Chapter 4

INFLUENCE OF ROOF SYSTEMS AND ROOF MATERIALS

4.1 General

In Sri Lanka, roof orientation, roof material and external colours of the roof are determined more on the basis of the aesthetics and/or cost than the thermal performance. In high altitudes of Sri Lanka, such as about 1500 m above the mean sea level, there is thermal discomfort inside the houses due to low temperatures that occur during the night. Therefore, it is prudent to determine the effect of various roof orientations and materials on the indoor thermal comfort. The roof should be designed in such away that solar heat gain through the roof is kept at the most appropriate level.

Among the elements of the building envelope, thermal performance of roofs in tropical buildings is very important. Due to the location of Sri Lanka, the solar altitudes are so high that all slopes of roofs are exposed to the sun virtually from sunrise to sunset.

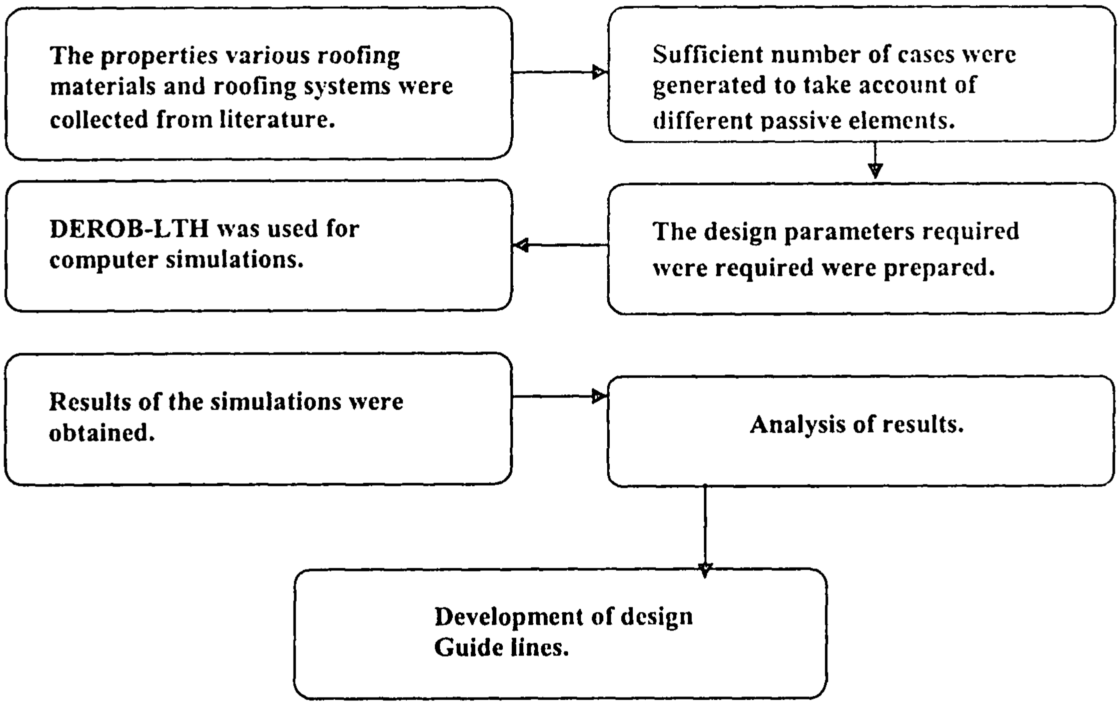
It is suggested that "climatic design" ill help the architect in the process of energy conservation. It should not simply be considered as a simple theory, which can be applied after an architectural solution has been found, but as a tool which may be used in the initial stages of the design process, through the preparation of "climatically sound solutions". Fundamental options of climate control for tropical uplands are mentioned below.

- Admitting heat gain from external energy sources
- Containing heat energy present in interior

The special attention should be given for this type of climate, because during the cause of the day, there will be warm periods. Thus, heat gains should be controlled. At night and morning hours, there will be great heat loss and therefore, heat containing is required. Thus, the duty of the designer is becoming more critical for this type of climate. For the tropical upland areas, following properties should be considered when the roof is designed.

4.2 The objectives and methodology

The main objectives of this part of study are to determine the effects of the roof orientation and materials on the indoor environment of a single storey house under the climatic conditions prevailing in tropical uplands of Sri Lanka. In order to achieve these objectives, the following methodology was selected:



4.3 The comfort zone for Bandarawela

Thermal comfort is a subjective quantity resulting from internal environmental variables such as dry bulb temperature, mean radiative temperature, humidity and air velocity. Thermal comfort could be achieved for several combinations of the environmental and personal parameters, which could be represented as a comfort zone on the psychrometric chart given in Figure 4.1. The centre point of the comfort zone is the neutrality temperature, which could be calculated using the mean annual temperature T_o. T_o can be calculated when the climatic data is available for a number of years. For example, T_o is about 20^0C for a town located about 1400 m above mean sea level in the tropical uplands of Sri Lanka, which was calculated using the climatic data given in Table 4.1. Sri Lanka is located between $5^0 55'$ to $9^0 51'$ N latitude and $79^0\ 43'$ to $82^0\ 53'$ E longitude. Thus, it experiences tropical climatic conditions in low altitudes and tropical upland conditions in high altitudes. . The corresponding value of T_n is about 24 ^{0}C.

$$\text{For } T_o = \frac{(297.4 + 187.8)}{(2 \times 12)} = 20.22\ ^0C \qquad - (4.1)$$

$$T_n = 17.6 + 0.31\ T_o$$

$$T_n = 17.6 + 0.31\ (20.22) = 23.86\ ^0C = 24^0C \qquad - (4.2)$$

It should be noted that the T_n value for tropical low lands of Sri Lanka, where warm humid climatic conditions prevail, is about 26^{0}C (Jayasignhe & Attalage, 1999a). Thus, the comfort zone developed for the tropical uplands based on guidelines given by Szokolay (1991) indicates a shift of about 2^{0}C on the psychrometric chart, to the left. The comfort zone given in Figure 4.1 has used an upper humidity ratio of 0.0015 as recommended by Jayasinghe and Attalage (1999b) based on comfort surveys carried out on subjects who lived in tropical climatic conditions. It indicates that a reasonable thermal comfort could be achieved by maintaining the indoor temperature within 22^{0}C-26^{0}C in tropical uplands. It also shows the average minimum and maximum temperature for each month as a collection of lines. It can be seen that the minimum temperatures lies outside the comfort zone.

This comfort zone is a very significant finding since it gives a definite goal that the designer of the passive house could try to achieve, That is maintaining the indoor temperature between 22-26^{0}C as much as possible with passive means.

Month	*Sunshine hours per day*	*Mean daily temperature (^{0}C)*		*Corresponding relative humidity (%)*	
		Max (around 14.00 hours)	*Min (around 06.00 hours)*	*At 06.00 hours*	*At 15.00 hours*
Jan	5.4	22.4	14.1	100,	62
Feb	6.4	24.1	13.6	100	60
Mar	8.3	25.5	14.5	100	55
Apri	7.0	25.9	15.9	100	58
May	7.2	26.3	16.7	100	58
June	6.3	25.8	17.0	98	54
July	6.6	25.8	16.7	98	54
Aug	7.0	25.7	16.5	99	56
Sept	6.0	25.3	16.1	99	55
Octo	5.2	24.6	15.8	100	60
Nov	4.7	23.5	15.6	100	65
Dec	4.0	22.5	15.3	100	70
Σ		297.4	187.8		

Table 4.1 Climate data for a town above 1500 Msl (Bandarawela).

