PASSIVE TECHNIQUES FOR RESIDENTIAL BUILDINGS IN LOW ALTITUDES OF SRI LANKA

by

M. T. R. Jayasinghe and R. A. Attalage

Abstract:

The role of passive techniques, which utilises a certain number of passive elements to maintain the thermal comfort within the built environments of residential buildings at low atlitudes of Sri Lanka, has been highlighted. The possibility of defining a unique neutral temperature of 26°C for low altitutes of Sri Lanka has been utilised in a rational way in presenting simplified set of rules of thumb, that can be used by the designers at early stages. The effects of orientation, shading devices, window sizes, roofing materials, insulation, colour of the exterior and interior walls, use of courtyards to maximise natural ventilation, and arrangement of roof to minimise structural cooling are shown with suitable examples.

1.0 Introduction

Passive design techniques means designing a building which conforms to the nature of the site and to the diversities of local climate instead of the built environment being controlled by active means such as mechanical and/or electrical means. Indigenous architecture is a direct result of adaptation to resource and environmental constraints and great architectural practices have always preached and practised these principles. Passive design can save energy during operation and prove economical since it uses a minimum amount of energy or no energy to provide thermal and visual comfort.

The science of passive design revolves around the study of heat and mass transfers taking place within a building. In any building, heat and mass interaction occurs simultaneously and continuously with surroundings through conduction, radiation and convection. The patterns of heat gain or losses due to these are generally predictable. For instance, it is predictable that at night there will be no heat gain, and if it is cold outside, much heat is lost. The extent of heat loss or gain depends primarily on the wind, the humidity and the temperature difference between inside and outside. It also depends upon how much heat was gained previously and how much of this remain stored in the building's thermal mass; the capacity of the building to store heat.

According to Eberhard & O'Donavan (1990), in the western world, passive solar design of buildings means an increase in capital outlay, coupled with a decrease in energy requirements over the lifetime of the equipment installed. As the pace of research escalates on passive technology, passive solar design has become less passive. The state-of-the-art techniques in the industrialised countries, where the main goal is maximisation of winter heat gain and minimisation of heat loss while preventing summer overheating, techniques like green houses, roof ponds with movable roof insulation, super-insulating materials backed by fans, ducting and electronic controls have been introduced.

In low altitudes of Sri Lanka, where warm humid climates are experienced, passive techniques should have a goal to minimise the solar gain storage and maximise the ventilation and structural cooling. It is shown that these goals can be achieved simply by proper planning without resorting to complicated techniques. The importance of using passive techniques for buildings, especially residential buildings of Sri Lanka can be emphasised due to its dependence on imported petroleum products to provide the shortfall of electricity produced with hydro-power. This will also enable a shift in power generating capacities additionally required to maintain thermal and visual comfort in residential buildings to those which could result in more social benefits.

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2.0 Thermal comfort conditions for Sri Lankans

Thermal comfort, which is the sensation of complete physical and mental well being, is a subjective quantity which results from internal environmental variables such as dry bulb temperature, mean radiative temperature, humidity and air velocity. It also depends primarily on personal variables such as activity and clothing levels of the occupants and secondarily on gender, age and local effects such as drafts. The thermal comfort could be achieved for a number of combinations of the above mentioned environmental and personal parameters. These combinations of parameters form the basis of a comfort zone on the standard psychrometric chart, where more than 70% of the population would feel thermally comfortable (Szokolay, 1978).

It is shown by Jayasinghe & Attalage (1997) that for a country like Sri Lanka, a single neutral temperature of 26°C can be used to obtain the standard comfort zone for any part of the country where the altitude is less than 300 m. Above 300 m up to 900 m, a value of 25°C can be used. It is also possible to enlarge the standard comfort zone to suit Sri Lanka by using a higher humidity ratio of 0.015 as the upper boundary. When the internal air velocity is greater than 0.25 m/s, the standard comfort zone can be modified to take account of the physiological effects of cooling. For these modifications, a humidity ratio of 0.020 has been suggested as an upper boundary when used with a neutral temperature of 26°C. The standard comfort zone and the modified zones for different internal air velocities are given in Figure 1. When the internal air velocity is high, thermal comfort can be achieved even at elevated temperatures and humidities. This indicates that the residential buildings should be designed so that maximisation of natural ventilation as one of the design goals. Figure 1 also indicates that when natural ventilation is not available, it would be possible to use artificial ventilation and provide thermal comfort at elevated temperatures and humidities.

