Chapter 6

AN ASSESSMENT OF THE THERMAL PERFORMANCE OF A HOUSE SUITABLE FOR TROPICAL UPLANDS

6.1 General

In tropical upland areas, the cold discomfort that occurs during the night is generally a problem for which the remedy would be the space heating, if it is affordable. With the economic developments that are taking place in many developing countries, space heating is generally becoming within the reach of many people. However, this may not be a positive feature with respect to sustainable development since majority of the people may use electricity for space heating. Electricity is usually generated using non renewable energy sources such as Petrolium. Therefore, energy efficient houses that would include sufficient passive features to minimize the use of active means such as space heating would be extremely useful for tropical upland areas.

In Chapter 5, a number of guidelines were given based on detailed computer simulations for tropical upland areas. A conceptual house was also presented based on the guidelines. This chapter presents results of detailed computer simulations carried out to determine the effect of various passive features when used with this conceptual house.

6.2 The Objectives

The main objectives and the methodology of this research are as follows:

1. Determination of the suitability of the conceptual house proposed for tropical uplands areas.

2. Evaluation of the effect of various passive features suitable for tropical uplands on the thermal performance of the conceptual house.

6.3 The methodology

The following methodology was adopted to achieve above objectives:

1. The conceptual house provided with many desirable passive features was selected.

2. Computer simulations were used to determine the thermal performance with these desirable features.

3. For the above house, undesirable passive features were introduced gradually in order to determine the effect of such features.

4. The passive features that have significant and marginal benefits were identified so those could be adopted in tropical uplands.

6.4. The computer simulations

6.4.1 The simulation software

For the computer simulations, dynamic energy response of Buildings (DEROB–LTH) program which was developed and validated at the Department of Building Science, Lund Institute of Technology (LTH), Sweden, was used. The details of the computer program was given in Chapter 3.

It could be said operative temperature is a better indication than the average indoor air temperature to represent indoor thermal comfort conditions. Because, it counts the effect of radiation effect of the surrounding bodies. Therefore, for the analysis operative temperature was considered as for better explanation.

Operative temperature is defined in DEROB-LTH using the equation given below:

$$T_{op} = \frac{T_v + (\sum T_i A_i) / \sum A_i}{2} \qquad - (6.1)$$

T_{op} operative temperature

T_v indoor temperature for the volume

T_i surface temperature

A_i surface area6.4.2 The computer simulations

6.4.2 The details of computer simulations

For the simulations, the conceptual house was modelled with DEROB-LTH. The plan views of the model used are given in Figure 6.1. It could be compared with the actual house given in Figure 5.5. The roof orientations could be seen in model shown in Figure 6.1. The orientation of the roof would have only a marginal influence as shown in Chapter 4. Therefore, it could be arranged other ways as well without much effect. The roof slope is 10^0 and provided with a sloping ceiling.

The 3D model of the house given in Figure 6.1 was used to generate a number of different cases. These cases are given in Table 6.2. Some description about the notations is given below.

1. The house given in Figure 6.1 was proposed with desirable features explained in Chapter 5 with the front of the house facing south. For the roof and the walls, darker colours were used. For all the simulations, the floor was considered as dark colour with an absoptance of 60%.

2. For walls and floors, an absoptance of 60% was used (Case C1). The roof with dark colours has an absoptance of 80% (Case R1). If new cement fiber sheets are used, an absoptance of 60% was used (Case R2). If the walls are painted with light colours, an absoptance of 35% was used (Case 2).

3. It is shown in past research that it is desirable to respond to the changing outdoor temperature by opening the windows during the daytime. Thus, three different air changes could be used as given in Table 6.1.

4. The windows are provided in the following manner. When there is a north or south facing wall in a room, windows of size 1.2m x 1.2m are provided on these walls. When such walls are not available, an east facing wall is used. Walls facing west are avoided for windows unless it is essential. The location of windows can be seen in 3D diagram given in Figure 6.1.