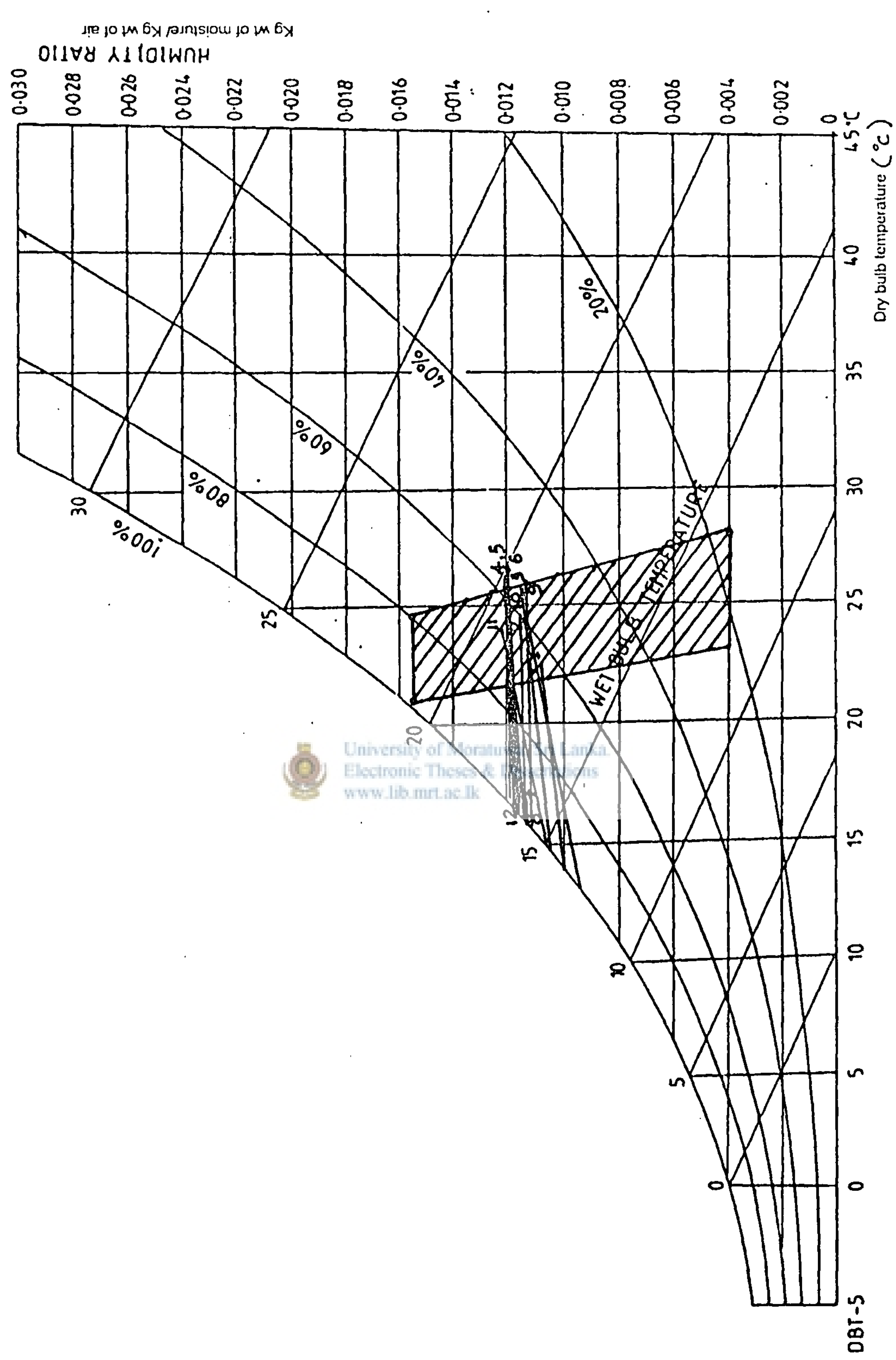


Figure 4.1: Comfort zone recommended for tropical uplands (Bandarawela – Sri Lanka)

4.4 Orientation of roof and roof materials on thermal comfort in tropical uplands

The most important element in a house is the roof. Not only it does protect the building from precipitation, but also the strongest thermal impacts occur here. The roof is that part of the building which receives most of the solar radiation and its shading is difficult.

The optimum roof arrangement can be selected by considering the wind pressure distribution above the roof. Flat ceiling and sloping ceiling are common for highlands. The attic space in the roof-ceiling combination inhibits the heat transfer through conduction, because the thermal conductivity of air is very low.

The materials common to high altitudes are mainly galvanized iron sheets (GI sheets), calicut tiles and asbestos sheets. Iron sheets are one of the main materials in tropical highlands. The thickness of the sheet is gauge 26-30 and there are two types of GI sheets. One type of GI sheets consists of long sheets and is used mainly on large buildings. The smaller roofing sheets, which are mainly used for dwellings, are nailed to purling at a distance of about 900 mm and the roof pitch is normally $10\text{-}15^0$. GI sheets have some advantages compared to other materials. Its lightweight means that strong and costly support is not needed and long distances can be used between purlings. As the material is flexible, some irregulaties in the support can be allowed. From the point of view of thermal comfort, when exposed to solar radiation, GI sheets will cause poor indoor thermal comfort. The material has poor thermal insulation properties like high conductivity which means that most of the heat from solar radiation will pass through the roof. Thus, it is advised to use them in cold climates, but not in the warm humid climates.

Corrugated asbestos cement roofing sheets are another popular roofing material in high altitudes. The roofing sheets have sinusoidal corrugation and a thickness of 6mm and 8 mm. One of the main advantages of cement fibre sheets is low thermal conductivity and hence they are good for warm humid climates.

Burnt clay tiles have been used in Sri Lanka for centuries. It is most common. Since the raw material clay is available and since the burning technique was well known.

4.5 The computer simulations

The computer software used for the simulations is DEROB-LTH (Dynamic energy response of buildings) which is a versatile and user friendly tool developed by the Lund University. It is a MS Windows based flexible simulation tool. The results of computer simulations are useful only to predict the trends, since the climatic data are average values.

In this case, the computer software, DEROB-LTH was used to predict average indoor air temperatures for the required cases. It also can predict the operative temperatures as well. But, the operative temperatures and the average indoor air temperatures show the same trend. Thus, in this part of research, average indoor air temperatures were used to explain. The broad description about DEROB-LTH was presented in Chapter 3.

For the solar radiation, an approximate distribution calculated for DEROB-LTH based on the number of sunshine hours was used. Since the same solar radiation distribution is adopted for all the simulations, the effect on the trends predicted would not be significant due to any inaccuracy in the solar radiation values. The solar radiation values used are given in Charts 4.1, 4.2 and 4.3 shows the variation of solar radiation during typical day of each month (21st day of each month).

