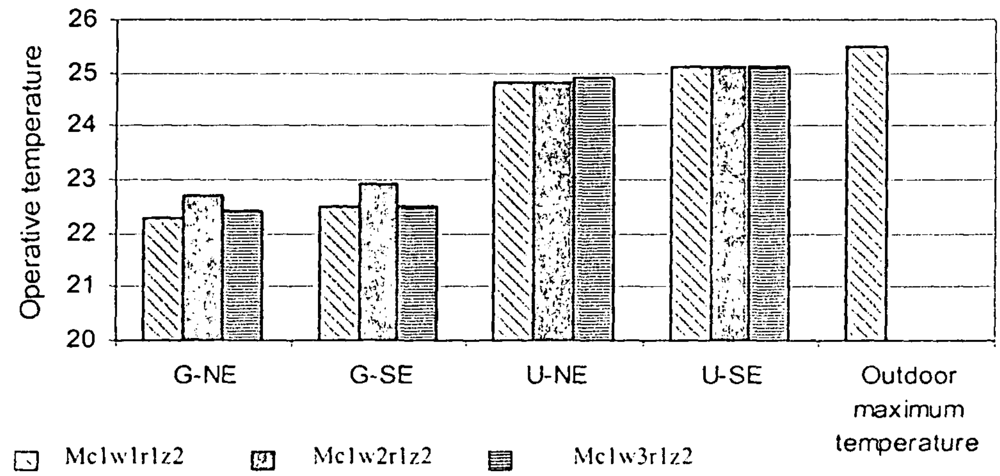


Chart 5.4: Variation of maximum operative temperature for the various window orientations



5.4.3 Effect of colour of the walls and the roof

Chart 5.5 and 5.6 indicate that the use of darker colours for the walls and roof would increase the operative temperature slightly while showing a similar increase in the maximum temperature as well. Due to the high absoptance of darker colours the penetration of solar radiation in to the house is high. When the absoptance is low, the amount of solar radiation is lower than the earlier case. Thus, low indoor temperatures are recorded. Since the cold discomfort during the night is the more serious problem, the use of darker colours could be recommended.

Chart 5.5 : Variation of minimum operative temperature for two colours of walls and roof