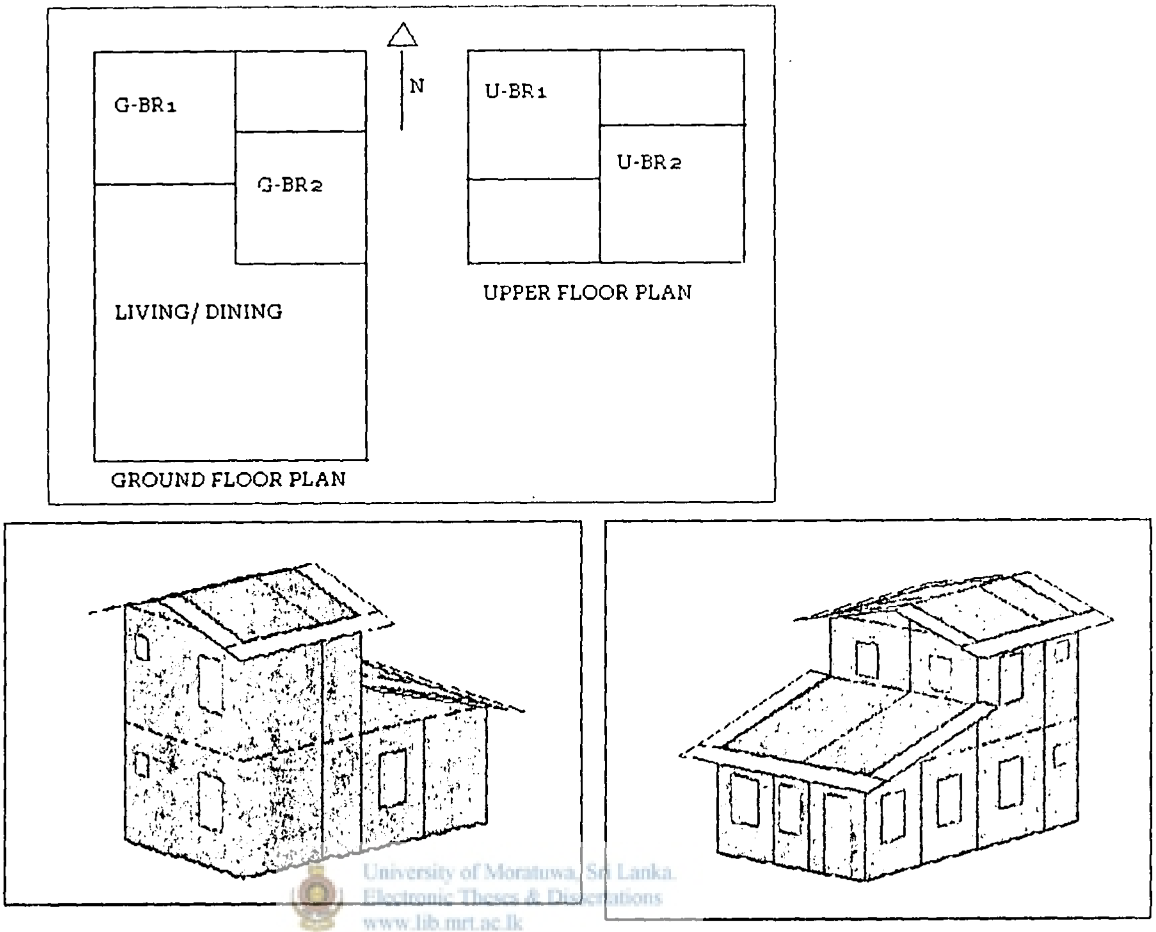


Figure 6.1: The plan arrangements used for the ground and upper floors and the corresponding 3D view.

Case	*Duration in hours*			*Remarks*
	1-11	12-17	18-24	
Z1	1	1	1	Windows closed throughout the day
Z2	1	3	1	Windows opened during daytime and closed during all the other time
Z3	3	3	3	House with poor construction, hence considerable infiltration throughout the day.

Table 6.1: Number of air changes used for computer simulations

Month	*Wall*	*Roof*	*Air changes*	*Case*	*Reasons*
Month (M)	C1 (Dark)	R1 (Dark)	Z1	MC1R1Z1	To determine the effect on infiltration on a proper passive house
			Z2	MC1R1Z2	
			Z3	MC1R1Z3	
	C1 (Dark)	R2 (light)	Z2	MC1R2Z2	Effect of roof colour (dark) and low infiltration
			Z3	MC1R2Z3	Effect of roof colour (dark) and high infiltration
	C2 (light)	R2 (light)	Z2	MC2R2Z2	Effect of light roof and wall colour with low infiltration
			Z3	MC2R2Z3	Effect of light roof and wall colour with high infiltration
June(J)	Same as above	Same as above	Same as above	Same as above	Same as above
December(D)	Same as above	Same as above	Same as above	Same as above	Same as above

Table 6.2: Different cases simulated to determine the effect of passive features

6.4.3 The material properties used for simulations

The important properties of the building materials used for the simulations are given in Table 6.3 and the constituent materials and the overall properties are given in Table 6.4. They were obtained from BRE (1984), Evans (1980) and Nayak et al. (1999).

