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CONCEPTS FOR SUSTAINABLE RESIDENTIAL DEVELOPMENTS FOR URBAN AND SUBURBAN AREAS IN SRI LANKA

by

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Abstract:

In Sri Lanka, the worsening problem of land scarcity due to urbanization has led to higher temperatures in the urban centers along with the reduction of the green cover. Consequently, the energy consumed to inhibit the thermal discomfort experienced in built environments is on the rise, which is not a desirable development due to the limited energy options available for Sri Lanka. This paper focuses on the domestic sector, with a view to formulate concepts for sustainable residential developments for Sri Lanka taking environmentally-friendly passive techniques as the basis. It is shown qualitatively that, to reap the maximum benefits of passive techniques, the three-storey house should be preferred to the single or the two-storey house; this will also maximize the effective use of expensive urban land. It is also shown that passive housing developments require an integrated approach from the beginning, i.e. in the stages of land subdivision and selection of the orientation of the access roads. By making special provision for vegetation within the plots as well as along the roads, it is proposed to create a microclimate desirable to thermal comfort. Employing a questionnaire survey and examples applicable to Sri Lanka, various aspects of thermal comfort, visual comfort, flash floods, functionality and construction cost are discussed. It is finally emphasized that, for best results, a collective effort by an entire neighborhood is vital.

1.0 Introduction

In Sri Lanka, people are steadily moving towards urban and suburban regions for settlement. As a result, the land available for housing in such regions is becoming scarce and expensive. This problem has reached crisis proportions in many parts of the world, particularly in Asia and Africa, where the urbanization is fastest (Grundstrom et al., 1999). The solution adopted for the immediate problem of diminishing urban land is two fold; slums for the underprivileged and highrise residential buildings for the others. Although the latter seems to be a good solution, it has failed in many countries due to various adverse effects such as cultural and social problems related to the congested life. In Sri Lanka, the adverse effects of the apartment life is not so evident as it is fairly new. Unless planned very carefully, air-conditioning and constant maintenance is imperative in such buildings.

In recent times, it is often reported that urban and suburban areas are becoming warmer due to changes in microclimate resulting from the thermal inertia of man-made structures, diminishing green cover and global warming. To inhibit the resulting thermal discomfort indoors, the occupants of both single unit houses and apartments are resorting to active techniques such as mechanical ventilation and air-conditioning. According to a questionnaire survey conducted under this study, 73.7% of those surveyed reveal that at least two fans are usually used in their houses. Most of the luxury apartments recently built in and around Colombo depend on air conditioning. According to Takakura et al. (2000), air-conditioning of buildings may create a vicious cycle. The waste heat from air-conditioning units drives up the city temperature, which in turn requires larger cooling loads for buildings. Another reason for increased use of energy for thermal comfort is rapid urbanization, which paves the way for greater social and economic changes, such as economic growth, which in turn demands better living standards, resulting in higher energy use for cooling of buildings (Grundstrom et al. 1999).

Although the electrical energy demand of Sri Lanka is increasing around 10.8% per annum (Statistical Digest, 1999), a corresponding increase in the capacity is unlikely in both hydropower and thermal power, which are the two main sources of electricity generation in Sri Lanka. In 1999, hydropower accounted for 68.6%, ther-

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mal power 31.3% and wind power 0.1%. Hydropower has already reached its economical potential; of the total estimated hydropower potential of 2000MW (Kariyawasam, 1999), around 1200MW has already been harnessed (Fernando & Ratnasiri, 1997). Attempts to develop new projects either may not be economical or may have adverse effects on the environment. Generation of thermal power depends on fossil fuels, which are non-renewable. The reserves around the world are consumed fast; for example, oil is estimated to last for another 50 years, coal much longer, but not for ever. Therefore, in the future, the world market prices can be expected to rise; being an importer of fossil fuels, Sri Lanka will have virtually no control over the price. Besides, power generation using petroleum, as is the case at present in Sri Lanka, can be the most expensive of all fossil fuel types. The increased concern of the public for the environment is another factor that will decelerate or even halt attempts to develop new power plants. The staunch opposition to two proposed projects, namely Upper Kotmale hydropower project and Norochcholai coal power project, reflects this development. Therefore, an adequate increase in the supply to meet the rising demand for electricity is unlikely; the price of electricity can be expected to rise in the future.

Sri Lanka is blessed with a desirable climate. Even in the early afternoon, the outdoor environment under a shady tree is thermally comfortable. Therefore, the strategy should be to extract the maximum benefits of the desirable outdoor climate to achieve thermal comfort indoors, while maximising the use of the scarce urban and suburban land. This is possible by way of passive houses. The significant benefit of the passive house is the reduction of the operating cost, by saving electricity that would otherwise be spent for inhibiting thermal discomfort. The tariff structure of the Ceylon Electricity Board will further reduce the bill as the unit rate increases with the usage. The benefits of passive houses at the national level, though not as significant as those at the user level, can be magnified if a significant slice of the population adopts them.

This paper presents a number of concepts that can be useful in developing a sustainable residential development policy for the urban and suburban regions of Sri Lanka. It is shown that three storey single unit houses can make better use of passive concepts, when compared with equivalent single or two storey houses. It is also shown that the improved passive performance of houses in a given neighborhood will need an overall approach, which takes account of the land subdivision, orientation of access roads, minimisation of land used for access roads while maximising the green cover. The discussion in this paper is focused on various aspects of thermal comfort, visual comfort, flash floods, functionality, structural form and construction costs.

2.0 Objectives

The main objectives of the research presented in this paper can be highlighted as:

1. to identify the current thermal comfort problems in Sri Lankan houses and the measures adopted by occupants to alleviate them.
2. to identify the passive concepts that can be used for planning of houses that could allow savings in energy spent for thermal comfort.
3. to determine the methods of incorporating them in future houses.
4. to evaluate the other benefits of actively promoting passive houses.

3.0 Methodology

In order to achieve the above objectives, the following methodology was used:

1. Carrying out a questionnaire survey among a predominantly employed group of 179 adults resident in the Western Province, Galle or Matara district.
2. Evaluation of the strategies that can be used in passive houses constructed in warm humid climatic conditions prevailing in Sri Lanka.
3. Carrying out a detailed study to determine the most effective ways of incorporating the above strategies for new houses in the future.
4. Development of concepts for land sub-division and planning of houses to maximise the beneficial effects of passive techniques.
5. Evaluation of the other beneficial effects of such concepts, with suitable case studies.

4.0 Thermal comfort

One of the primary objectives of the building designer should be to ensure that the built environment is thermally comfortable to its occupants, possibly throughout the day and round the year. According to Mathews et al. (1992), this should receive sufficient attention from the very beginning as a good thermal design is started during the sketch design stage.