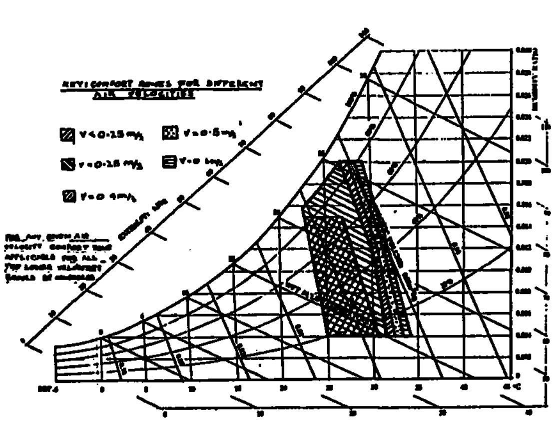

Figure 1: Psychrometric chart giving modified comfort zones taking account of physiological effects of cooling

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The variation of relative humidity of the external environment during month of August in four days with different weather conditions in Moratuwa area is given in Figure 2. August is generally considered as a warm month for this area. The highest humidity generally occurs in the morning around 0600 hrs and it drops to around 70% at about 1400 hrs.

The variation of dry bulb temperature for the same days is given in Figure 3. There is a certain pattern where the morning temperatures are generally about 70°C below the maximum temperature. The morning dry bulb temperatures and relative humidities are generally within the modified comfort zones when there is sufficient internal air movement. This is an indication that it is practically possible to use passive techniques such as improving ventilation to obtain thermally comfortable conditions within the built environment provided that the thermal heat gain during the day time is minimised.

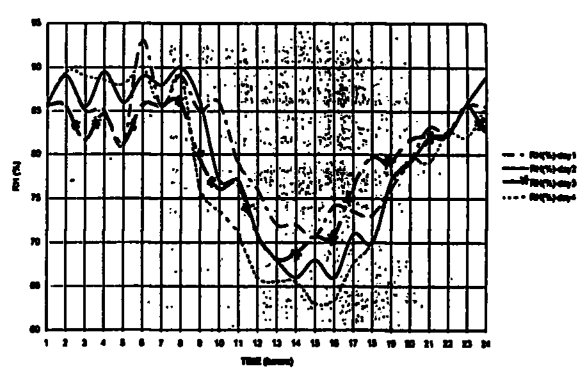

Figure 2: Variation of relative humidity in four typical days of August

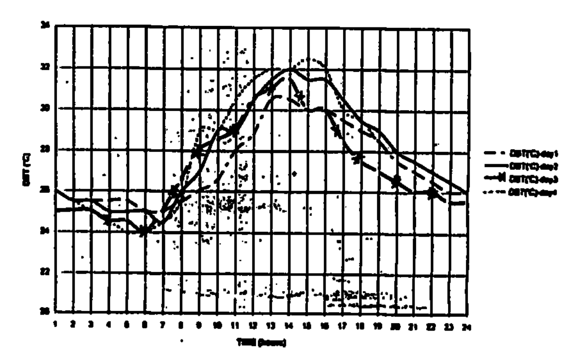

Figure 3: Variation of dry bulb temperature in four typical days in August

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3.0 Trends of passive techniques for tropical climates

Throughout the world, from ancient times, people have used passive techniques that have evolved through generations. Indigenous people were admirable architects. Their architecture is adaptive, and it evolved by way of a combination of culture and natural selection in response to peculiar environmental conditions. They designed intuitively, and as a result those buildings conformed to the diversities of climates (Eberhard & O'Donovan 1990).

An example is the huts built by OvaHerero people of Okarango district in Botswana as reported by Eberhard & O'Donavan (1990). In this hot dry region, the priority is natural cooling. The early morning chill is a relief from the intense heat of the afternoon. The huts were of circular shape of thick clay walls, thatch roofing with ample overhang and thin slits for windows. A gap has been left between the wall and the roof for ventilation. The entire hut has been covered with a substance like white paint in order to reflect the intense direct and diffuse solar radiation. These huts were found to be sufficiently cool and comfortable during the whole day. Apart from keeping the heat out, these huts used natural ventilation, night time cooling and ground cooling as passive cooling strategies.

As described by Silva & De Vos (1980), the ancient houses in Sri Lanka were based on organic architecture where the walls had been built with mud which has very good insulating properties. The roof structure was made of jungle poles covered with straw, illuk etc. The wide eaves projected beyond the face of the building which helped to keep the sky and glare out thus minimising passive solar gain. The openings were small and maintained to satisfy minimum requirements. They were used only for the passage of people, possessions, air and natural light. The interior was gloomy by western standards, but restful and pleasant and was in contrast to the excessive light available outdoors. Additional openings were placed at roof level to permit the accumulated hot air at the upper levels to escape, reducing the creation of hot pockets.