Material type	*Conductivity (W/mk)*	*Specific heat (Wh/kgK)*	*Density (kg/m^3)*
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 6.3: Material properties used

Elements	*Constituent materials from front to back as defined for DEROB-LTH*	*Time lag (Hours)*
Concrete floor	500mm earth, 50mm plain concrete, 20mm cement plaster	10.430
External or internal wall	15 mm cement plaster, 210mm thick brick wall, 15mm cement plaster	6.134
Cement fibre roof with cement fibre sloping ceiling	8mm thick cement fibre sheets, 250 mm air gap, 6mm thick cement fibre sheets	0.217

Table 6.4: Constituent material properties used for the simulations

Item	*Colour*	*Absoptance (%)*	*Emittance (%)*
Walls	Dark	60	90
	Light	35	90
Roof	Dark	80	90
	Light	60	90
Soffit of the slab	Same as the wall colour	Same as the wall colour	Same as the wall colour
Cement rendering floor	Dark	60	90
Eaves	Same as the roof colour	Same as the roof colour	Same as the roof colour

Table 6.5: Absoptances and emittances used for simulations

6.5 Results

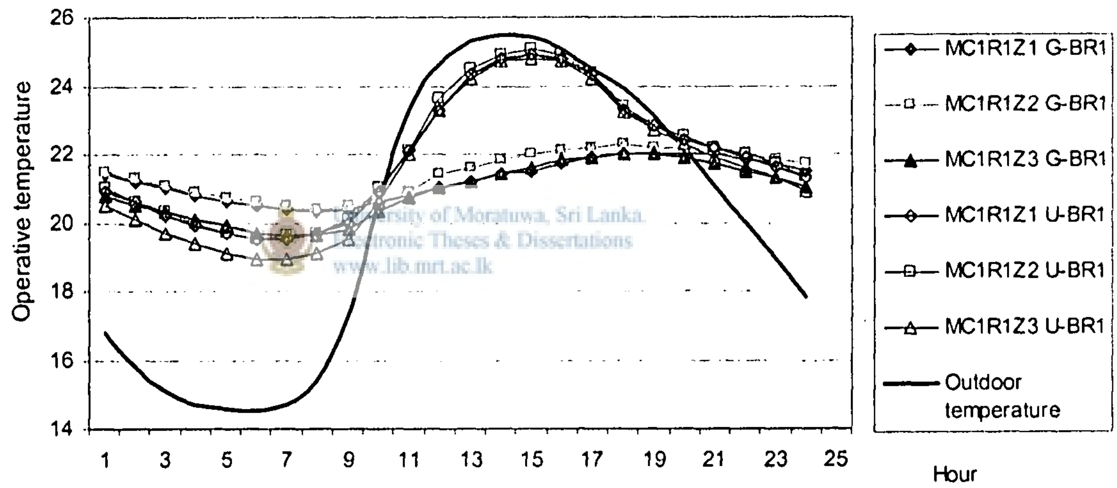
The computer model of the house was selected so that upper floor and ground floor volumes could be compared. For example, it can be seen from Figure 6.1 that the ground floor bed room No 1 (G-BR1) and upper floor bed room No 1 (U-BR1) could be compared. This will allow a comparison of the upper floor and ground floor with various passive features. Similarly, G-BR2 could be compared with U-BR2.

6.5.1 Effect of Infiltration

In order to determine the effect of infiltration, three cases were selected as given in Table 6.2. Those are MC1R1Z1, MC1R1Z2 and MC1R1Z3 as represented in Chart 6.1. The infiltration rates for Z1, Z2 and Z3 can be found in Table 1.

Chart 6.1 indicates that the upper floor will give much larger fluctuations of operative temperature than the ground floor. However, during the daytime, the upper floor would be quite comfortable, since it reaches higher temperatures. During the night time, it records a lower temperature than the ground floor. Therefore, the ground floor of the house could be more comfortable than the upper floor of the house during night time.

Chart 6.1: Variation of operative temperature for March with different number of air changes



When the effect of infiltration is considered, the case which allow greater ventilation only during the daytime (Z2) gave a higher day time temperature for the ground floor. This is true for the upper floor as well. Thus, either Z1 or Z2 could be adopted in a well planned passive house. Z2 is more practical, since it allows the opening of some windows during daytime.

The high infiltration during the night time could reduce the operative temperature by about 1^0C in both upper and ground floors. However, it would reduce the maximum daytime operative temperature only, marginally. Such a reduction in operative temperature during the night time is quite undesirable, since it could lead to cold discomfort during the night which may promote people to consider active means for thermal comfort. When cold air comes in to the house. This means that the construction of houses with sufficient attention to minimise the infiltration rate is quite important for tropical uplands. These observations are true for June and December as can be seen from Charts 6.2 and 6.3.

The temperatures recorded during June were somewhat higher than the March. This could be attributed to the higher outdoor temperature during night. December recorded quite low operative temperatures which could be attributed to the reduction in the intensity of solar radiation. For the remaining simulations, only Z2 and Z3 cases given in Table 6.1 were considered. This will facilitate the comparison of the effects of infiltration along with other passive features.

