CONCEPTS FOR DEVELOPING ENERGY EFFICIENT
PASSIVE HOUSES

M. T. R. Jayasinghe¹

Abstract

In order to realise the full potential of passive features for energy efficiency of houses, it is necessary to adopt site specific features that will take account of the effects of orientation, altitude above the mean sea level and micro-climate. It is shown with a case study for tropical low and uplands of Sri Lanka that the house layouts required could differ considerably when such site specific features are taken into account. The importance of using the details such as surface temperatures for isolating the effects of heat gains and losses rather than relying on average indoor temperatures or operative temperatures was also highlighted with examples.

Keywords: passive houses, energy efficiency

1. Introduction

For many countries not blessed with natural energy sources, energy conservation could be considered as an invisible resource. In most of the countries, the residential buildings consume about 25-35% of the total electrical power, and hence could be considered as an ideal candidate for energy conservation. The reduced usage will indirectly contribute to the preservation of environment while lowering the greenhouse gas emissions and also reducing the depletion rate of non-renewable energy sources.

Although the use of passive techniques have been well researched for many years, still the actual use of such strategies in housing sector has not been appreciable. This could be attributed to many reasons such as lack of knowledge among the general public who may prefer features that may lower the passive performance. Sometimes, it is not possible to achieve all the benefits of passive features even when the designers and owners are committed to passive houses when land is subdivided in an inappropriate manner. It also often happens that the majority of the passive houses are planned based on broad guidelines which may not capture the site specific features such as micro-climate, topography and altitude above the mean sea level.

One of the strategies for better adoption of passive strategies would be to develop location specific guidelines starting from the land sub-division that could supplement the broad guidelines generally known to the designers and clients. Such an approach could assist in developing architecturally pleasing energy efficient houses that could lead to minimization of total ownership cost. This paper presents such a study carried out for tropical climatic conditions prevailing in Sri Lanka with site specific variations that could be observed in lowlands and uplands. Sri Lanka is located between the north latitudes of 5°55' and 9° 51' and east longitudes of 79° and 82°.

¹ School of Civil Eng., Queensland Uni. of Technology, Brisbane, Australia, t.jayasinghe@qut.edu.au
2. Thermal comfort

Creation of “built environments” that are thermally comfortable to its occupants throughout the day, around the year is a challenge to the building designers. Thermal comfort, which is the sensation of complete physical and mental well being, is a subjective quantity that results from internal environmental variables such as dry bulb temperature, mean radiative temperature, humidity level and internal air velocity. It is also affected by the personal variables like activity and clothing levels of occupants.

![Figure 1: The comfort zone for tropical lowlands with modifications for higher air velocities [1]](image1)

![Figure 2: The comfort zone for tropical uplands](image2)
The thermally comfortable conditions could be presented as a “comfort zone” on a standard Psychrometric chart where the centre point is the neutrality temperature for a given climate. It also could be enlarged to take account of the effects of air velocity, specially for warm humid tropical climatic conditions. It was shown by Jayasinghe and Attalage [1] that the neutrality temperature for the tropical climatic conditions prevailing in Sri Lanka would be 26°C for low altitudes and 24°C for high altitudes (about 1500 m above mean sea level). This indicates that the comfort conditions for tropical lowlands and uplands could be somewhat different. The comfort zones could be drawn by using the recommendations of Sokolay [2]. Such comfort zones are presented in Figures 1 and 2, which also include some modifications suggested for tropical climates [1] to take account of acclimatization of the people [3]. Figure 1 also gives the enlarged comfort zones when the enhanced air movement is present.

3. Main passive guidelines for houses in tropical climates

Tropical climatic conditions generally prevail from 15° to -15° latitude from the equator. Due to the tilt in the earth’s axis, the sun path could take either a southern or northern direction depending on the time of the year. Therefore, it is a challenging task to achieve sufficient thermal comfort with passive means. The houses are generally constructed with clay bricks, cement stabilised soil blocks or cement sand blocks with external wall thicknesses varying from 100 - 240 mm and hence could be considered to have high thermal capacities. The broad passive guidelines for a house in lowlands of Sri Lanka could be considered as the following [4]:

1. It is advisable to place most of the openings either facing north or south since those openings could be shaded from direct solar radiation.
2. It is better to avoid large openings facing west since those would allow plenty of direct solar radiation when the outdoors are also warm, thus leading to overheating.
3. The roof area should be minimised to reduce the solar gains. Thus, either two or three storey houses could be better than single storey.
4. The use of insulating materials for roof is highly desirable.
5. The walls could be painted with light colours.

These broad guidelines are generally applicable to tropical uplands as well and hence the modern houses planned for both lowlands and uplands looks alike. However, the consideration of site specific features could result in quite different layouts for these houses as revealed in a case study carried out using detailed computer simulations for Sri Lanka.