It is stated by Barozzi et al (1992) that in developing countries with hot climates, the indigenous architecture has been superseded by imported modern building designs. Compounded by the cost of foreign made materials and components, the increased fuel consumption required to keep these buildings cool has invariably contributed to the financial ruin. An interesting observation reported by Ahmad et al. (1985) was that when the ambient average temperature was 31°C, a new house had an average indoor temperature of 35°C, while a traditional house built more than hundred years ago in the same city has recorded only 28°C.

On the basis of the above discussion, it could be stated that for the passive building design in low altitudes of Sri Lanka, it is necessary to consider the effects of orientation, proportion, colour, ventilation, openings, shading devices and lighting with the aim of minimising solar heat gain and maximising the natural ventilation and structural cooling. When using the recommendations, it is also necessary to take account of micro-climate factors such as ground topography, height of the building, effect of surrounding buildings since these factors can affect the solar heat gain and wind velocity at a given site. In the design of buildings based on passive techniques, it would be necessary to bring in these recommendations at a very early stage of design. As described by Mathens et al. (1992), the foundation for a good thermal design is laid during the sketch design phase.

4.0 Study on passive elements

Sri Lanka is located at a latitude of 5° to 8° N and a longitude of 79° to 82° E. As a result of low latitude, all external surfaces of buildings are liable to receive direct sunlight during the daytime. In order to develop passive techniques with proper scientific background for Sri Lanka, the following factors have been studied in detail with respect to its location:

1. the orientation of the building
2. effects of shading devices and size of openings
3. effect of roofing material and shielding
4. effect of the colour of exterior wall
5. use of courtyards to maximise the natural ventilation
6. effect of windows on natural ventilation
7. roof arrangements to maximise the structural cooling

4.1 The orientation of the building

The orientation of the building with respect to the relative movement of the sun is an important factor in controlling the heat gain. If an example of a rectangular shaped building is considered with its longer axis directed east - west and also the front face directed to south, the front face will receive direct sunlight from sunrise to sunset for nearly six months starting from the end of September to end of March. The rear face will receive sunlight from sunrise to sunset for nearly five months starting from mid April to mid September. The wall facing east will receive sunlight until around 1100 hrs. The wall facing west will receive intense sunlight from 1300 hrs until sunset. This is due to the changes in the solar declination since the axis of the earth is inclined by 23.45°.

Of these solar gains, the direct sunlight falling on the eastern wall is generally considered less offensive since it falls in the morning where the external temperatures are low. When the sun is at a high angle of incidence as at 1000 hrs, it would be possible to use shading devices to cut down the gain of solar radiation. The walls facing north and south can be effectively protected in Sri Lanka with shading devices, and thus could be considered as the ideal face to have windows. The wall facing west is the most affected with respect to thermal gain since it receives intense direct sunlight for about five hours when the external dry bulb temperature is also high. The solar radiation that penetrates through the windows facing west will be absorbed by the internal walls and floors, and also it is very difficult to provide fully effective shading devices to cut down these heat gains. During the night, this heat stored in the western part of the building will be transmitted within the internal space as radiation and by convection.

The use of dense material can increase the time lag for the heat transfer from the external to internal surfaces, but this would be of little help with respect to the goal of minimising the thermal gains in residential buildings with continuous occupation. Thus, even when heavy material are used, it is advisable to have the longer axis of the building in east - west direction. This should be facilitated when lands are subdivided by ensuring the roads are generally in east-west direction.

4.2 Effects of shading devices and size of openings

The thermal mass related to thermal diffusivity of the external fabric of a building can delay and reduce the thermal signal penetrating through walls. However, it does not reduce the total heat flow moving inwards, unless the accumulated heat in the wall is dissipated back to the cool night air, which may occur only to a certain extent in hot humid areas due to low diurnal temperature fluctuations.

There are two ways of dealing with this limitation which are the use of external shading devices and thermal insulation. Use of more insulation is not very effective in hot and humid areas, especially where there is a chance that condensation would occur in air conditioned buildings since the temperature can drop below the dew point. Condensation greatly degrades the thermal performance of the building environment and can also cause the midew problems (Yang & Hwang 1993). In non air conditioned spaces, insulation may not be an attractive solution in terms of reducing conduction in general since the temperature difference between exterior and interior is not much. However, internal insulation or radiative shielding can be attractive for facades with high equivalent temperatures due to radiation effects, such as those exposed to direct radiation. Even in this case there is a risk because if the interior has high internal heat generation due to occupants and the devices and is also not properly ventilated, the inside temperature can become extraordinarily high because low heat losses resulting from of increased thermal resistance of the structure due to insulation.