Chart 4.1 : The variation of Solar radiation in March

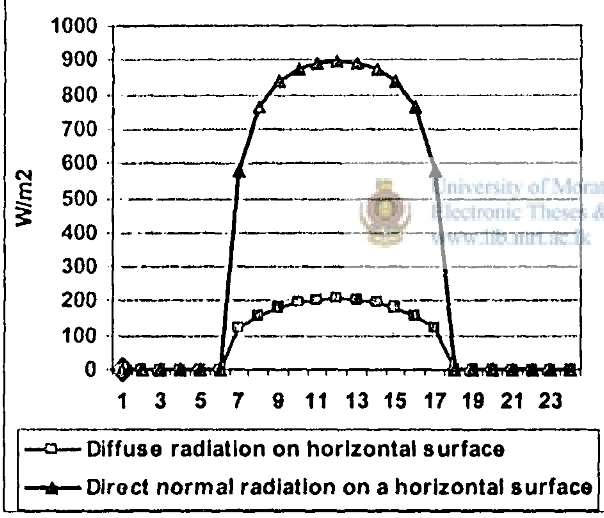


Chart 4.2: The variation of solar radiation in June

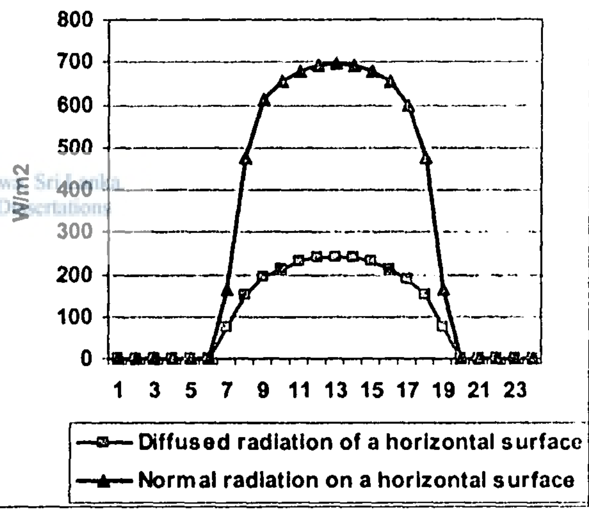
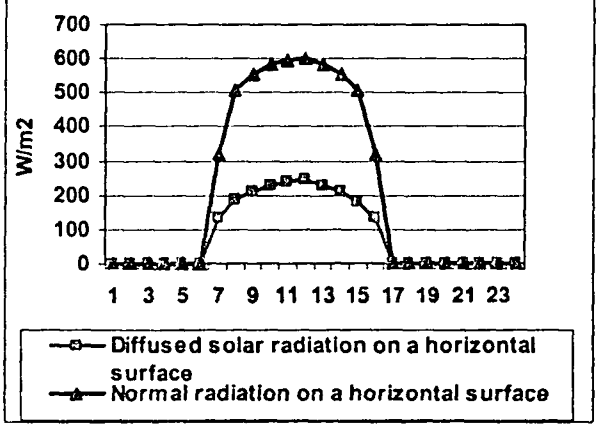


Chart 4.3: Variation of solar radiation in December



4.6 The model house used for simulations

The floor plan of the model house selected for simulations is given in Figure 4.2. It is also provided with openings facing either north or south only. This will minimise the direct solar rough the windows and hence will be useful in isolating the effect of the roof. The size of the openings is 1.2 x 1.2m (Building Regulations, 1985)

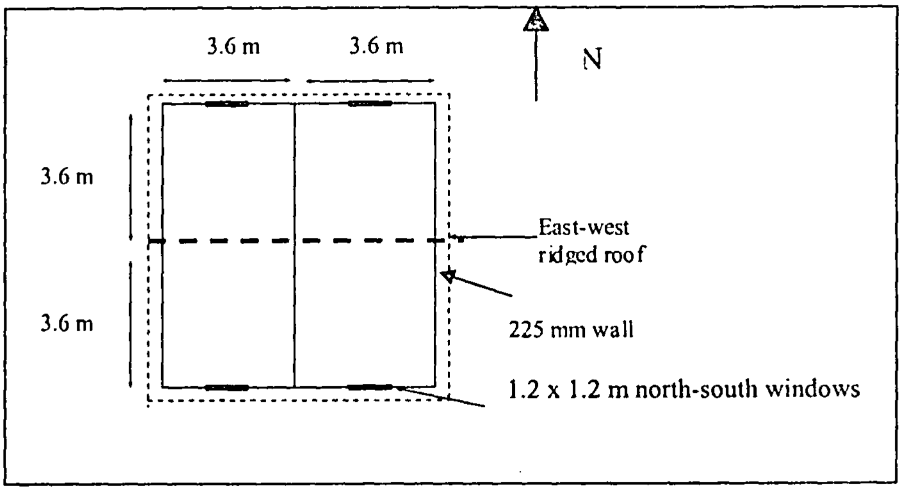


Figure 4.2: Floor plan of general case of the model house

These roofs were combined with two ceiling types that are commonly used in houses in Sri Lanka. They were flat and sloping cement fibre ceiling as shown in Figure 4.4. Number of air changes in the space between the flat ceiling and the roof is considered as 1 ach

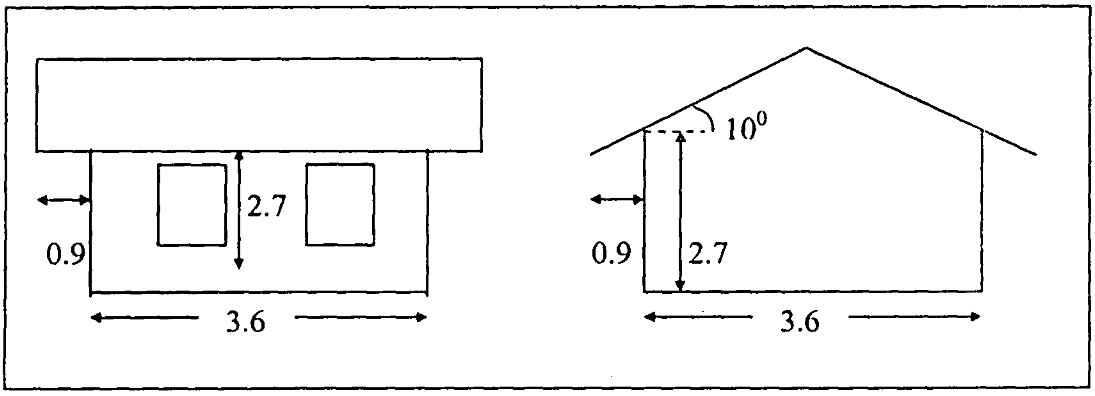
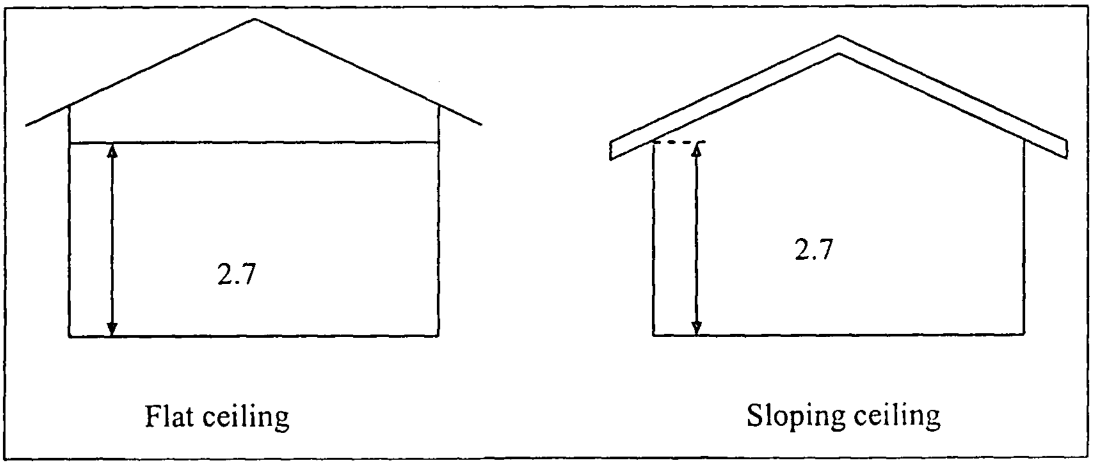