Thermal comfort is a sensation of complete physical and mental well being; it is a subjective quantity resulting from internal environmental variables such as dry bulb temperature, mean radiative temperature, humidity and air velocity. It is also affected by personal variables such as activity level and clothing level of the occupants. The thermally comfortable conditions for Sri Lankans involved in sedentary activities such as desk work can be presented as shown in Figure 1 for various internal air velocities (Jayasinghe & Attalage, 1999a). It can be seen that Sri Lankan's can be thermally comfortable at elevated temperatures like 30°C, when sufficient air movement is available.

In order to determine the present conditions in the existing houses and to develop passive strategies to enhance these conditions, a questionnaire survey was carried out among 179 adults. The questionnaire survey form is given in Appendix A. The summary of the results of questionnaire survey is given in Appendix B.

According to the questionnaire survey, the current situation in houses is not satisfactory, and the majority resort to active techniques to inhibit the thermal discomfort experienced. For example, 54.7% admit that at least one room of their house is sometimes too warm to be comfortable even when all its windows are open. Of them, 86.7% switch on a fan; 19.4% leave the roofn. Some of them resort to either of these options. Thus there is a need to develop better concepts for future houses.

5.0 Strategy for passive built environments

In low altitudes of Sri Lanka (i.e. below 300m), where the climate is warm and humid, the designers should aim to minimise the *heat gains* while maximising the *natural ventilation* and *structural cooling* (Jayasinghe & Attalage, 1999b). In this region, distinct seasonal changes do not occur, and the general requirement throughout the year is cooling. The external gains occur through the building envelope; the internal gains are generated indoors. The strategy should be to resist radiant and conductive heat gains and to minimise internal heat gains. Natural ventilation is very important for the warm humid climatic conditions prevailing in Sri Lanka. It promotes conduction-convection heat loss from the human body, evaporation of skin moisture from the human body (i.e. physiological cooling effect), and night time cooling and structural cooling, which allows a cooler structure at the beginning of the day. Since all these strategies are important for developing appropriate concepts for passive houses, they are considered in detail.

5.1 Minimisation of heat gains

The roof, the external walls and the external windows of a building contribute to the external heat gains to different extents depending on the materials used and the orientation. A comparison of materials can be done by using the overall thermal conductance and time lag. Overall thermal conductance is generally called the U value. The time lag represents the delay that a certain material can cause for the heat transfer. These values are compared in Table 1.

Table 1: Thermal properties of various elements in a house (Szokolay, 1991)

Element	Material	U value (W/m2K)	Time lag (hours)
Roof	Asbestos	4.9	0.0
External wall	Brickwork with plaster (225m)	2.2	6.5
Window	Wood framed plane glass	4.3	0.0

As Table 1 shows, the roof and the windows can be quite weak against absorbed solar radiation and conduction since they allow almost instantaneous heat transmittance. Since roof is exposed to direct sunlight due to its upward orientation throughout the year, its minimisation is highly desirable. A thermal survey conducted in a three-storey hostel building has shown that the most desirable level is the first floor, probably because it is sheltered from the second floor and the effect of the ground reflected radiation is negligible. This indicates that a multi-storey house can be preferred instead of a single storey house of the same floor area, since it can have lesser roof area. However, of those surveyed, 69.3% lives in single-storey houses.

The walls, on the other hand, can give a considerable time lag, which can be particularly helpful not only in delaying, but also in reducing the total heat flow into a building. For windows on north or south facing walls, direct solar gains can be reduced by using overhang type shading devices. It was shown by Jayasinghe & Attalage (1999b) with the aid of cylindrical sun charts developed for Sri Lanka that an overhang, which makes an angle of about 60o with the horizontal as shown in Figure 2, can provide adequate shading throughout the year. However, overhangs are not so effective on east facing windows. They can be almost useless on windows facing west, because such windows can allow a large amount of direct solar radiation as the sun sets irrespective of the presence of shading devices. It is also important to have light colours for overhangs. A dark overhang can absorb heat and then in turn emit infrared radiation into the building through the open window, which is now protected from direct solar radiation. Since shading devices are less effective on east and west facing openings, strategically located trees or nearby houses could be used to protect such windows.

The prevailing situation with respect to shading of windows is not satisfactory. Only 8.4% have overhangs for windows; 24.6% have trees as shades for windows. Tinted glass account for 10.6%; however, it demotes visual comfort, resulting in the use of artificial lighting during daytime. The majority (75.4%) claim that they employ curtains to reduce heat gains; however, curtains cannot intercept sunlight although they can be used as a remedy to excessive glare. In this question of the questionnaire, more than one choice could be selected by a particular subject.

The diffused and ground reflected radiation are the other two components of solar radiation. Unlike direct solar radiation, controlling the gains due to these is difficult. However, the intensities of these are comparatively lower. To mitigate adverse effects, unshaded artificial surfaces such as paved areas and roads should be avoided in the proximity of the house as much as possible and vegetation should be promoted instead (Watson & Labs, 1983). A concrete surface reflects about 25-35% of incident solar radiation, a grass surface, only 10-15% (Mohan, 1989). According to Watson & Labs (1983), an irregular or rough surface of shrubbery can further reduce the ground reflected component.

The colour of the external fabric also plays an important role in determining the extent of the heat gained through the walls. According to Bansal et al. (1992), the colour of the outside surface of a building envelope is expected to influence the thermal performance of a building significantly as it determines the amount of absorbed solar radiation, and therefore, its inward transmission into the building. In this respect the existing situation is satisfactory; 69.3% have light colour exterior surfaces (i.e. white to yellow) in their houses.

The thermal comfort indoors can be improved by lowering the outdoor air temperature by using trees. By evapotranspiration, vegetation can convert large amounts of solar radiation into latent heat, which does not cause the air temperature to rise (Takakura et al., 2000). Thus, by way of strategically located vegetation around a house, a more desirable microclimate can be achieved. The lack of evapotranspiration surface can be a reason for the temperature in big cities to be higher than those of rural vicinities. Although 91.0% of those surveyed own gardens, only 63.8% of them grow vegetables or fruit.

When planting trees, priority should be given to fruit trees, which will not only provide food for the occupants but also promote bird life, leading to a better environment. When selecting the type of trees, the nature of the root zone is important. Because of its high nutritious value, guava (Psidium guajava) is a useful tree for the garden. It is a shallow-rooted shrub, growing up to 3 to 10 m in height. Another shallow rooted tree is avocado (Persea Americana). Various citrus types though useful have lateral roots growing horizontally. Moreover, mango (Mangifera indica) and breadfruit (Artocarpus altilis) have adventurous roots with a dense surface mass of feeding roots (Purseglove, 1988). They should be planted in the back garden away from the house as much as possible to prevent damage to the foundation of the house. This is difficult specially when the plot extent is small and the house has a horizontally spread plan as in the case of a single-storey house.