On the other hand, shading devices cut part of the solar heat gain so that the total heat flow is actually reduced, not just delayed. Hence, roof construction with adequate eaves could be extremely useful.

In order to provide sufficient light and ventilation for the interior, windows are used on the external surfaces and openings in internal surfaces to improve air movement. In houses with passive elements, the occupants will have to understand the role played by windows and will have to operate them to maximise the passive effects. The solar irradiance gained through a window consists of three types:

1. Direct irradiance - the radiation from the sun to the earth undisturbed by the earth atmosphere
2. Diffused irradiance - some direct irradiance will strike clouds, water, vapour, dust etc. and scatter in all directions. Some of this diffused irradiance will reach the earth.
3. Ground reflected irradiance - direct and diffuse irradiance striking the ground and being reflected onto a surface.

Through external windows, this radiation can be transmitted directly inwards. Therefore, it is advisable to use adequate shading devices such as overhangs or vertical fins for the windows. The colour of the shading devices should be light since dark colours can absorb heat and in turn emit more infrared radiation inwards.

In order to determine the effects of the size of the shading device throughout the year, a cylindrical sun chart as shown in Figure 4 can be developed and used. It is developed for Colombo using the equations in standard solar geometry (Achard & Gicquel, 1986). A shading calculator shown in Figure 5 can be used to develop the shading mask depending on the projection of the shading device (Achard & Gicquel, 1986). Then, it can be overlapped on the cylindrical sun chart and it will give the effectiveness of the shading device as shown in Figure 6, which is drawn for a window facing south. It can be seen from Figure 6 that a shading device facing south giving an angle α

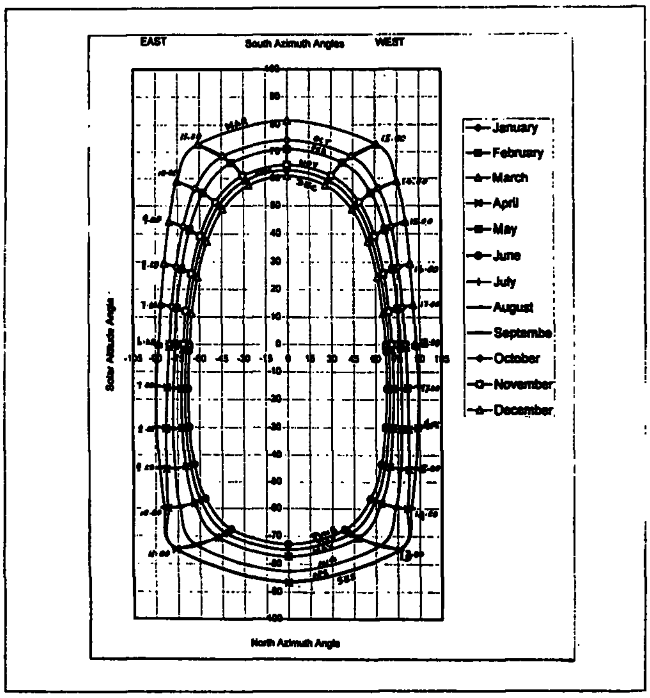

Figure 4: Cylindrical sun chart for Colombo (Latitude 7° C)

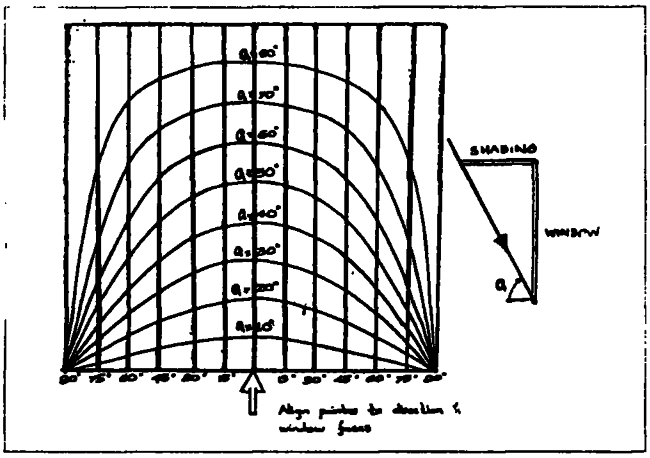

Figure 5: Shading calculator (From Achard & Gicquel, 1986)