Figure 4.3: Front and side elevation of model house with east-west ridge roof

The climatic data given in Table 4.1 is applicable to Bandarawela. Using those data, simulations were conducted for three different months (June, December and March) to identify the effects throughout the year. In June, the sun is at a north most location and, in December, it is at a south most location. Towards the end of March and September, the sun is over the equator. However, March gives a greater fluctuation in the diurnal temperature. Hence, it was selected for simulations.



Dimensions in meters

Figure 4.4: Ceiling types used for simulations

Two roof orientations were selected for the simulations, (Figure 4.5). One Roof had its ridge along east-west while the other had its ridge along north-south.

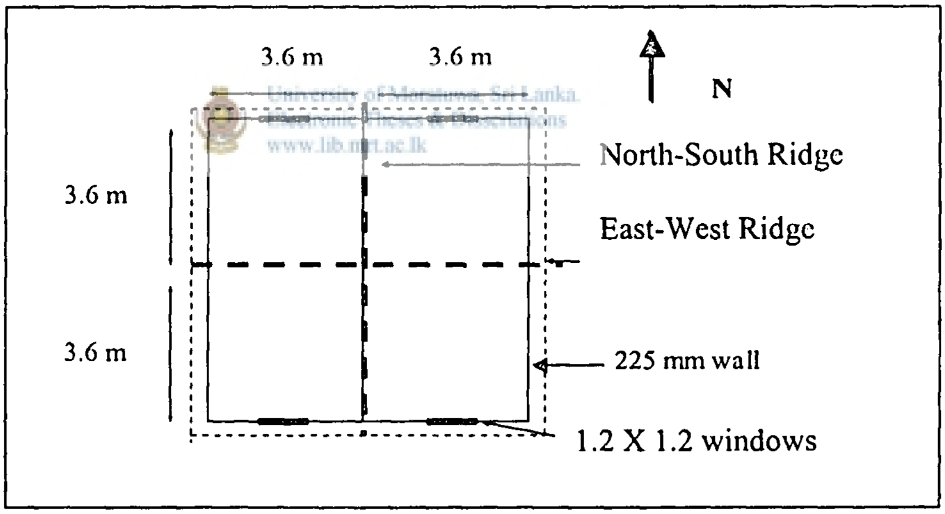


Figure 4.5: Roof Orientations

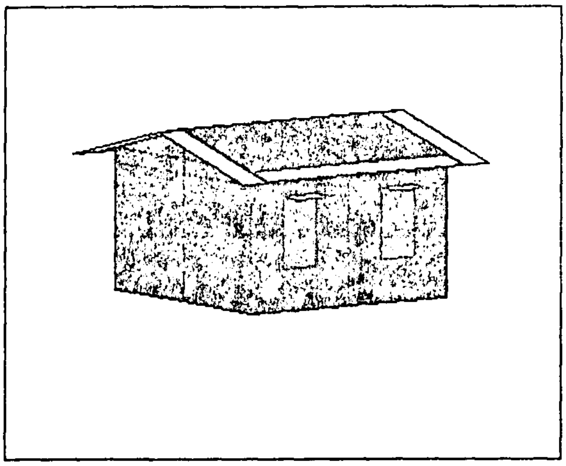


Figure 4.6: 3D view of the model house

Since the attention is on the thermal performance of the roof, the materials used for walls and the floors were kept the same for all simulations. The values of absorptance and the emittance used for the simulations are given in Tables 4.2a and b. They were obtained from Nayak et al. (1999).

Item	*Surface colour*	*Absorptance (%)*	*Emittance (%)*
Walls	Off-white	35	90
Floors	Red, green, brown etc.	70	90
Old Cement fibre sheets	Blackish grey of aged surface	70	95
Eaves	Same as the roof	Same as the roof	Same as the roof
Shading devices (overhangs)	Same as the roof	Same as the roof	Same as the roof

Table 4.2 a: Absorptance and emittance used for simulations of roof orientation

Roof materials data	***Surface colour***	***Absorptance (%)***	***Emittance (%)***
Old Cement fibre sheets	Dark colour	70	90
Burnt clay tiles	Light red	50	50
GI sheets-new	Metallic	55	25
GI sheets-painted	Dark colour	70	90
GI sheets-old	Dark colour	70	90

Table 4.2 b: Absorptance and emittance used for simulations of roof materials

4.6.1 Material properties used for the simulations

The important properties of the building materials used for the simulations are given in Table 4.3 and the constituent materials and the overall properties are given in Table 4.4 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

Table 4.3: Properties of the materials used for the simulations

	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
Cement fibre flat ceiling	6mm thick cement fibre sheets	0.027
GI roof-	1 mm GI sheets	0.000
Calicut tiles	20mm clay tiles	0.026

Table 4.4: Constituent material properties

4.7 Results and Analysis

The neutrality temperature is about 24°C in Bandarawela and hence the corresponding comfort zone can be presented as given in Figure 4.1. This indicates that indoor temperatures between 22°C to 26°C could be considered as thermally comfortable conditions for high altitudes of Sri Lanka.*

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* *For better explanation following code was introduced.*

NW-volume having northern-western external wall facing outdoor
NE - volume having northern-eastern external wall facing outdoor
SW- volume having southern-western external wall facing outdoor
SE - volume having southern-eastern external wall facing outdoor

For the example NW referred north-west volume in the house.

For the simulations, two roof orientations were considered. One type of roof orientation had the ridge along east-west direction. Other type had the ridge along the north-south direction. Two types of ceilings were introduced; cement fibre flat ceiling and cement fibre sloping ceiling, which is maintained to a slope of 10^0. For the base case, shaded openings on north and south were introduced. Numbers of air changes was controlled as given in Table 4.5. This simply represents the opened window situation, during the daytime and closed window situation, at all the other time.