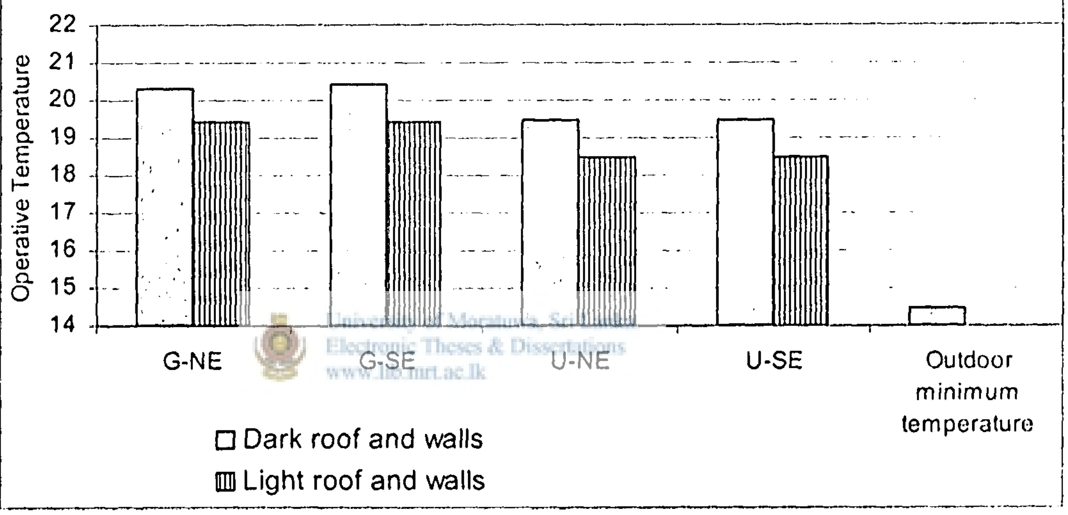
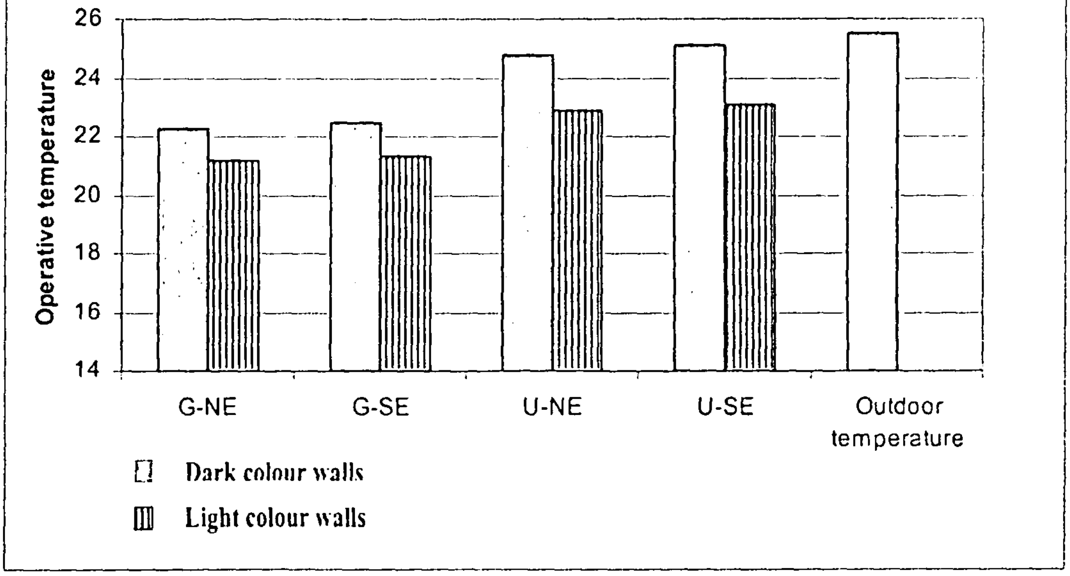


Chart 5.6: Maximum operative temperature recorded during March for dark and light colour walls and roofs



5.4.4 The thermal performance during July

Chart 5.7 indicates that a similar trend can be observed for both March and July for all the volumes. The upper floor indicated a greater fluctuation of temperature than the ground floor. Such a trend could be expected for other months as well.