Chart 6.2: Variation of operative temperature for June with different number of air changes

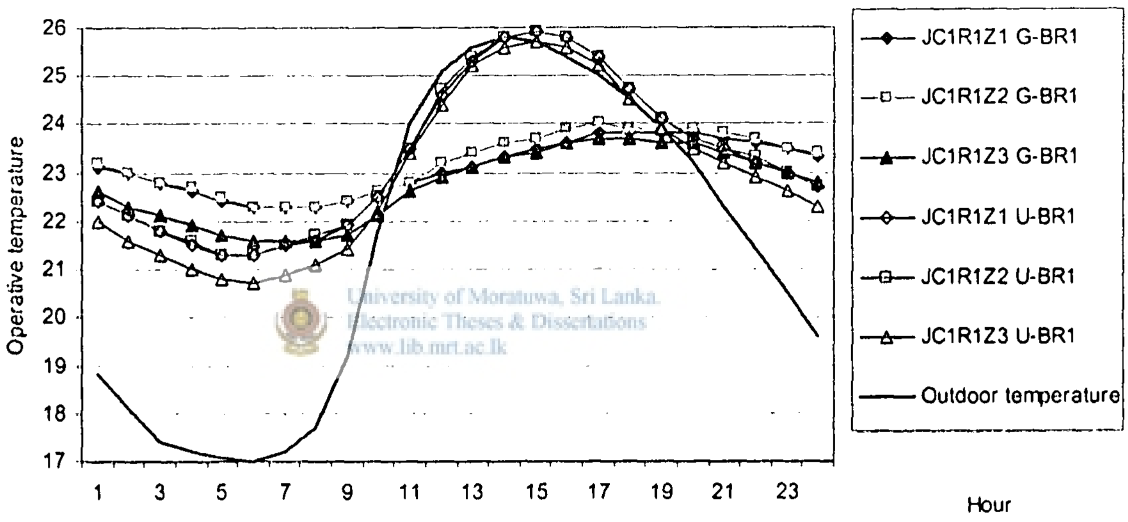
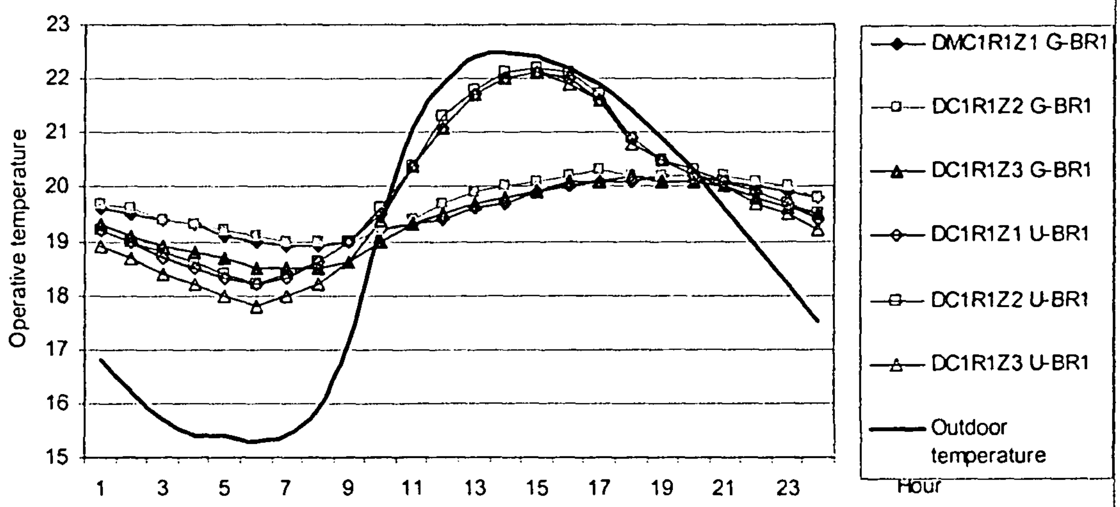


Chart 6.3: Variation of operative temperature for December with different number of air changes



6.5.2 Effect of wall and roof colours

The effect of roof colour could affect the upper floor operative temperature specially during the day time. Charts 6.1 and 6.4 indicate that the light colour roof could lower the maximum daytime operative temperatures by about 1^0C in the upper floor. However, it could have a lesser effect on the ground floor (less than 0.5^0C). The light colour roof could affect the night time upper floor minimum operative temperatures also marginally. Even for the light colour roof, higher infiltration rates could affect the operative temperature as could be seen in Chart 6.4. For example, the ground floor bed room No 1 (G-BR1) indicated a drop of about 1^0C during night time 3.00 to 5.00 o' clock in the night as indicated Z3 case. This reiterates the fact that controlling the infiltration of cold outdoor air during the night is extremely important in tropical uplands.

Chart 6.5 shows the effect of infiltration on a house with light colour walls and roof. This also indicates a similar trend to earlier case with Z3 case showing a lower temperature. A comparison of Chart 6.1 and 6.5 indicates that the operative temperature of the ground floor rooms drops by about 1^0C when light colour roof and walls are used. When the colour is light the radient energy absorbed by the walls and roof is reduced. High infiltration also reduces the indoor temperature. This is significant, since almost throughout the day, the ground floor rooms remain below 22^0C which could generally be considered as the lower limit for thermal comfort as shown in Figure 4.1 in Chapter 4.