	Air changes	
Time-Hour	*Rooms*	*Flat Ceiling*
1.00-11.00	1	1
11.00-18.00	3	1
19.00-24.00	1	1

Table 4.5: Number of air changes used

4.7.1 Effect of roof orientation

The results of the simulations for March, June and December are presented as the minimum and the maximum indoor temperature occurred in the eastern volumes in the ground floor. Chart 4.4 and 4.5 presents the maximum indoor temperature corresponding to hot discomfort for the months March, June and December for the sloping ceiling and flat ceilings. Asbestos sheets were used for roof and for the ceiling.

In general, since the sun is located above the equator during March , the performance of both volumes looks the same. Even though the sun is at a northmost location in June, the temperatures of the north facing volumes are not appreciably higher than those of southern volumes. Sun is at southmost location in December. But, the corresponding difference in December also quite insignificant. This is because the house is single storey, high amount of solar gains are transferred by cement fibre sheets, what ever the roof direction. Cement fibre sheets are very good heat transferring material which has low thermal capacity low time lag.

According to Chart 4.4 for sloping ceiling, it can be seen that, whether, the ridge is directed along the east-west or north-south, indoor maximum temperature lies around similar value. Thus, a significant effect cannot be seen. According to Chart 4.5, for flat ceiling, indoor maximum temperature does not show any significant difference for both roof orientations in March, June and December.

The main mean to heat transfer in to the roof is radiation. Small amount of conduction can be occurred through the air space. The solar incident angle is affected to the amount of direct solar radiation in to the house. Thus, with the change of ridge direction, the total solar radiation in to house can be changed. But, the results show the similar performance for the selected two ridge directions. Since the house is single storey the effect of the roof material is significant than the ridge direction.

Chart 4.4: Maximum temperature recorded during the December, June and March for the two types of ridges, Sloping ceiling

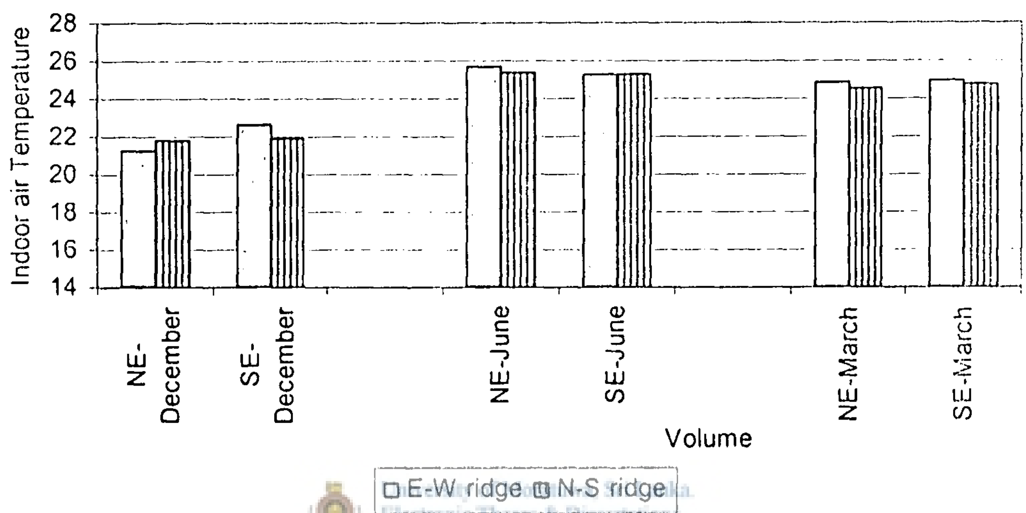


Chart 4.6 and 4.7 show the variation of indoor minimum temperature for east-west and north-south ridged roof cases for the months March, June and December, for the two types of ceilings.

Chart 4.6 says that the indoor minimum temperature for the month March, June and May cause for cold discomfort through out the year. According to Chart 4.6, the difference of indoor minimum temperature for two types of ceilings between northern and southern volumes for March, June and December is quite negligible for both roof cases.

According to the Chart 4.7, both ridge directions will not be able to avoid cold discomfort during the year. According to the above results, it can be said that orientation of roof along east-west or north-south has no significant effect on indoor minimum temperature. This is because the amount of solar radiation is less and relative humidity is high in the morning. Thus, cold discomfort may occur.

This finding talleys with the recommendation for tropical lowlands by Jayasinghe et al (2001). For tropical lowlands also, the orientation of the roof did not have a significant effect on the indoor thermal temperatures.

Chart 4.5: Maximum temperature recorded during the December, June and March for the two types of ridges, flat ceiling