4. The case study

For the case study, a special two storey house consisting of eight volumes as shown in Figure 3 was selected. This will allow distinguishing between the thermal performance of ground and upper floors and also the different orientations.
**Figure 3: The ground and upper floor plans of the house**

### 4.1 The simulation tool used

For the determination of thermal performance, a versatile computer software called DEROB – LTH [5] was used. It was originally developed at the Numerical Simulation Laboratory, School of Architecture, University of Texas. Later, it was further enhanced at the Department of Building Science, Lund Institute of Technology (LTH), Sweden.

DEROB-LTH facilitates the creation of models of actual buildings with a relatively high level of accuracy. It handles energy transmission across the building envelope by taking account of thermal properties of building materials. In addition to the thermal loads from direct and diffused solar radiation, it considers solar radiation reflected from the ground and shading devices. It not only takes account of infiltration and forced ventilation, but also static pressure driven air exchanges between volumes that occur across openings at different levels (advection connection). This programme was validated for tropical conditions prevailing in Sri Lanka with actual measurements [6].

### 4.2 The simulation model

The simulations were carried out using the 3D model shown in Figure 4. For the climatic data, the average values for March were selected. For tropical lowlands, March is the warmest month with lease rainfall. Thus, maintaining sufficiently low temperatures within the indoors will be a challenging task. For tropical uplands, March gives a substantial diurnal variation in the temperature, and hence could lead to quite low temperatures during night and overheating during the daytime. The climatic data pertaining to three months for both uplands and lowlands are given in Table 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean daily temperature °C</th>
<th>Mean daily humidity (%)</th>
<th>No of sun shine hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td>March</td>
<td>23.3 (14.5)</td>
<td>31.0 (25.5)</td>
<td>87.2 (95)</td>
</tr>
<tr>
<td>June</td>
<td>25.2 (17.0)</td>
<td>29.6 (25.8)</td>
<td>86.2 (95)</td>
</tr>
<tr>
<td>December</td>
<td>22.4 (15.3)</td>
<td>29.8 (22.5)</td>
<td>88.7 (96)</td>
</tr>
</tbody>
</table>
For the model, a loadbearing brickwork house with desirable passive features is selected, which is representative of the construction techniques generally used in Sri Lanka. The thickness of all the external walls was 230 mm inclusive of 15 mm plaster on either side. The same walls have been used at the ground floor for partitioning. The internal walls were 130 mm thick with 15 mm plaster on either side at the upper floor. The slabs were reinforced concrete. The roofs were cement fibre sheets below which 50 mm thick mineral wool insulations was provided. Generally, more insulation is not desirable since it could impair the night time cooling in low altitudes and daytime rise in temperature at high altitudes. It is provided with a 6 mm thick timber sloping ceiling with a 100 mm air gap below the insulating materials. The ground floor is provided with a concrete slab and tiled finish. The thermal properties were obtained from Nayak et al. [7]. The walls are painted with light colours (an absorptance of 40%). The roof had an absorptance of 60% as for cement fibre sheets.

4.3 The results of simulations
Since the temperatures were of similar magnitude, only two volumes were considered for the presentation of results. Those were Volume 3 on the ground floor and Volume 7 on the upper floor, both facing south. The results of the simulations are presented in graphical form in Charts 1 and 2. These charts give the following:

- the outdoor temperature
- the average indoor temperatures for Volumes 3 and 7
- the surface temperatures of floor and slabs for Volume 3
- the surface temperatures of floor slab and the underside of the roof (ceiling) for the upper floor Volume 7
- the operative temperatures for Volumes 3 and 7

The operative temperature is generally considered as a better indication of the ability of the surrounding surfaces to emit long wave radiation. This is calculated as half the indoor temperature added to half the average value of all the indoor surface temperatures for a given volume.
Chart 1: Variation of indoor and surface temperatures for tropical lowlands

Chart 2: Variation of indoor and surface temperature for tropical uplands
In order to isolate the most important effects, minimum and maximum temperatures are also presented in Tables 2 and 3.

### Table 2: The temperatures for volumes and surfaces in tropical lowlands

<table>
<thead>
<tr>
<th>Temperature in Centigrade</th>
<th>Outdoor temperature</th>
<th>Volume 3 surface tem.</th>
<th>Volume 7 surface tem.</th>
<th>Operative temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vol 3 Vol 7 Floor Slab Floor Roof Vol 3 Vol 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>23.3 27.3 27.3 28.2 28.3 27.2 27.6 27.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>31.0 29.0 29.9 28.8 28.9 29.5 31.7 28.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: The temperatures for volumes and surfaces in tropical uplands

<table>
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<th>Temperature in Centigrade</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>14.5 20.6 20.6 21.5 21.8 21.6 20.3 20.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>25.5 22.7 23.4 22.1 22.3 22.8 25.3 22.5</td>
<td></td>
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</tbody>
</table>

### 5. Analysis of results

The results given in Section 4 are analysed for tropical lowlands and uplands separately.