However, the use of light colour walls and roof has not got a significant effect on the upper floor indoor temperatures as can been seen by comparing Charts 6.4 and 6.5. A comparison of Chart 6.1 and 6.5 indicates that high infiltration rate could diminish the advantages gained with darker colours for roof and walls for both ground and upper floors.

Chart 6.4 : Variation of operative temperature for March for dark colour walls and light colour roof

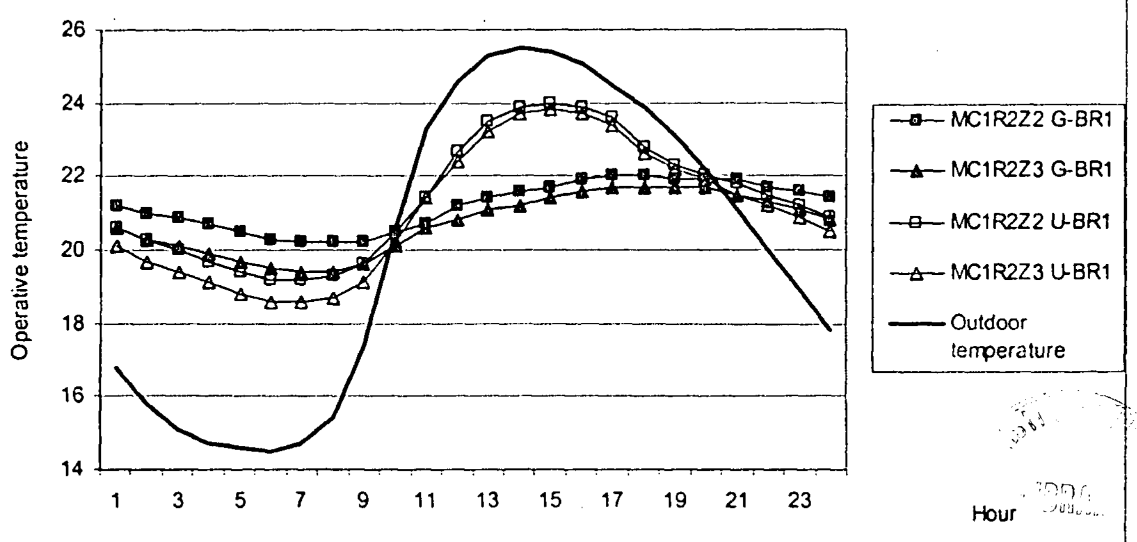
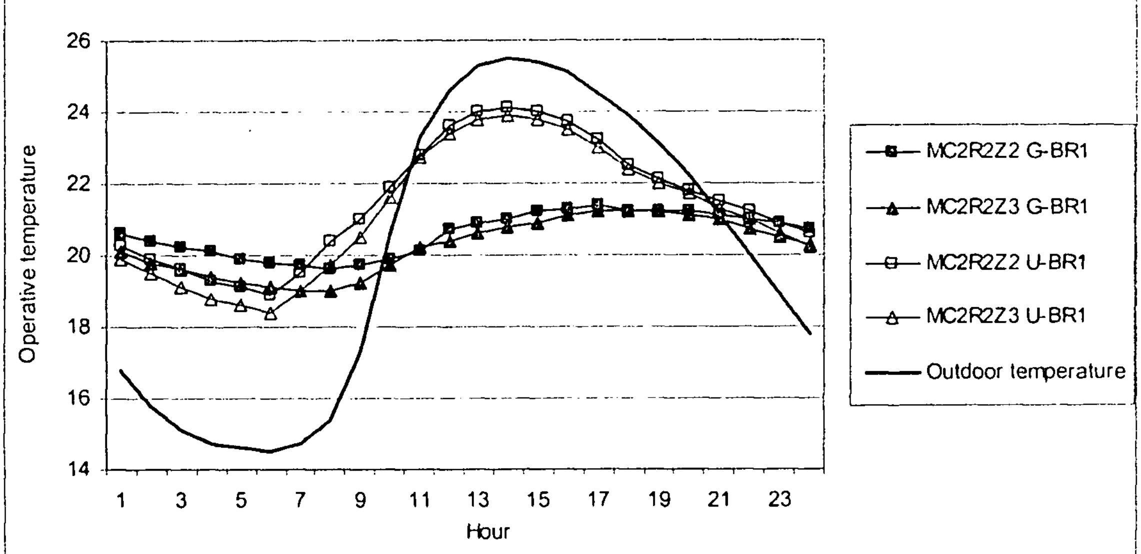


Chart 6.5 : Comparison of operative temperature month March for light colour walls and roof