Adjacent buildings also can play a vital role in reducing the solar gains. The thermal measurements taken in Medina, Morocco, have indicated that this town is cooler than the surrounding country side (Grundstrom, et al., 1999). The principle of this "reversal" is that the buildings are located so close to each other in Medina that very little solar radiation reaches down to the street level. This indicates that even man-made surfaces could be useful if strategically placed with appropriate orientation.

Visual comfort can be promoted by increasing the amount of diffused radiation entering a room across its windows (Neeman, 1977). By employing light colour indoor surfaces, the diffuse radiation that enters a room can be made to scatter, enhancing the visual comfort indoors. As far as walls are concerned, the current situation is satisfactory; 72.1% have light colour internal surfaces. However, only 10.1% have light colour floor surfaces as can be expected due to cleaning difficulties.

Use of electric bulbs is a contributory factor to internal heat gains. This is unavoidable at night. However, 30.7% say that at least one room of their house is gloomy during daytime even when all its windows are open. Of them 90.9% resort to artificial lighting if they have work to do there. Skylights may be undesirable because they give access to direct solar radiation, which not only contributes to thermal discomfort but also is not so effective in promoting visual comfort. However, 20.1% have skylights in their houses.

5.2 Maximisation of ventilation

An effective distribution of fresh air within an occupied space is of considerable importance in securing thermal comfort and good indoor air quality. A well designed natural ventilation system is not only energy efficient, but also provides a healthy indoor environment (Gan, 2000). The importance of maintaining adequate ventilation with a sufficient air velocity can be seen from Figure 1. Up to an indoor temperature of around 30oC, as the air velocity increases, the comfort zone becomes larger, capturing more points on the psychrometric chart. However, beyond 1.5m/s, discomfort may be experienced due to excessive air movement. The survey reveals that mechanical ventilation is extensively used in houses, most probably due to poor natural ventilation indoors; 72.7% claim that at least two fans are usually used in their houses.

For improved cross ventilation, the inlet should face the general wind direction. It is stated by Watson & Labs (1983) that cross ventilation can be improved further by locating both the inlet and outlet on exterior walls. For single storey houses, this is not easy to achieve as indicated in Figure 3. However, in an equivalent multi-storey house, more rooms will be able to have exterior walls thus allowing more openings on them as indicated in Figures 4 and 5. Single storey houses constructed close to each other suffer because the breeze tends to blow over them (Mohan, 1989). On the other hand, a multi-storey house can act as a barrier to wind, effectively increasing the surface air pressure, which will force air through the building. This can be further improved by having a recess for the windward face of the building to trap more wind.

Cool outdoor air at night can be employed to flush out the warm indoor air. However, the survey reveals that, even when the night is hot, 57.5% do not keep the bedroom windows open; 21.8% keep them open until late night. The concern of the former is security (85.4%), followed by mosquito menace (44.7%) and privacy (15.5%). Some people have more than one reason as the percentages indicate. In a multi-storey house, bedrooms can be located upstairs, alleviating security and privacy concerns. As a solution to the mosquito menace, nets can be used to protect the open windows.

In both single and multi-storey houses, the courtyard can enhance natural ventilation. A multi-storey houses can offer better use of the courtyard since the same courtyard can be shared at different levels (Figure 6). The courtyard is of particular use since the windows around it can be kept open without any security or privacy concern. The concepts for the proper planning of courtyards for houses built in Sri Lanka were given by Jayasinghe and Attalage (1999b).

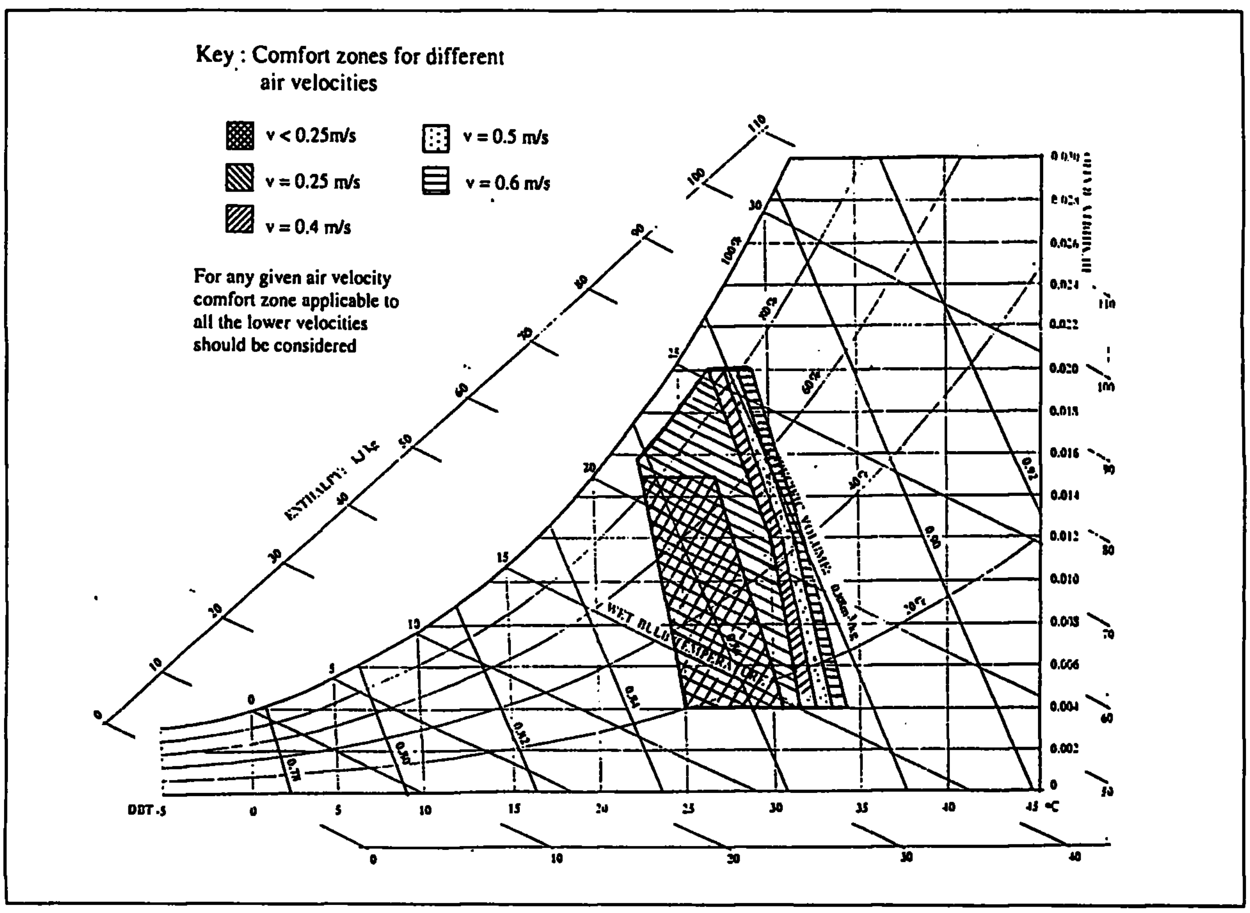


Fig. 1 - Psychro metric chart giving modified comfort zones taking account of physiological effects of cooling