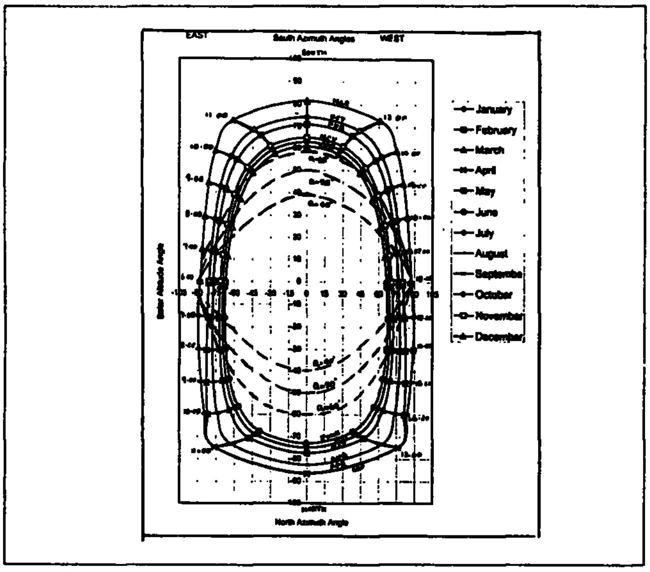

Figure 6: Cylindrical sun chart and shading caculator to show the effects of the shading devices

of 50° and a shading device facing north giving an angle *a* of 60° can provide shading from about 0800 hrs to 1600 hrs when the solar declinations are highest. The shading device is effective when solar altitude angle is higher than that indicated by the shading calculator.

It can also be seen that an angle *a* of 60° on a window facing south will be effective from about 7.00 am in March. It will be effective only from 10.00 am in December. For windows facing other directions, such as 30° from south towards west, the pointer of the shading calculator should be located at 0° solar altitude angle and 30° south azimuth angle towards west.

When windows are used on walls facing west, it is impossible to provide 100% shading. However, this is a good direction to have windows for buildings in western coast. Ventilation from westerly wind could be maximised with minimum solar heat gain by having very short windows provided with an overhang of considerable projection.

The effects of shading devices on the daylight penetrating into the building also should be given careful attention. It is suggested by Neeman (1977) that the quantity of sunlight penetration into a room is the key variable for both visual and thermal comfort in the built environment. The quantity of sunlight is mainly determined by the depth of penetration, rather than by the intensity of direct sunshine. People do not like the sun to shine in their close vicinity because of visual requirements and particularly keen to avoid the sun falling on their working area. This is in agreement with the normal experience that direct sunlight falling on the eyes is a cause of intolerable glare. The depth of penetration of daylight can be maximised by maximising the diffused light which can be achieved with light coloured internal walls, ceilings and floors.

4.3 Effects of roofing material and shielding

In hot humid climates, the roof is one of the main sources of heat gain since the roof slopes vary from 8° to about 15°, when corrugated asbestos sheets are used. In Sri Lanka, the solar irradiance values can reach about 1kW/m^2 during the late morning and early afternoon. Therefore, it may be advisable to minimise the roof area by using multi-storey construction instead of single storey buildings. The other main advantage is that the lower floors of multi-storey buildings will have heat gains only through external walls, thus it could be maintained at thermally comfortable temperatures easily with the help of proper ventilation which is discussed in Section 4.5.

It is reported by Ahmad et al. (1985) that in western part of Libya (30° N latitude), traditional architecture has combined compactness and minimum exposure. The family used heavy weight construction of the ground floor for summer use and relatively light weight first floor for winter use. A similar concept can be used in Sri Lanka for houses where the ground floor can be planned for day time activities and the well ventilated upper floor can be used in the evening and night when the ambient temperatures subside.

Techniques of reducing the heat inflows into internal spaces across the roof due to radiation effects could be very effective in Sri Lanka when asbestos sheets are used as the roofing material. For lightweight roofs, Lotz and Richards (1964) have studied the effects of various types of insulation with reflective surfaces on the ceiling temperature, indoor air temperature and the heat flow through ceiling, corresponding to hot climates of South Africa. The houses used for experiments had been constructed using 280mm cavity brick and galvanised corrugated iron roofs. The maximum indoor temperature with draped aluminium foil insulation was 23.3°C and it was 25°C without insulation. The maximum ceiling temperature was 24.8°C with insulation and 31.9°C without insulation. The heat flow through the ceiling was 13.58 W/m^2 with insulation and 51.46 W/m^2 without insulation. These values could be applicable to asbestos roofs as well since the heat absorption coefficient is about 0.6 for asbestos and 0.65 for galvanised iron. Thus, Aluminium foil insulation can be highly recommended for buildings constructed with asbestos roofs in Sri Lanka.