6.5.3 A comparison between orientations

Chart 6.6 : Comparison of operative temperature for BR1 and BR2 at ground and upper floors during March

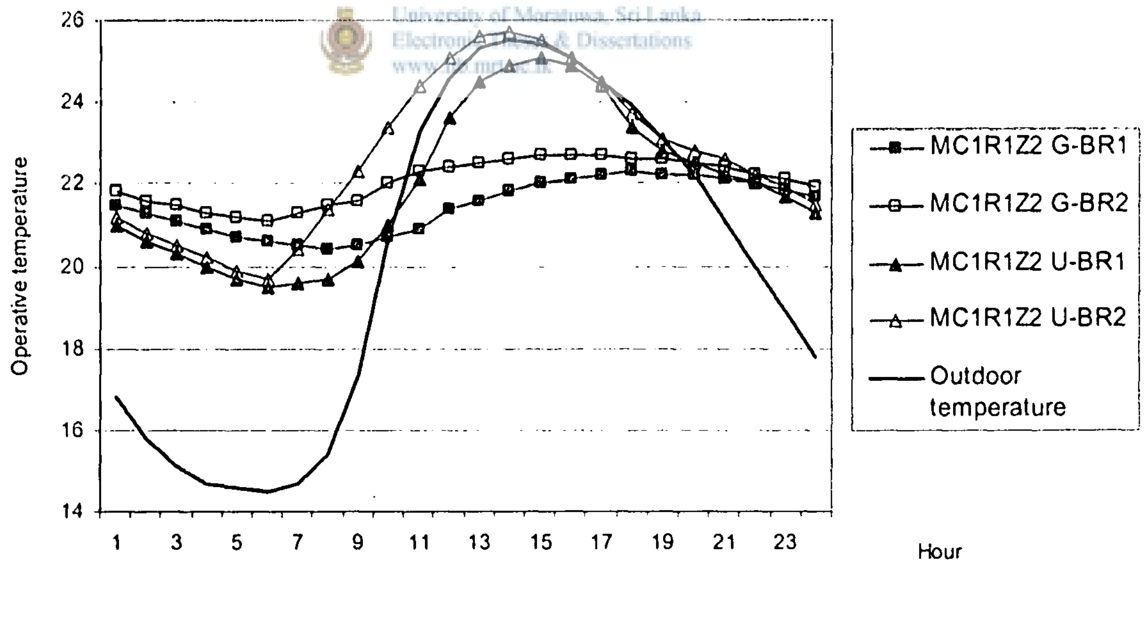


Chart 6.6 gives a comparison between bed room 1 and 2 at ground floor and upper floors. This could be used to determine the effects of various roof orientations in tropical uplands. It can be seen from Chart 6.6 that between 6.00 to 13.00 hours, there is a considerable difference in the bed room No 1 (BR1) and bed room No 2 (BR2) temperatures. This could be attributed to the window facing east. It would allow a considerable amount of direct solar radiation, during the morning.

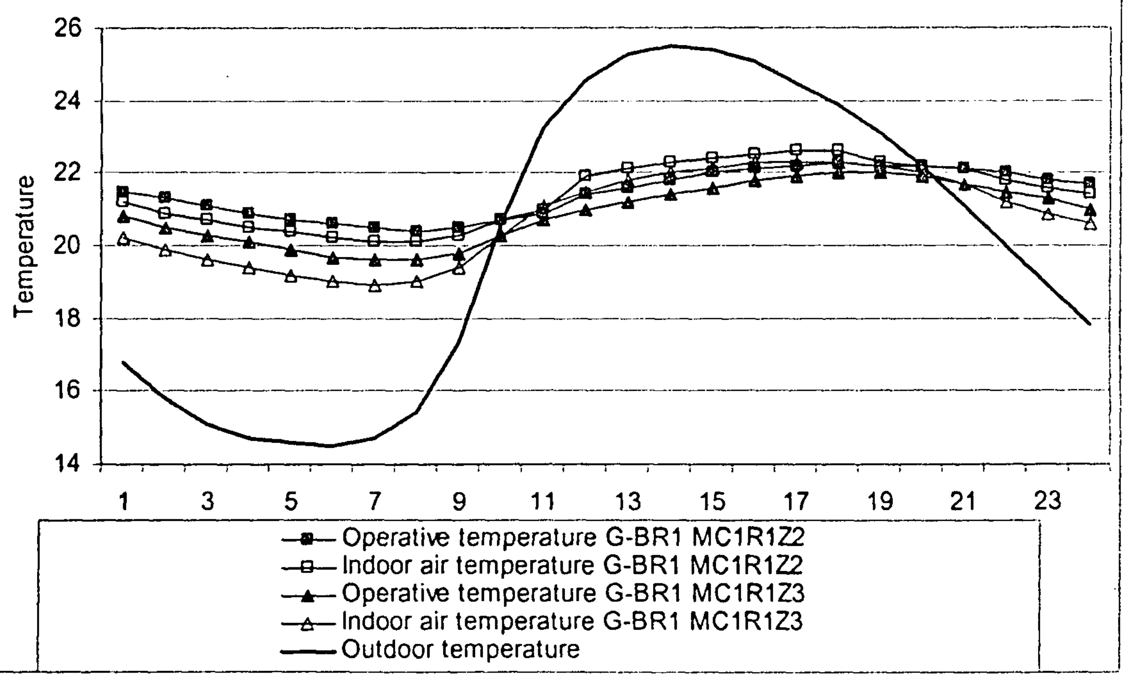
During the night time, the temperatures of BR1 and BR2 are only marginally different. However, the difference is higher for the ground floor. This could be attributed to the number of walls exposed to outdoors. At the ground floor, in BR1, there are two walls facing outdoor while BR2 has only one. However, in the upper floor, both BR1 and BR2 have two walls facing outdoors.