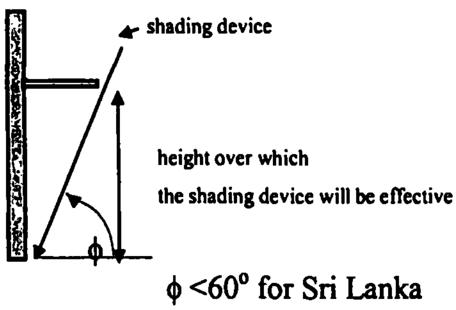
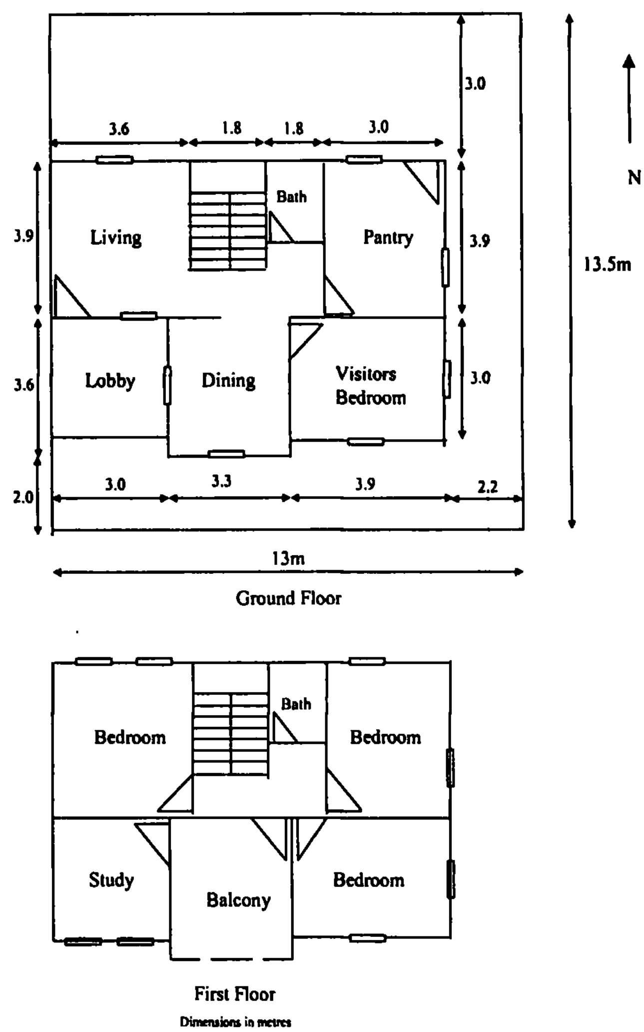