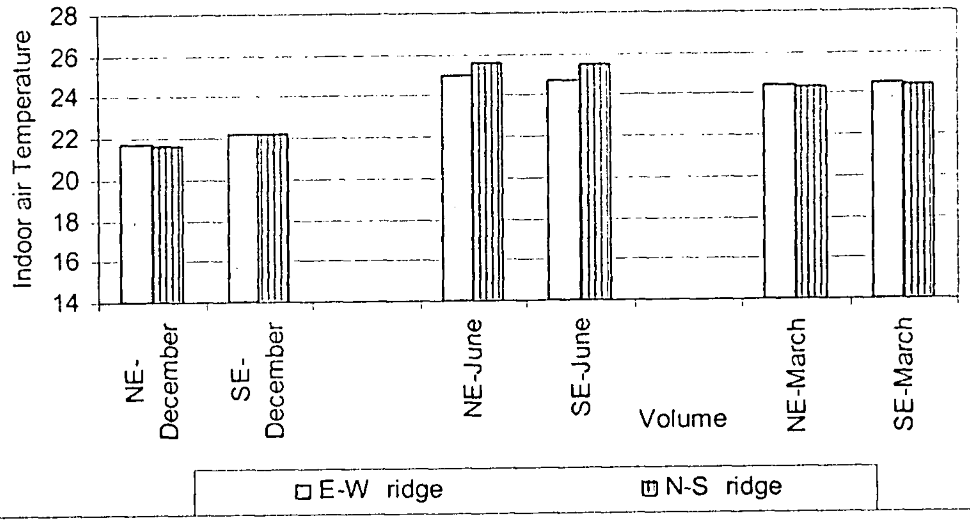
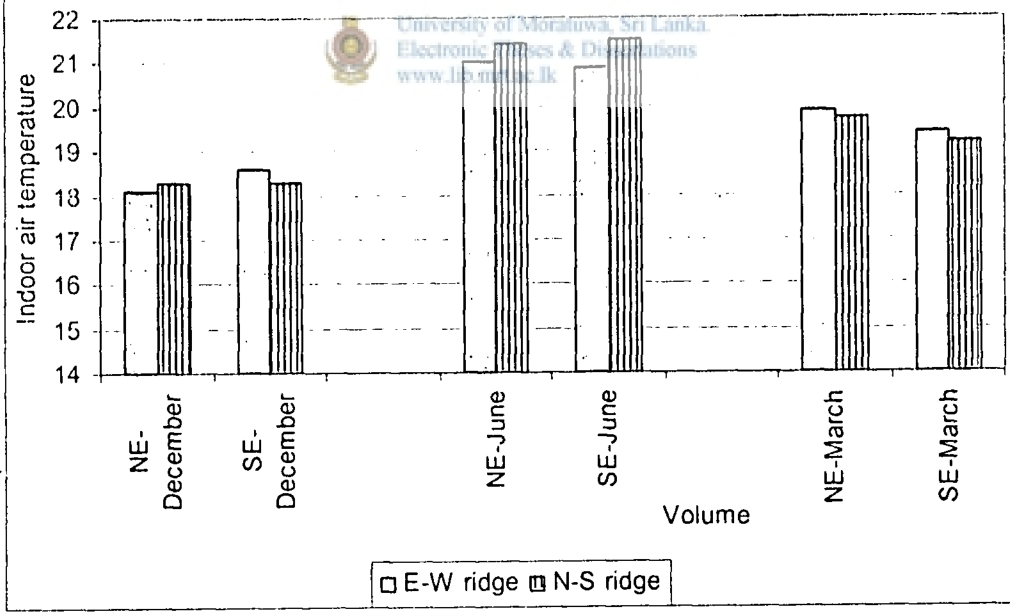
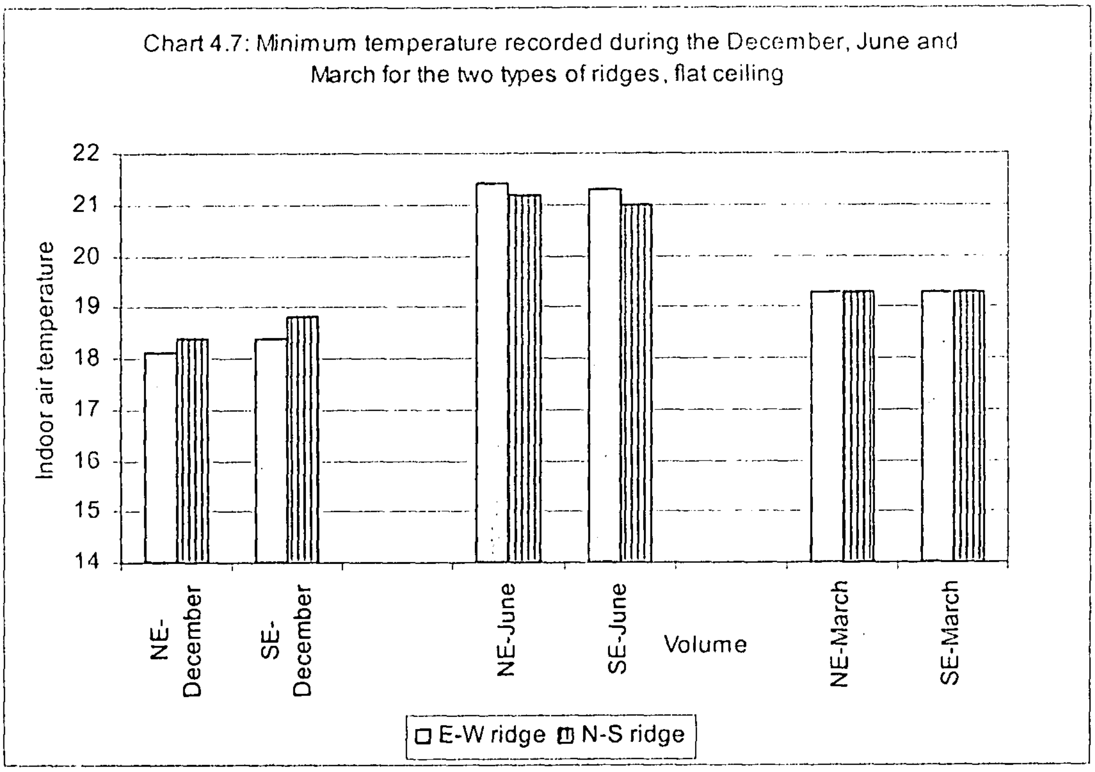


Chart 4.6: Minimum temperature recorded during the December, June and March for the two types of ridges, sloping ceiling





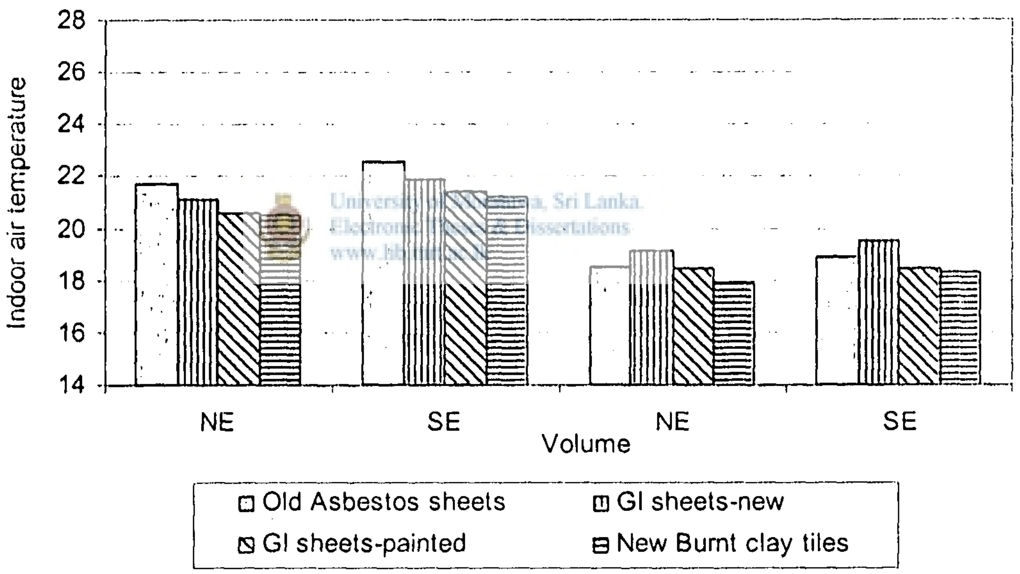
4.7.2 Effect of various types of roof materials

Materials	*Maximum and Minimum temperature recorded during the December*			
	NE	*SE*	*NE*	*SE*
Old Asbestos sheets	21.4	22.1	18	18.3
GI sheets-new	21.1	21.9	19.1	19.5
GI sheets-painted	20.6	21.4	18.4	18.4
New Burnt clay tiles	20.5	21.2	17.9	18.3

Table 4.6: Maximum and Minimum temperature recorded during the December

Table 4.6 shows the indoor maximum and minimum temperature recorded for December for the selected roofing materials. Chart 4.8 gives better graphical representation of the Table 4.6. This is because the various absoptances and emittances of the materials. If new GI sheets and GI painted sheets are compared, new sheets have less absoptance and very low emittance. This allows high solar radiation in to the house. But, when it is painted the absoptance and emttance both are high. Thus, amount of direct solar radition in to the house is lower than the earlier case. When old cement fibre sheets are also considered, the absoptance and emittances are high. GI sheets has low time lag than cement fibre sheets. Thus, solar radiation will be transferred into the house quickly. But when calicut tiles are considered, the high thermal capacity can be obtained. Thus, the heat transferred in to the house can be reduced. In addition to that the infiltration rate through calicut tiled roof is high. Thus there is a possibility of reducing the indoor temperature due to pressure variation.