6.5.4 A comparison between indoor air and operative temperatures

Although, operative temperatures were used for earlier predictions, the average indoor temperature also could be an important indicator, specially for night time temperatures. Chart 6.7 gives a comparison between the operative temperatures for the operative and the indoor temperatures for the ground floor. It can be seen from Chart 6.7 that the indoor average temperature is about 1^0C lower with higher infiltration. There could be a slight draft associated with it. Such a draft has with a marginal chill factor which represents a loss of heat when the warm air around the body is replaced with cooler air. Chart 6.8 shows the corresponding results for the December

This also further reiterates the importance of curbing higher infiltration during the night with suitable construction techniques. In this context, provision of a ceiling is quite important for the upper floor and also some steps to reduce the ventilation of the roof void would be quite important. It will also be quite important to minimise infiltration through windows.

Chart 6.7 : Comparison of operative temperature and indoor air temperature for March.



In Chart 6.9, the zero temperatures denote the case C1R1Z2 for March, June and December. That means the operative temperatures of the house with desirable passive features and the ventilation denoted by Z2 case was taken as the datum. The other charts indicate the variation of temperatures for C2R2Z3 case. That is the operative temperatures of the house with light colour roofs and walls and also with high infiltration. The advantage of this representation is that it clearly shows the variation of temperatures that could be achieved. All these charts are having negative temperatures. This indicates that higher infiltration and light colour reduce the indoor operative temperatures. This trend is more pronounced for June.

Chart 6.8 : Comparison of operative temperature and indoor air temperature for December