Fig. 2 - Effectiveness of shading devices



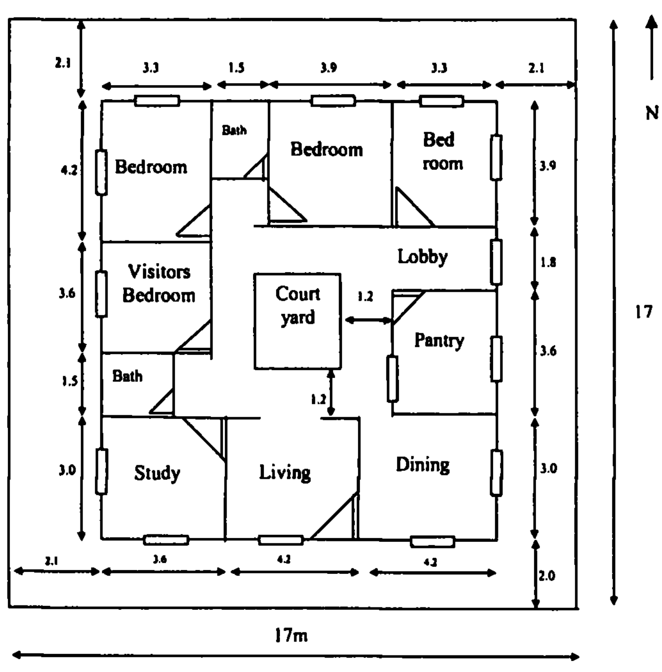


Fig. 3 - Single storey house of floor area 150 m² in a plot of 11.5 perches

Fig. 4 - Two-storey house of floor area 150m² in a plot of 7 perches

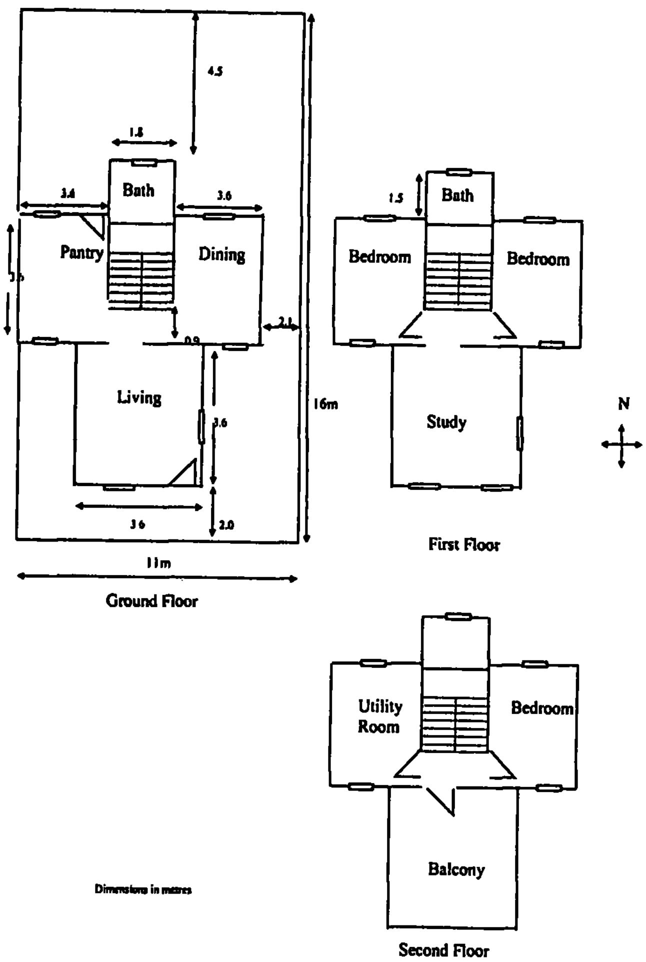


Fig. 5 - Three storey house of floor area $150m^2$ in a plot of 7 perches

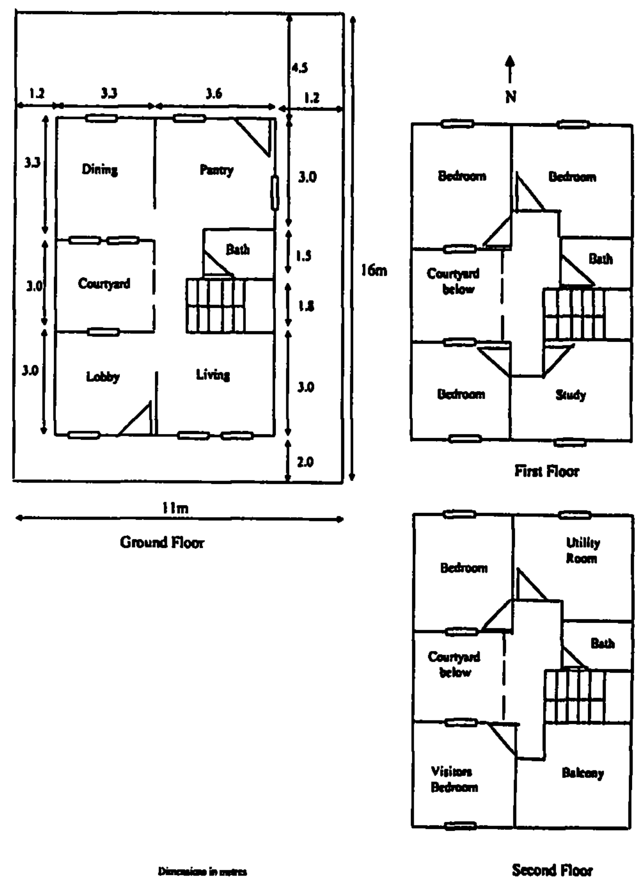


Fig. 6 - Three storey house floor area $200m^2$ in a plot of 7 perches

6.0 An integrated solution for passive residential developments in Sri Lanka

The concepts and guidelines developed in this research are:

1. Access roads along east-west direction to minimize solar gains.
2. Staggered road arrangement to improve road safety.
3. Minimised plot width to maximize the number of blocks in a given area.
4. Promotion of vegetation and gardening by allowing sufficient space for the creation of a desirable microclimate.
5. Three-storey single-unit housing to minimize the plot coverage, to minimize the roof area and to maximize the number of external walls for the provision of openings.
6. Brickwork for both loadbearing and partitioning walls to reduce the construction cost.
7. Light colours for exterior and interior surfaces to inhibit conductive gains and to enhance visual comfort indoors.
8. Sheltered spaces for frequent occupation to inhibit the use of active means.
9. Maximization of the number of external walls per functional space to promote ventilation.
10. Large openings on shadable and small ones on unshadable orientations to minimize solar gains.
11. Sharing of the same courtyard at different storey levels to maximize desirable effects.

6.1 Concepts for future residential buildings with land sub-division

Of those surveyed, 3.9% prefer to live in an urban neighbourhood; 68.7%, in an urban area full of trees. However, urban and suburban land is becoming scarce, so it is of primary importance to maximise the use of land. In Sri Lanka, the minimum block size for constructing houses is 6 perches when the pipe borne water service is available and 10 perches when this service is not available (Building Regulations, 1985). For both these sizes, it will be necessary to ensure that the access roads are planned in the east-west direction as indicated in Figure 7. This will help in planning houses facing either north or south, with shadable front windows.

The width of the access roads are likely to be a minimum of 6.0m when the number of blocks served are substantial. The building regulations require sufficient space from the centre of the road to the building line, which is about 4.5m to 6.0 for access roads. It is also necessary to respect a lighting angle of 62° at the rear of the house. Thus, the blocks should have the narrow side facing the access road and the longer side perpendicular to it. Since the creation of a microclimate is important, specially to shade the roads to minimise the ground reflected radiation, a reservation strip of 1.5m in width on either side of the access road for planting small bushy trees can be particularly useful.

A possible land sub-division plan that can be adopted in a large housing scheme to maximise the land usage is shown in Figure 7. For this, the minimum block size is considered as 7 perch (175 m²) in order to allow a substantially large houses such as given in Figure 6. The width and the depth of a block are 11m and 16m respectively. These blocks form clusters, which can be arranged in staggered manner to prevent speeding of vehicles. In this arrangement, each block will consume about 10 perch (250 m²) area with roads. If 10% of land is reserved for common facilities as required for large housing projects, around 3600 houses can be located in an area of 1km². Therefore, with an average occupancy rate of 4 persons per house, a population of over 14,000 can be accommodated in an area of 1km² comfortably with minimum impact on the environment.

Frequent use of areas of vegetation is a traditional recommendation in town planning (De Waal, 1993). It is stated by Landsberg (1981) that many small areas of vegetation is more effective than one equivalent large park. In the block arrangement proposed by this study, two adjacent rows of back gardens can de considered as a "park" measuring 9m by 110m (i.e. around 0.1 ha). These parks, located at 32m-intervals, could help to create a desirable microclimate resulting in a cooler outdoor environment. This land subdivision proposal will also allow trees along the roads.

Since a space of 1.5 m is kept on either side of the road, it is possible to construct covered underground water detention and infiltration pits at a suitable interval along access roads, thus eliminating the need for a drainage network and also improving the groundwater recharge, thus supporting the growth of trees. These unlined pits can be provided with a suitable concrete cover. For example, if water detention pits are located at 15 m intervals, to collect all the water falling in a rainfall intensity of 25 mm/hour lasting one hour (or 50 mm/hour rain lasting half an hour), a pit would need only 1.5 m³ of volume. This can be easily achieved with an unlined pit of 1.0 m length x 1.0 m width x 1.5 m depth. It should be noted that these are not expected to completely eliminate the surface runoffs, but to substantially reduce them. Increased surface runoff from the developed land is one of the main reasons for flash floods in many low lying areas. This concept has already been successfully implemented at Karanawanwatta industrial estate at Dankotuwa as described by Wijesekera (1999).