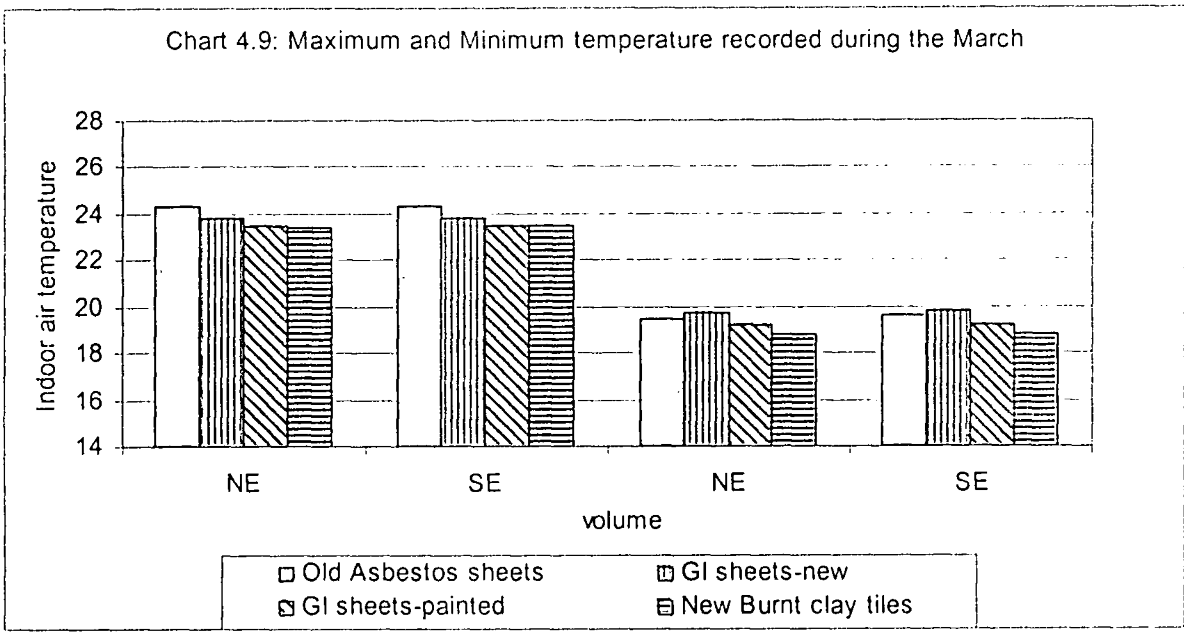
Charts 4.8 shows the results of indoor maximum and minimum temperature for various types of roofing materials for the month, December. According to Chart 4.8, it can be seen that indoor maximum temperature for all materials in all volumes does not lie in the suitable range. Hence cold discomfort is a critical problem. But according to the Chart 4.8, the possibility of occurrence of cold discomfort is comparatively less, when unpainted new GI sheets are used. This is because the property of low emittance and the low thermal capacity of GI sheets. Clay tiles allow infiltrations in to house. Thus, the indoor temperature can be reduced.



Materials	*Maximum and Minimum temperature recorded during the March*			
	NE	*SE*	*NE*	*SE*
Old Asbestos sheets	24.3	24.3	19.5	19.6
GI sheets-new	23.8	23.8	19.7	19.8
GI sheets-painted	23.5	23.5	19.2	19.2
New Burnt clay tiles	23.4	23.5	18.8	18.8

Table 4.7: Maximum and Minimum temperature recorded during the March

Table 4.7 presents the indoor maximum and minimum temperature recorded for March for the various roofing materials. Chart 4.9 gives better explanation of the results in Table 4.7.



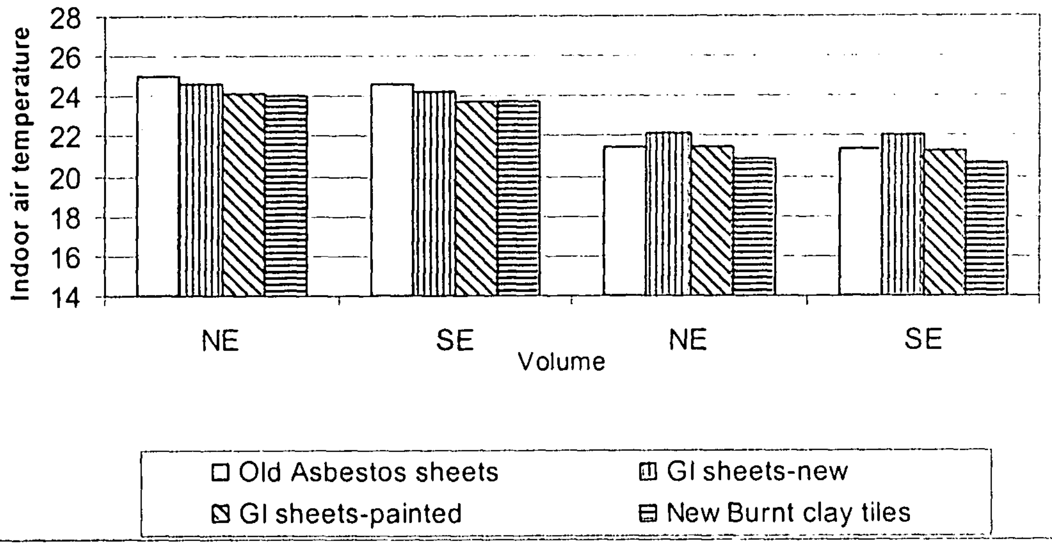
Materials	Maximum and Minimum temperature recorded during June			
	NE	*SE*	*NE*	*SE*
Old Asbestos sheets	25	24.6	21.4	21.3
GI sheets-new	24.6	24.2	22.1	22
GI sheets-painted	24.1	23.7	21.4	21.2
New Burnt clay tiles	24	23.7	20.9	20.7

Table 4.8: Maximum and Minimum temperature recorded during the June

Chart 4.9 shows similar results as shown by Chart 4.8. According to Chart 4.9, the indoor maximum temperature obtained for all the materials lie between the desirable ranges. Thus, hot discomfort may not occur throughout the year. But indoor minimum temperatures for all the materials do not lie in the desirable range. Specially, burnt clay tiles has a low thermal performances than the selected other materials in tropical uplands. Although, all the other materials give high indoor minimum temperatures than burnt clay tiles, they also do not lie in the desirable range. Hence cold discomfort may occur.

Table 4.8 presents the indoor maximum and minimum temperature recorded for June for the various roofing materials. Chart 4.10 gives better explanation of the data in the Table 4.8. The trends shown by the Chart 4.8 and Chart 4.9 can be seen here. According to Chart 4.10, it can be said that for all the materials the indoor maximum temperature lie between the desirable range, avoiding hot discomfort. According to Chart 4.10, when all the four materials are compared, burnt clay tiles give lower indoor minimum temperatures than the other materials. Calicut tile roof allows the infiltration in to the house.

Chart 4.10 Maximum and Minimum temperature recorder during the June



For new GI sheets and painted GI sheets, the possibility of occurrence of cold discomfort is comparatively less, compared to burnt clay tiles. Thermal capacity of GI sheets is low when compared to the calicut tiles. New GI sheets have low absoptances and very low emittance than painted GI sheets. Clay tiles allow infiltrating in to the house. Thus, when calicut tiles are used, indoor temperature could be reduced. But, with all the materials, cold discomfort is not completely removed. This is because the outdoor temperatures are fairly low in tropical uplands.