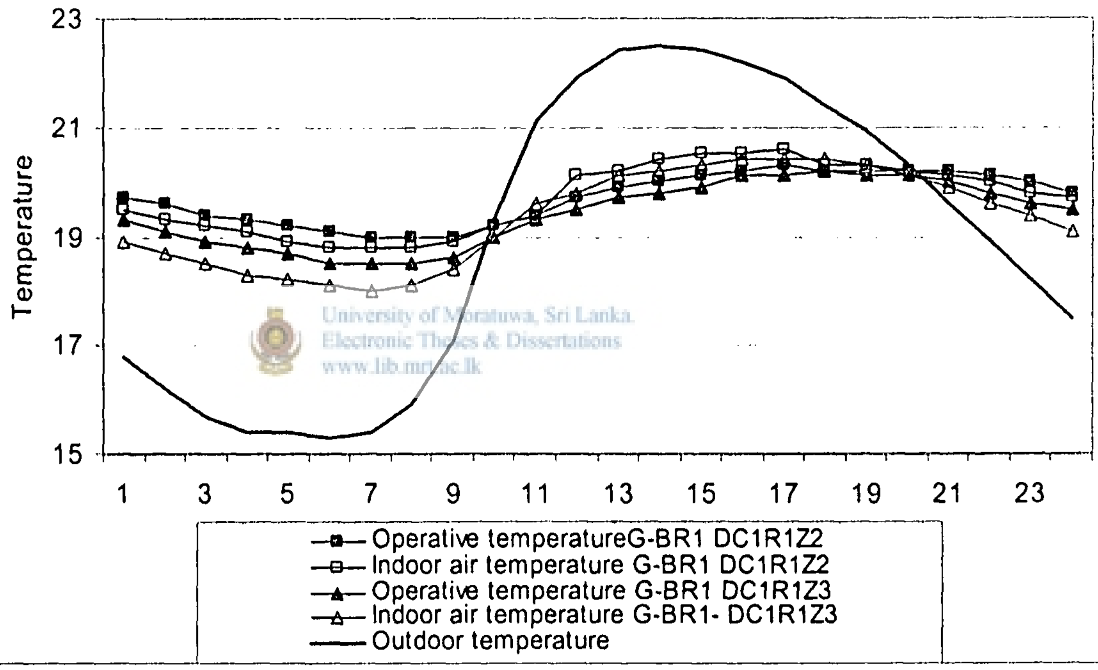
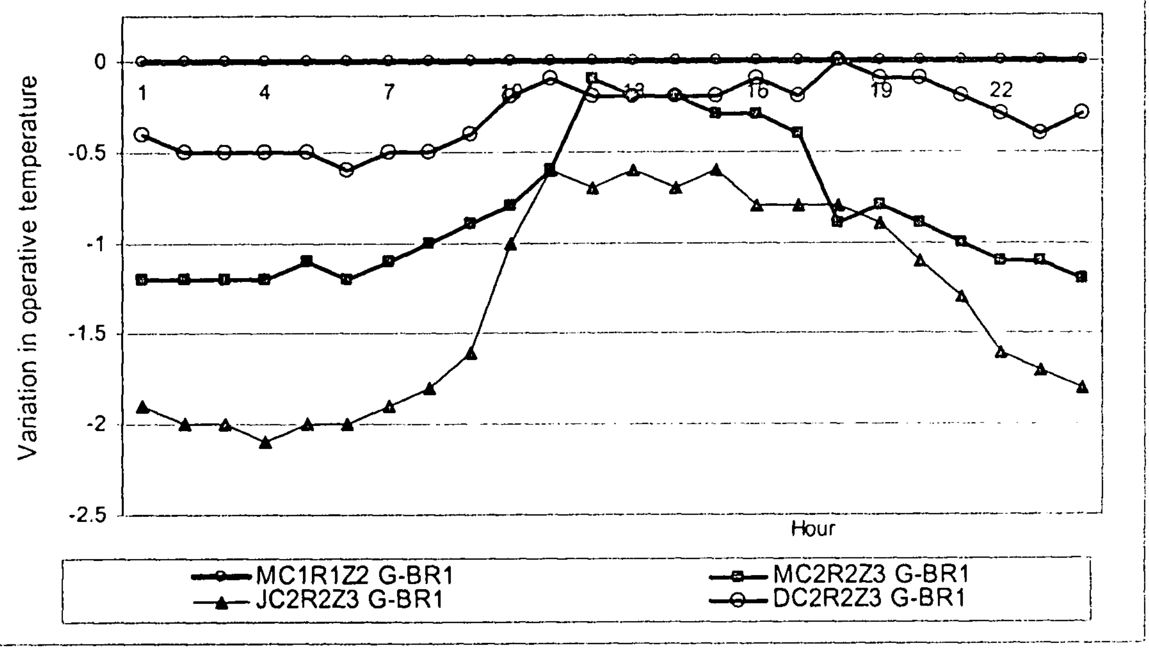


Chart 6.9 The variation of operative temperature of the C2R2Z3 cases against the C1R1Z2 cases for the three months March, June and December



This also further reiterates the importance of curbing higher infiltration during the night with suitable construction techniques. In this context, provision of a ceiling is quite important for the upper floor and also some steps to reduce the ventilation of the roof void would be quite important.

6.6. Conclusions

In tropical uplands due to the high diurnal fluctuations in outdoor temperatures, the rooms protected by the roof show a greater degree of fluctuations in indoor temperatures than those protected by the upper floor slab. This was used to suggest a compact house for tropical where bed rooms are located both ground and upper floors. The computer simulations carried out for the compact house indicated the following:

1. The upper floor bed room would be thermally more comfortable during the daytime than the ground floor bed rooms sheltered by the upper floor. However, when outdoor temperatures drop significantly during the night, the ground floor room could be better. Thus, it is advantageous to have bed rooms at both upper and ground floors in houses constructed in tropical uplands.

2. In this compact house, it is found that the infiltration of cold air during the night could lower the indoor operative temperatures by about 1-2^{0}C. This is true for both upper and lower floors. Thus, planning the houses to minimise such infiltration would be quite advantageous. Such infiltration could occur through windows and

the doors. Therefore, paying attention to the details that could prevent the infiltration of air while fixing doors and windows would be quite useful.

3. Such infiltration could occur through the ceiling as well. Therefore, ceiling construction also will need sufficient attention during the construction.
4. The use for darker colours for the roof and walls also could be useful. The roof material generally turns to darker colour in tropical uplands within one or two years of infiltration due to the wet climatic conditions that generally prevails. The walls could be painted with somewhat darker colours such as green, blue, gray etc.

5. If it is possible to provide a window facing east, it would be advantageous in increasing the indoor temperature rapidly, during the cold mornings.

These findings clearly indicate that the passive houses constructed for tropical uplands would need greater attention to the construction details. This is in contrast to the tropical lowlands where the natural ventilation in promoted with extra openings and courtyards. Thus, this difference has to be clearly identified and a modern architecture that adopts the useful features of the conceptual house would have to evolve. Such adoption could reduce the need to use of energy consuming active means for thermal comfort.