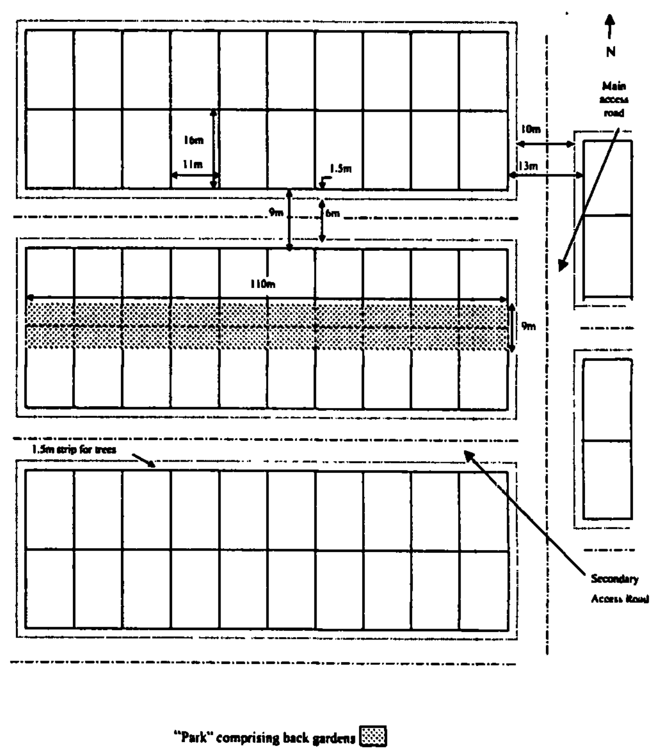


Fig. 7 - Proposed land subdivition plan

6.2 Concepts for future residential buildings with single-unit multi-storey housing

In promoting thermal comfort indoors, three storey houses can perform better than single or two storey houses mainly due to sheltered floors and the reduction in roof area. In order to show the possibility of planning houses of moderate total area (about 150m^2) with three storey buildings, a case study was carried out. The two storey and single storey houses of comparable total area are used for the comparison purposes. In addition to these, a three storey house with a courtyard is also presented to show the other advantages of three storey houses.

Three-storey passive houses can be planned in the following way. The ground floor, which would be sheltered during the day time, can accommodate utility areas such as living, dining and pantry. If the house is large, these spaces can be planned at the ground floor level around a courtyard, which can serve all floors (Figure 6). It will promote ventilation and somewhat improve the visual comfort in the spaces around it. However, in plan, it need not be as large as those dictated by the building regulations because alternative windows can be provided on the external walls of the spaces concerned (Figure 6). The first floor is sheltered both from the solar radiation from above and the ground reflected radiation. It is therefore the most desirable floor level to accommodate bedrooms and the study room. In a large house (Figure 6), bedrooms can be planned around a courtyard so that their windows can open into it without privacy or security problems. Even in a 3-storey house without a courtyard (Figure 5), keeping windows open day and night will not be a problem as serious as in the case of a single-storey house. The second floor is the least desirable, and therefore it should be employed to locate spaces that are occasionally occupied, such as visitors bedroom, utility room. The balcony can be ideally located at this level since it is likely to have better breeze at the third floor level.

It can be seen that the three storey residential buildings offer a number of options to achieve thermal comfort such as strategic location of bed rooms and study rooms at the well sheltered first floor, possibility of organising the functional spaces around the courtyards, etc. Another notable feature is sharing of the same courtyard, if available, at three different levels, namely ground, first and second floor levels. It would also be possible to use the houses in adjacent blocks to shelter each other from solar radiation gains as the sun sets. Single and two storey houses will not be able to offer all these flexibility in planning residential buildings with respect to thermal comfort.

7.0 Comparison of alternative types of houses

In order to compare the advantages of three storey houses with those of single and two storey ones, a case study was conducted for the houses given in Figures 3, 4, and 5. The plot extent selected for the comparison purposes is 11.5 perches (17m x 17m) because the single storey house requires a minimum plot of this extent. The two and three storey houses can be easily constructed on 7-perch plots, measuring 13mx13.5m and 11mx16m, respectively. In the comparison, the parameters for the three storey house is considered as 100% to calculate the corresponding percentages for the other two houses. A comparison for these houses based on centre line dimensions can be presented as given in Table 2.

Table 2: A comparison of alternative types of houses

	3-storey	2-storey	Sinlge-storey
Total usable floor(m^2)	100.44	116.64	101.34
Total floor(m^2)	126.36	144.72	131.40
Usable/Total floor	0.795	0.806	0.771
Plot extent(m^2)	175 (7 perches)	175 (7 perches)	289 (11.5 perches)
Plot extent for comparison(m^2)	289 (11.5 perches)	289	289
Plan area of groundfloor (with courtyard) (m^2)	43.20	72.36	140.40
Plan area of roof (with 1 m eaves) (m^2)	72.24	111.76	190.80
Roof/Total floor	0.572 (100%)	0.772 (135%)	1.452 (254%)
Roof/Plot area	0.250 (100%)	0.387 (155%)	0.660 (264%)
Exposed area/plot area	0.750 (100%)	0.613 (82%)	0.340 (45%)
Gross external wall area for windows(m^2)	200.88	156.33	119.88
Gross ext wall area for windows/Served floor	2.268 (100%)	1.492 (66%)	1.183 (52%)

The usable area to total area in both three and two-storey houses are comparable. Single-storey houses may need more area for circulation, thus resulting in a lower ratio for usable to total area.

As shown in Table 2, in the single storey house in Figure 3, the roof area with respect to the total floor area as well as the plot area can be around 2.5 times that in the three storey house in Figure 5. Besides, the garden space can be doubled by preferring the three storey house to the single storey house. Therefore it is clear that the three storey houses facilitate reduction of heat gains, creation of a desirable microclimate, and reduction of the possibility of flash floods.

Table 2 also shows that the area of external walls where windows can be provided is reduced by 50% when the preference shifts from three storey to single storey even when the single storey house contains a courtyard. In the single storey house, the benefits of the courtyard are limited due to privacy concerns. For its bedrooms, windows cannot be provided on the external walls facing the courtyard as the living room is open to the courtyard. On the other hand, as shown in Figure 6, the same courtyard can be used at three different levels in a three storey house without any privacy problems. Therefore, it is clear that a three storey house provides a larger choice of external walls so that shadable orientations can be selected for its windows.