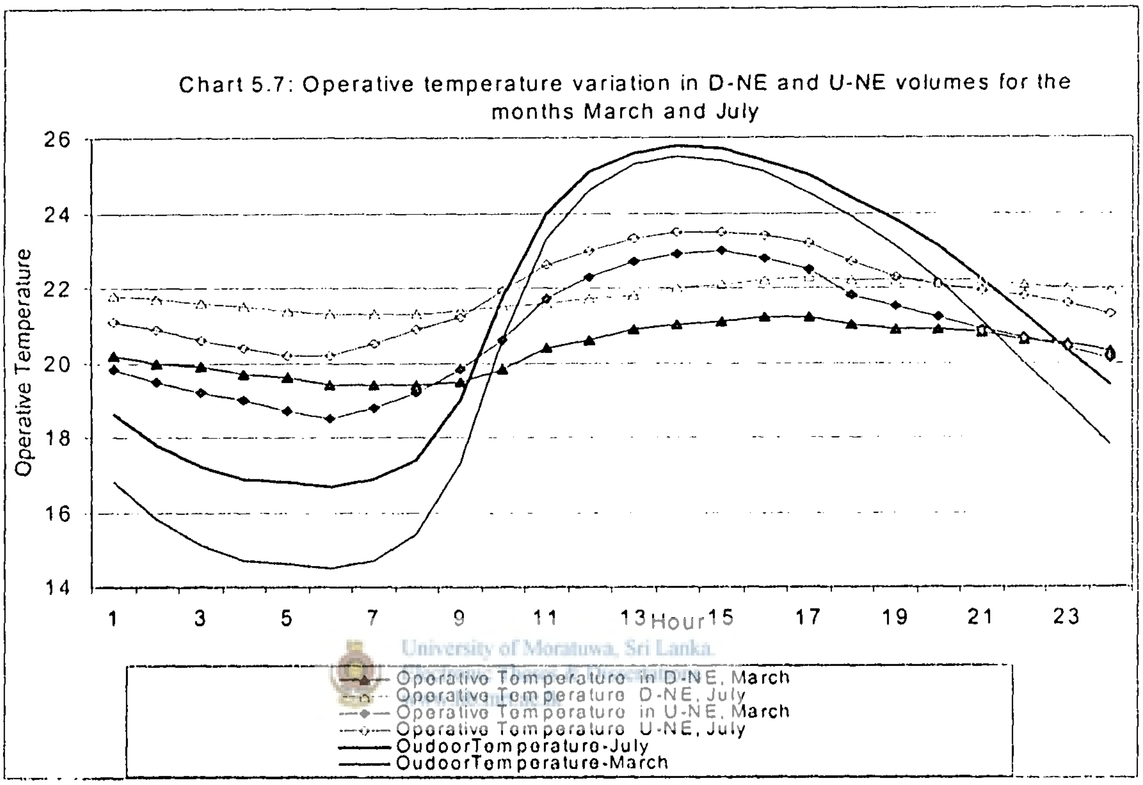


Chart 5.7: Operative temperature variation in D-NE and U-NE volumes for the months March and July

5.4.5 Applications of findings

The Chart No	General Information	Practical Application
Chart 5.1	The infiltration should be minimised during the night. Z3 case records a much lower temperature than Z1 and Z2.	The bedroom should have minimum infiltration through doors, windows and roof during the night
Chart 5.2	Upper floor rooms record a lower temperature than the ground floor room.	The ground floor bedrooms would have a cold discomfort to a lesser degree than the upper floor bed rooms.
Chart 5.3 and Chart 5.4	There is no significant effect of having windows either facing east or west on minimum or maximum temperatures	An extra window facing east could be advantageous in allowing a lot of daylight during cold mornings.
Chart 5.5 and 5.6	There is a marginal increase in the minimum and maximum temperature when darker colours are used.	Since cold discomfort is a serious problem, even the marginal advantage that could be obtained with darker colours would be useful for houses in tropical uplands.

Table 5.5: Applications of findings

5.5 Guidelines for passive houses in tropical uplands.

Houses would generally be either single or two storeys. The upper floor of a two-storey house is similar to a single storey house. Therefore, the comparison is made between the upper floor and the ground floor. The computer simulations indicate that the upper floor could be much desirable during the daytime, because the indoor temperature reaches a higher value than the ground floor. During the night, the ground floor would have a higher temperature, since it is sheltered by the upper floor thus reducing the losses. Therefore, the compact house shown in Figure 5.4 could be a solution for the tropical uplands.

However, it should be noted that even this of type house will not be able to guarantee a thermally comfortable conditions for all occupants everyday throughout the year by maintaining the indoor temperature between 22 - 26^{0}C. Nevertheless, it would have the thermal discomfort to a lesser degree than a house where the passive concepts were ignored.

The proposed conceptual house consists of two-bed rooms at the ground floor and two bedrooms at the upper floor with other utility areas at the ground floor. This concept offers a number of advantages. The occupants would be able to use thermally more comfortable areas like living, dining, pantry and upper floor bedroom during the night. For those occupants to whom the cold discomfort is annoying, the ground floor bedrooms could be selected during the night. Others could select the upper floor bedrooms. Such a concept would give sufficient freedom for the occupants to respond to the wider fluctuation in day and night time temperatures that occur in tropical uplands.