4.7.3 Effect of shading devices on indoor thermal comfort

To determine the effect of shading devices two cases were considered. They are no shadings with north-south ridged roof with flat ceiling and shadings with north-south ridged roof with flat ceiling cases can be compared. As the roof and ceiling material, asbestos sheets were used. The windows are provided only north and south. The openings were considered as opened (3 ach) during the daytime and closed (1 ach) at all the other time.

Chart 4.11 shows the results obtained for the above simulations for December, June and March. For flat ceiling, when shading devices are removed, the indoor maximum temperatures for North-south volume in December, June and March is quite similar for both cases. When shades are added the average indoor maximum temperature of the same volume is approximately the same. Thus, it could be stated that there is no significant effect of the availability of shadings on indoor maximum indoor temperature. Shadings generally cut off the direct solar radiation and the diffuse solar radiation. The main reason for this result could be attributed to the fact that the adverse effect of the roof is the governing factor in this case and, therefore, shading of properly oriented openings can cause only a marginal improvement.

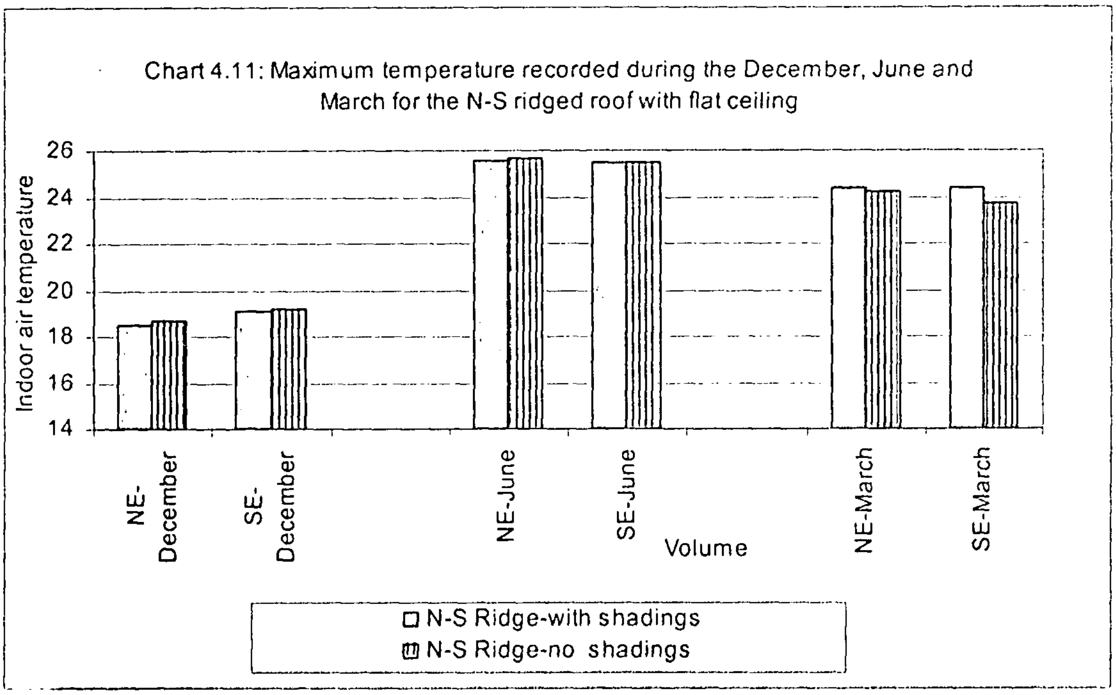
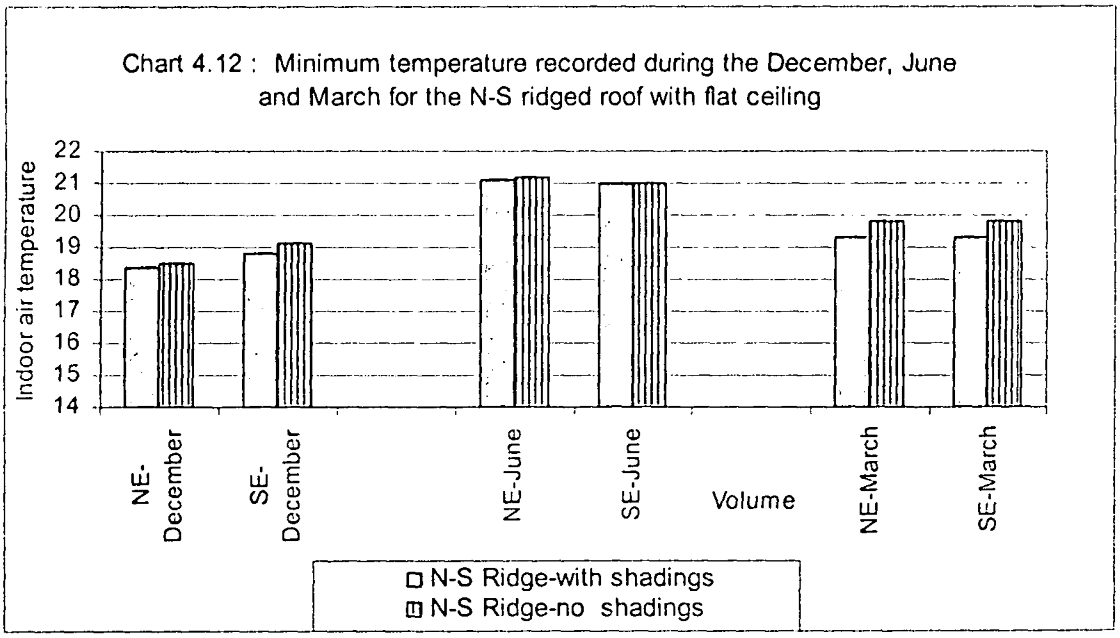


Chart 4.12 shows the indoor minimum temperatures for the same case. For the flat ceiling, when shades are allowed and when shades are not allowed, the reported indoor minimum temperatures lie around the same range. Thus, it could be stated that, there is no significant effect of shadings on indoor thermal comfort.



4.8 Conclusions

It is useful to investigate the effect of passive elements for the houses in high altitudes of Sri Lanka, specially to reduce the cold discomfort that generally occurs during the night. The findings of this study could be applied by the designers for their designs at the preliminary stage of work.

For the houses in tropical upland areas, there is no significant effect of roof orientation. It is a very important finding, because designers and house builders can use any ridge direction according to their preference.

Heat transfer through roofing materials is also an important factor to get a good thermal performance inside a house. The thermal performance for high altitude areas will gradually increase from burnt clay tiles, painted asbestos sheets, painted GI sheets and new GI sheets, respectively. For existing houses, as well as new houses, painting the asbestos roof surfaces with dark colours (for example, red, green, blue, brown etc) is desirable, as it would reduce the likelihood of cold discomfort occurring at night. According to the results obtained, the effects of shading devices are quite negligible.