The use of three storey instead of single storey houses can have a number of additional benefits as well. Those are given below.

Reduction of flash floods

Of those surveyed, 20.1% revealed that, following a heavy rain, their street or house gets flooded. Such flash floods occur in urban and suburban areas mainly due to two reasons; inadequate exposed surface area for infiltration of storm water and inadequate capacity of the drainage system which now has to handle a much larger amount of storm water. For example, for a rainfall intensity of 25 mm/hour lasting for one hour, the total volume of runoff due to roof is about 190.80 x 0.025 =4.770 m^3 for the single storey house (Figure 3); 2.794 m^3 for the two storey house (Figure 4) and, 1.806 m^3 for the three storey house (Figure 5). Thus, the runoff from the roof of a three storey house will be only about 40% of the runoff from a single storey house of similar total area. Another main advantage of lower lot coverage of three storey house is that there will be sufficient vacant space on the land for the construction of a detention pond (Wijesekera, 1999) than in other two types. The effect of constructing a such pond on the foundations of a three storey house also could be minimized by locating it away from the house. These ponds will be helpful to increase the ground water recharge, which in turn will sustain the growth of trees. Trees will reduce the speed of runoff thus reducing soil erosion and siltation of drains.

Improved functionality

In a single storey house, all activity spaces are located at ground floor level, resulting in problems associated with privacy. The three storey houses shown in Figure 5 and 6 provide three different levels for space allocation. The ground floor can be occupied by the family members and visitors during the daytime comfortably. The first floor can be occupied by the family members. The second floor bedrooms can be allocated for infrequent use such as visitors bedrooms. The balcony can be used for sleeping in hot nights or for drying of clothes during daytime.

In three storey houses, activity spaces can be arranged around the staircase as shown in Figures 5 and 6, minimising the circulation space. The space beneath the staircase at ground floor can be used as a storage area. The water tank can be located at the roof level above the staircase or bathrooms.

Cost aspects

Despite these advantages, the general public is reluctant to consider three storey houses as a possible alternative due to the misconception that three storey houses can cost much more than single or two storey houses. It is shown by Jayasinghe & Jayawardane (2001) that loadbearing brickwork can be safely used in three storey house construction while achieving substantial cost savings with respect to reinforced concrete framed structures.

In order to compare the likely costs of single, two and three storey houses, a comparison is made for different types of gross surface areas of the houses given in Figures 3, 4 and 5. The results are given in Table 3.

Table 3: Comparison of gross surface areas of alternative types of houses

		3-storey	2-storey	1-storey
Vertical surfaces(m^2)	Total	327.24	326.43	268.92
	Total surface/	2.590	2.256	
	Total floor	(100%)	(87%)	(79%)
Non-vertical surfaces(m^2)	Earth fill area	43.20	72.36	131.40
	RC slab area	85.14	73.08	0
	(incl. Stair slab)			
	Roof (plan area)	72.2	111.76	190.80
	Total	200.58	257.20	322.20
	Total surface/	1.587	1.777	2.452
	Total floor	(100%)	(120%)	(155%)

It can be seen that three storey house needs only two thirds of non vertical surface area of that of the single-storey house. A reason, for example, is that the first floor slab serves both as the floor of the first-storey and the roof of the ground-storey. Thus, efficient use of structural materials such as loadbearing brickwork would be able to keep the cost per unit area for two and three storey houses approximately the same.

In order to compare the actual costs of the three types of houses, a detailed cost study was carried out by Subashi et al. (2000), assuming that the houses were provided with basic finishes such as asbestos roofs, asbestos ceilings and cement rendered floors etc. The cost of bathrooms and fittings was not considered. All three houses have loadbearing brickwork and rubble foundations. The rates used were those specified for the local authority contracts by the Western Provincial Organization for the year 1999, which includes a mark-up of about 15%. These results are given in Table 4. It can be seen that the construction cost per unit area is in the same region.

ance of 10% for common facilities), thus allowing a population density of over 14,000 persons/km^2. That is, an area of only 70 km^2 (8.5km x 8.5km) is required to settle one million people comfortably with a minimum impact on the environment. In other words, for the total population of 18 million Sri Lankans, only about 1300 km^2 is required, which is less than 2% of the total land mass of Sri Lanka (65000 km^2). This is a particular advantage in an urban or suburban context as the land is scarce and the environment is under threat.

It is also shown that such concepts allow the creation of a much desirable microclimate with increased vegetation. The low plot coverage of three storey houses will also allow the construction of detention ponds to minimise the runoffs from the roofs. This will minimise the changes to the drainage patterns and will inhibit flash floods.

Table 4: A comparison of cost of construction for single, two and three storey houses

	Three storey	Two storey	Single storey
Total cost (Rs)	1002,164/=	949,915/=	904,392/=
Total floor area (m^2)	139.86	144.72	132.66
Cost per unit area (Rs/m^2)	7165.50	6563.80	6817.40

Moreover, non-dependence of passive houses on active techniques for comfort will bring savings in the long run in particular. Those are the savings in capital, maintenance and repair cost of various mechanical plant. It will also have desirable environmental benefits such as lesser use of energy.

8.0 Discussion

It is has been qualitatively shown that the three storey house tends to perform better than single and two storey houses with respect to providing thermal comfort throughout the day, all round the year. According to the survey, the preference of the people is shifting from single-storey to multi-storey type. Although only 27.9% of those surveyed live in two-storey houses, 51.4% prefer the two-storey type. The corresponding figures for the single-storey case are 69.3% and 38.0% respectively. Those for the three-storey house, which is a new concept, are 0.6% and 3.9% respectively.

It is also shown that such houses can be easily constructed on 7 perch (175 m^2) plots. With a properly planned access road network and orientation as explained in this paper, it will be possible to have about 3600 houses in an area of 1.0 km^2 (even with an allow-

The survey reveals that the majority has realised the importance of a sustainable environment and also is willing to contribute. Of those surveyed, 68.2% view environmental pollution as ìa serious problem threatening the futureî; 17.3%, as ìjust one out of many problems.î Moreover, 88.8% claim that they will grow trees if garden space is available.

To reap the benefits of passive concepts, understanding and appreciation of their importance is vital. The general public should also be prepared to work for the creation and maintenance of a much desirable microclimate in the whole neighbourhood since that can bring more benefits than creating such an environment around a small number of houses.

9.0 Future work

At present, the passive performance of various house types (i.e. single, two and three storey), are quantified using the software DEROB-LTH (Dynamic Energy Response of Buildings). DEROB was originally developed at the Numerical Simulation Laboratory of the School of Architecture, University of Texas. It was further developed at the Department of Building Science, Lund Institute of Technology(LTH), Sweden. The results will be published in a subsequent paper.