The function of the Aluminium foil is to act mainly as a radiation shield. Therefore, it should not touch either the asbestos nor the ceiling except for points of fixation since it is a good conductor; it can transmit the heat absorbed to the ceiling, thus the purpose will be lost.

4.4 The effect of colour and finish of exterior walls

The colour and finish of the outside surface of a building influences the thermal performance of a building significantly as it determines the amount of solar radiation absorbed and emitted back as long wave radiation, thus its inwards transmission into the building (Givoni, 1976). It is expected that the effect of external surface colour on the room temperature inside a building will depend on other parameters also, the most important from the view of passive design being:

1. rate of air ventilation in the building
2. direct solar radiation gain into the building.

According to a study carried out in India in very hot climatic conditions (Sodha et al. 1986), it is shown that in a building of light construction, a black painted normal size room is shown to record 6°C higher internal temperature without ventilation and direct radiation than a white painted exterior. When ventilation is provided with number of air changes equivalent to 3 per hour, the difference has reduced to 4°C. When direct radiation is permitted into the building, there was not much difference between white and black coloured exterior situations.

The above results have been obtained with light construction. The basic difference between a light weight structure and a heavy weight structure is the expected phase shift of the temperature signal and the distribution of the effect. When black coloured exterior is used, it would absorb more solar radiation and hence would give a warmer interior than the white exterior. Therefore, when passive techniques are used, the exterior should be of light colour, close to white. The building should be properly ventilated and the direct solar gain must be cut down to a minimum with sufficient shading devices.

4.5 Use of courtyards to maximise the ventilation

Courtyards have been successfully used in hot dry climates and hot humid climates. The level of thermal comfort in a courtyard space is determined by the micro-climatic forces acting on it, most notably those of radiation and wind. The effects of these parameters may be evaluated with respect to the courtyard's geometry as defined by height/width (H/W) ratio of its section in each direction, and the orientation of the courtyard as defined by its longer axis or by the direction to which it opens. It is absolutely necessary to ensure that the gain of solar heat and that stored during day time by the walls forming the courtyard is minimum to ensure that extra heat is not radiated to the interior during the night (Meir et al., 1995).

It was reported by Mohsen (1979) that the courtyard height is the most important factor with respect to solar penetration. For a given courtyard, increasing the height from one storey to two causes a decrease of 2 or 3 hours of solar penetration. In order to keep the inside temperature as low as possible, colours of external surfaces exposed to the sun can be painted in light colours; dark colours should be avoided.

The impact of air movement through a courtyard is critical to thermal comfort, since sufficient internal air velocity can be generated to give a physiological cooling effect. According to Meir et al. (1995), the pattern of wind velocity in courtyards is generally characterised by the direction and H/W ratio as given below:

1. When the long axis of the courtyard is in the direction of the wind, there can be strong winds within the courtyard.
2. When the long axis of the courtyard is oriented perpendicular to the courtyard, eddies form across the courtyard with H/W ratio up to 0.65.
3. When H/W ratio is more than 0.65, the courtyard may be considered sheltered from the direct impact of the winds perpendicular to its axis.

In many parts of Sri Lanka, the main wind blowings are in south-west and north-east directions, provision of courtyards in western and eastern sides could be highly desirable. However, the courtyards facing west should be carefully planned to minimise the gain of solar radiation as shown in Figure 7. The pressure distribution expected in this arrangement is also shown on the basis of pressure distribution given in CP 3: Chapter V: Part 2, 1972. It is advisable to have the courtyard effective up to the top floor of the building since large openings can be provided facing west, shaded by the outer walls and protected by pergolas. This will allow sufficient structural cooling and ventilation even during night when the other windows are closed. Since the courtyard internal dimensions are in the range of 3.0 m in Sri Lanka, this arrangement will give an H/W ratio in excess of 0.65, which may not be desirable. Hence, it would be advisable to provide openings at intermediate height to allow wind flow. The pergolas should be provided in the north-south direction in these courtyards to cut down direct solar radiation. The arrangement for a courtyard facing east is shown in Figure 8.

When courtyards are provided facing north or south, ventilation can be maximised by placing openings at intermediate height since there will be suction on the walls as shown in Figure 9. The pergolas at top should be in the east-west direction and should be of sufficient depth to reduce the direct solar radiation.

It was also reported by Chand et al.(1989), that when a central courtyard is used with openings on the windward side, it is possible to trap the wind in the courtyard, forcing the air to move through the various openings available around the courtyard, especially through the leeward rooms. Hence, the court yard at centre should be connected to openings provided in other faces through the rooms to obtain this effect.