#### 5.1 Tropical lowlands

The results for tropical lowlands indicate that as far as the indoor average temperatures are concerned, there is only a marginal difference between the upper floor and ground floor rooms of a two storey house (maximum of 29°C for Vol. 3 and 29.9°C for Vol. 7). Thus, either a single or two storey house could be planned without much difference for tropical lowlands. However, this could be contradicted as soon as more detailed results such as inner surface temperatures are concerned. For example, Vol. 3 has floor and slab (ceiling) maximum temperatures of 28.8 and 28.9°C, respectively. For Vol. 7, floor is 29.5°C and roof (ceiling) is 31.7°C. This indicates that a person in the upper floor would be affected by the long wave radiation emitted by underside of the roof (ceiling), although the indoor average is at a generally acceptable value of 29.9°C as indicated by Psychrometric chart given in Figure 1. Thus, the study of surface temperatures would give a different conclusion which indicates that in tropical lowlands, better thermal comfort could be provided at the sheltered floors than directly under the roof.

Therefore, it would be advisable to minimise the roof area by using either two or three storey houses where the occupants could use the sheltered floors during the daytime for better thermal comfort. If the building materials used permits the construction of three storey houses economically, those could provide not only two sheltered floors, but also a reduction in the plot coverage hence saving more land for vegetation.

These conclusions are drawn by considering detailed results such as surface temperatures. However, it is difficult to come to such a conclusion even by considering the operative temperatures that takes account of the temperatures of the surrounding surfaces in addition to the average indoor temperature. An occupant in the upper floor, who would be either seated or sleeping, could be affected more by the
direct solar radiation emitted by the roof than the walls. The consideration of average values as in operative temperatures will hide such effects.

5.2 Tropical uplands
For tropical uplands, the average indoor (maximum for Vol. 3 = 22.7°C and Vol. 7 = 23.4°C) or operative temperatures would indicate either single or two storey houses would perform almost the same. However, again a closer look at the surface temperatures will reveal a completely different situation. For the upper floor Vol. 7, the roof surface temperature rises far above the other surfaces to 25.3°C. This will be ideal during the daytime since occupants would be benefited by the radiation emitted by the roof to achieve warmer conditions.

However, during the night, the roof of Vol. 7 will record a lower temperature (20.3°C) than the slab in Vol. 3 (21.8°C). This means, the occupants will loose more heat from their bodies in the upper floor than the ground floor and hence could feel cold discomfort. Thus, the ground floor sheltered volumes would be better suited for bedrooms than the upper floor. This will need a compromising solution in which the modern houses could be planned only with part as two storeyed, with bedrooms located one on top of the other. The other areas like living, dining and pantry could be located in the single storey part since those would not be generally occupied during the night. This allows a lot of flexibility for the occupants to respond to the considerable diurnal variations in temperatures with minimum thermal discomfort since there would be at least some areas which would provide better thermal comfort at any time of the day.

6. Other benefits of site specific planning
Once these conceptual houses are adopted, the land saved due to multi-storey construction could be used for creating a desirable micro-climate. It is shown by Shashua-Bar and Hoffman [8] that in warm climatic conditions, plenty of trees could lower the temperature by about 0.5 to 1 °C or more in some cases. Large amount of trees scattered over an area could have a greater effect on the immediate vicinity than having a nearby large park with many trees [9]. This could be promoted with multi-storey concept. The drop in temperature associated with trees will be extremely beneficial in providing even better conditions for thermal comfort especially in sheltered volumes. This is because those would have hardly any heated bodies that will emit long wave radiation affecting the occupants. Higher density of trees also could assist in achieving a net reduction of CO₂ emissions in large housing schemes.

In tropical climatic conditions, it is usual to experience quite heavy rainfall. The extensive coverage of land by roofs could thus reduce the infiltration while considerably increasing the surface runoffs. This is a highly undesirable situation since the development of land at a certain location could cause flash floods in the surrounding areas of lower elevation which were quite safe prior to the development activities. The lower roof coverage of multi-storey construction could reduce the quantity of water collected while the extra bare land could improve the infiltration of water. The extra land saved could also allow the creation of rainwater detention ponds within each block.
In tropical uplands, it is difficult to find flat lands for house construction. In such areas, the minimization of lot coverage achieved with proposed single and two-storey house combination could reduce environmentally undesirable cut and fill operations.

7. Conclusions

It is shown with detailed computer simulations that passive houses planned on broad passive guidelines could be modified to yield better thermal performance by considering site specific features such as altitude above mean sea level and micro-climatic effects. The effective use of surface temperatures instead of average indoor or operative temperatures to predict the effect of indoor environment on the occupants was highlighted with examples. The conceptual houses suitable for tropical lowlands and uplands have been suggested based on such detailed results.

References