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Appendix A: Form of Questionnaire Survey

QUESTIONNAIRE SURVEY

Project : Passive Techniques for Energy Efficiency of Buildings in Sri Lanka
Researchers : Dr MTR Jayasinghe, Dr RA Attalage & AI Jayawardena
Funding : Senate Research Committee, University of Moratuwa

INSTRUCTIONS

1. Only those who were born before January 01, 1982 should take part.
2. DISTRICT you live in should be Colombo, Gampaha, Kalutara, Galle, or Matara
3. UNDERLINE your choice or FILL IN the blanks as expected

Name : ....
Address : ....
Age : .... Sex : Male / Female
Occupation & Place of Work : ....
Type of House : flat / single-storey / two-storey / three-storey
Number of Occupants : ....
Date of Participation in the Questionnaire Survey : ....

THE HOUSE NOW YOU LIVE IN ...

A1. Roof type of your house?
Clay tiles / Asbestos / ....

A2. Ceiling type? No ceiling / Asbestos / Timber / ....

A3. Any room in your house which is sometimes too warm to be comfortable even when all its windows are open? Yes / No

A4. If Yes, what do you do then ?
Switch on the fan / Go to a comfortable room /...

A5. Usually, how many fans are used in your house? No fans / One / Two / Three / More than three

A6. For the windows of your house, what provides protection from sunlight ?
Overhangs / Tinted glass / Trees / Curtains / External blinds / ....

A7. Colour of the outside surfaces of your house?
Light colour / Dark colour / In between Colour is ....

B1. Inside the house, what is the colour of the walls?
Light colour / Dark colour / In between Colour is ....

B2. Colour of the floor?
Light colour / Dark colour / In between Colour is ....

B3. Any skylight in the roof to take daylight in? Yes / No

B4. Any room that is gloomy during the daytime even when all its windows are open? Yes/No

B5. If Yes, what do you do if you have work to do there ?
Switch on the light / ....

B6. In your electricity bills for the last 3 months, number of units used and amount ?
Units:...... Rs.........../ Units:......, Rs.........../ Units:......, Rs.........

C1. Usually, where do you sleep at night ? Downstairs / Upstairs / ....

C2. When the night is hot, do you keep the windows open ?
No / Yes, throughout the night / Yes, only till late night

C3. If No, why? Security / Privacy / Mosquitos / ....

D1. Do you have a garden ? No / Front garden only / Back garden only / Both

D2. Your family grow vegetables or fruit there ? Yes / No

D3. If Yes, why ? Hobby / To save money / To obtain pesticide-free food
/ To prepare for a famine in the future / ....

D4. You use organic waste as compost manure ? Yes / No

D5. If No, why ?
Garden space not enough / No time / Don't know the technique /..........

D6. Following a heavy rain, your street or house gets flooded ? Yes / No

THE HOUSE YOU LIKE TO HAVE...

NOTE: Please avoid over-imagination; you should be able to afford what you like to have

E1. Neighbourhood you like to live in ? Rural / Urban / Urban area full of trees

E2. Type of house you prefer ? Flat / Luxury apartment / Single-storey / 2-storey / 3-storey house

E3. Special features needed :
Visitors bedroom / Visitors bathroom / Court yard (indoor garden) / Study room
/ Storeroom / Larger kitchen instead of a storeroom / ....

E4. Number of bedrooms (without visitors) needed ? ....

E5. Number of bathrooms (without visitors) needed ? ....

ENVIRONMENT AND YOU

F1. Your view on Environmental Pollution ?
A serious problem threatening the future / Just one out of many problems /
Not a problem because modern technology will always find a solution

F2. Are you prepared to do something about this problem ? Yes / No

F3. If garden space is available, will you grow trees ? Yes / No / May be

NOTE : Please submit the completed questionnaire to :....................................

Appendix B: A Selected Summary of Questionnaire Survey

General

Total number of subjects : 179
Gender : Male 55.9%; Female 44.1
District : Colombo 59.8%; Gampaha 15.1; Kalutara 11.2; Galle 7.3; Matara 6.7
Age group: 18-30yrs, 46.9%; 31-40yrs, 25.1; 41-55yrs, 21.2; over 55yrs, 3.4

Occupation:	Engineer	14.5%
	Clerk, Stenographer, Secretary, Receptionist	9.5
	Research officer, Research assistant	8.9
	Manager, Director, Executive, Librarian	7.8
	Technical officer, Technician, Technical assistant, Supervisor	7.8
	Final year student, Instructor	7.3
	Architect, Quantity surveyor	5.6
	Draughtsperson	5.0
	Academic	4.5
	Businessman, Banking assistant, Sales rep	3.9

Type of house : Single-storey 69.3%; Two-storey 27.9; Three-storey 0.6

Prevailing situation

Roof type: Clay tiles 38.0%; Asbestos 55.9; Both 2.8
Ceiling type: No ceiling 26.3%; Asbestos 47.5; Timber 18.4; Both 7.3

A room too warm? Yes 54.7%; No 44.7
If Yes, what? Switch on fan 86.7%; Go to another room 19.4

Number of fans usually used: No fans 11.2%; 1 No 15.1; 2 Nos 27.4; 3 Nos 26.3; Over 3 Nos 19.0

Protection for windows: Curtains 75.4%; Trees 24.6; Tinted glass 10.6; Overhangs 8.4

Colour of outdoor surfaces: Light 69.3%; Dark 3.9; In between 26.3
Colour of indoor wall surfaces: Light 72.1%; Dark 1.7; In between 26.3
Colour of floor: Light 10.1%; Dark 75.4; In between 14.0

Any skylight? Yes 20.1%; No 77.1

A room too gloomy during daytime? Yes 30.7%; No 67.0
If Yes what? Switch on light 90.9%

When night is hot, open windows? No 57.5%;Yes, throughout night 21.8; Yes, only till late night 19.0
If No, why? Security 85.4%; Mosquitos 44.7; Privacy 15.5

Have you got a garden? Yes 91.1%; No 8.4
Grow vegetable/fruit there? Yes 63.8%; No 35.6
Your street/ house gets flooded? Yes 20.1%; No 78.8

Preferences

Neighbourhood: Rural 21.8%; Urban 3.9; Urban area full of trees 68.7
Type of house: Single-storey 38.0%; Two-storey 51.4; Three-storey 3.9

Environment

View on environmental pollution: A serious problem threatening future 68.2%;
Just one out of many problems 17.3; No problem, technology will solve it 3.9
If garden space is available, will you grow trees? Yes 88.8%; No 0.0; May be 7.3