It is recommended by Givoni (1976) that indoor space should be connected to courtyard space through large openings protected by movable shutters to cool the interior. This is of particular relevance to Sri Lanka since there can be tropical monsoons with driving rain at certain times of the year during which rain penetration can be excessive through courtyards.

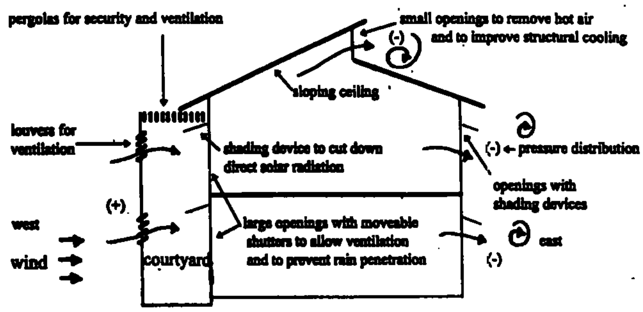

Figure 7: A building with a courtyard facing west

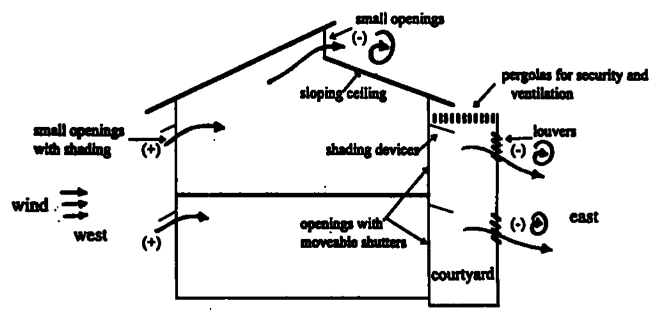

Figure 8: A building with a courtyard facing east

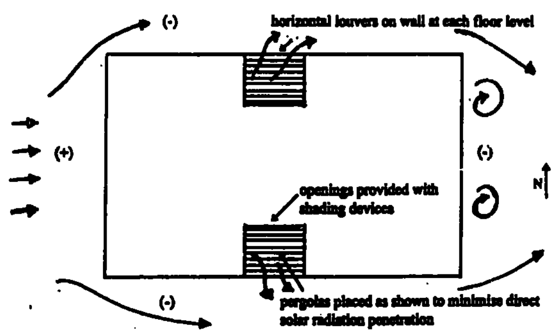

Figure 9: Courtyards facing north and south

4.6 Effect of windows on natural ventilation

Natural ventilation can be due to two reasons namely due to difference between the indoor and outdoor temperatures (thermosyphonic ventilation) and due to wind. In order to obtain the thermosyponic ventilation, it is necessary to have two windows on a given face separated vertically. However, the height difference that can be provided in a normal building would not be sufficient to have significant ventilation effect. Thus, it would be necessary to rely on windows to obtain sufficient ventilation. In order to obtain better ventilation in a room, the air stream should be forced to change its direction. This can best be achieved by having windows on two adjacent walls, one facing the direction of wind. When there are long rooms with the axis in East-West direction, the ventilation effects can be maximised by placing the windows as shown in Figure 10 so as to create pressure differences at the windows. When the windows are opened, the upstream window causes a positive pressure zone which will drive the wind inside and the downstream window causes a negative pressure zone which will force the internal air outwards, thus enhancing the natural ventilation.

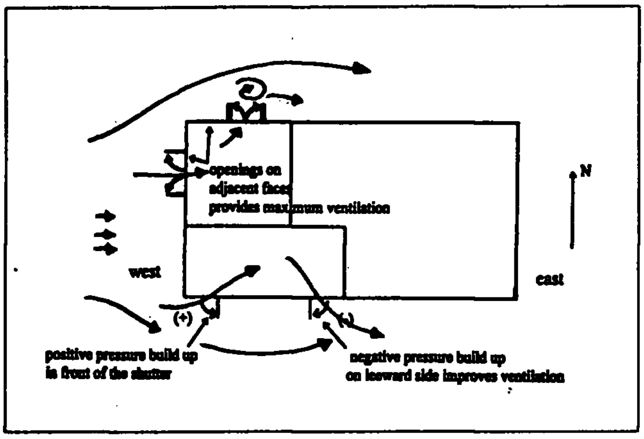

Figure 10: Window arrangement to maximise ventilation

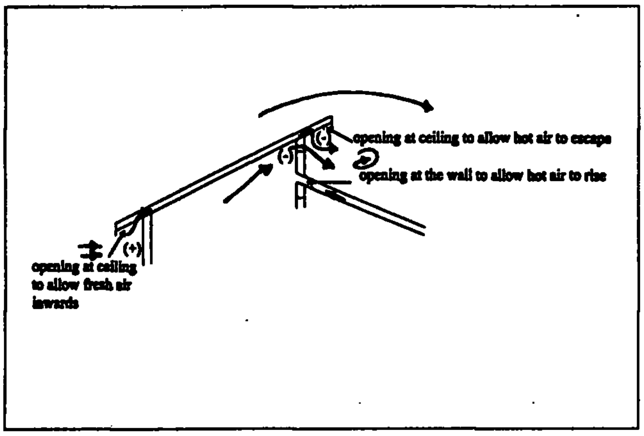

Figure 11: Maximisation of structural cooling of a pitched roof

4.7 Roof arrangements to maximise the structural cooling

The attic space in the roof ceiling combination inhibits the heat transfer through conduction because the thermal conductivity of still air is very low; the heat transfer by conduction is negligible and can be ignored when the air space is thicker than 20 mm. Thus the main means of heat transfer through the cavity is by radiation. This heat transfer could be minimised considerably by allowing adequate structural cooling for the ceiling space which would need a continuous stream of air so that a certain amount of heat absorbed would be lost to the atmosphere through convection.

An optimum roof arrangement can be selected by considering the wind pressure distribution above the roof and at the leeward face. The methods available for arranging a roof are shown in Figures 11.

5.0 Rules of thumb for passive solar design of buildings in Sri Lanka

It would be extremely useful to express various passive techniques in the form of rules of thumb since the passive solar techniques should be brought into the building at the layout design stage. The following rules of thumb could be applicable for low altitudes of Sri Lanka. However, they should be used with careful consideration to the micro-climate of the building area.

It is absolutely necessary to minimise the solar gain into the building. This should be started by selecting a proper orientation for the building. It is also preferable to have large windows only on sides facing north and south. These large openings should be provided with sufficient shading devices of light colours to minimise the solar gain without impairing the daylight. The size of openings on the eastern face and especially the western face should be carefully controlled since the amount of direct solar radiation penetrating through these openings cannot be controlled with shading devices.

The building should be provided with adequate ventilation. This can be achieved with either windows or courtyards. When windows are used, it is useful to have one window facing the wind direction and the other on the adjacent wall so as to change the wind direction internally thus maximising the number of air changes. When long rooms are placed facing either south or north, two windows should be provided far apart so that when opened, they create desirable positive and negative pressure zones at upstream and downstream windows, respectively. When courtyards are used for natural ventilation, it is useful to have deep courtyards with pergolas which will cut down the direct solar gain of the courtyard. In order to maximise the ventilation effects, openings should be provided with horizontal pergolas at each floor level to provide sufficient ventilation without gaining solar heat.

The roof area should be minimised by using multi-storey construction whenever applicable. The structural cooling of the roof should be facilitated either by arranging the roof layout or providing sufficient vents for the hot air to escape thus facilitating a continuous air stream through the roof structure. The provision of roof insulation can also be highly desirable.

The exterior colour and the smooth finish of the structure can be important in minimising the solar radiation gains. The interior colour would be important in maximising the diffused light so that the day light level interior of the building would be sufficient.

Adequate steps should be taken to provide shading to exposed elements like balconies to minimise solar heat gain, storage and the possibility of re-radiating to occupied spaces.

6.0 Conclusions

For a tropical country like Sri Lanka, the minimisation of solar radiation gains by and through a building envelope and the dissipation of the internal heat generated due to activity, occupancy and storage are the key factors to effective use of passive solar techniques. It is treated in detail using the experiences in many other countries with similar climates where a number of passive solar techniques are used. They can be categorised as selection of correct orientation, selection of correct opening sizes, use of shading devices of correct dimensions, use of courtyards with correct dimensions and openings, use of light colours for exterior and interior, appropriate arrangement of the roof structure while minimising the roof area, provision of roof ventilation and minimisation of exposed members that would absorb and transfer the solar radiation inwards. The ventilation, natural or forced, play a very important role in the high humid Sri Lankan climate, not only for structural cooling, but also for human thermal comfort through the evaporation mode of heat and mass transfer.

A set of rules of thumb that can be used at the layout design stage is also presented. The adoption of passive solar techniques to minimise the energy demand of buildings can be quite appropriate to Sri Lanka since a considerable portion of electrical energy produced with depleting energy sources like petroleum can be saved to utilise for some complementary development activity to reduce the required power generating capacity and the resulting undesirable gas emissions.

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