A 'NEW' APPROACH TO PASSIVE DESIGN FOR RESIDENTIAL BUILDINGS IN A TROPICAL CLIMATE

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ABSTRACT The typical passive design suggested for residential buildings in tropical hot-humid climates is a lightweight building with many openings on the north and south walls to allow continuous natural ventilation, shaded by wide overhangs. In reality most people no longer favour this design approach for several reasons: building durability, noise problems, privacy, and social status. The work presented in this paper challenges the typical design suggestions and shows other alternatives that are more suitable for this climatic region. The use of massive construction, which is a common practice in Asia, is tested. Other investigations include examining the effects of using radiant barriers and roof insulation, changing the building orientation and shading conditions, and using various floor and roof claddings. The results demonstrate that the default approach of using lightweight, continuously ventilated structures, is not necessarily the most climate-responsive for this climatic region. Also, the use of radiant barriers provides the most significant improvement in the indoor thermal comfort.

1 Introduction

For a number of years most publications about climate-responsive, low-energy, or passive designs for residential buildings in tropical hot-humid climates have suggested the same approaches. The typical suggested design is a lightweight building with many openings to allow cross ventilation, shaded by wide overhangs. This suggestion is obviously rooted from the traditional dwellings in these regions. In his book "Design with climate", Olgyay (1962) discussed the work by Jean Dollfus in characterising dwellings around the world. Dollfus emphasised that in the equatorial forest and tropical savannahs the buildings are of timber skeleton, wood construction, or woven sticks, where the roof is more important than the walls, and the walls can even be omitted altogether. Shading, both by large overhangs and trees, is very essential to reducing the solar heat gain, whereas openings are important to promoting air movement.

More recent publications also give similar explanations about the characteristics of buildings in the tropics. Lechner (1991) argues that "since in humid climates nighttime temperatures are not much lower than daytime temperatures, massive construction is not an advantage". To explain the basic principles of ecological building, Daniels (1994) explains that "in tropical zones, open building designs and high pitch roofs reduce convective and radiation gains and promote evaporation loss for cooling (rainy seasons)". Examples of this type of construction can still be seen in South East Asian countries, as shown in a recent publication about traditional buildings in Indonesia (Tjahjono 1998). During the last twenty years, there have also been publications on the contemporary style of tropical buildings. The example buildings are usually stand alone large houses or hotels, each sitting on a large piece of land with a lot of trees surrounding the building. The design follows the same principles as the traditional approach; that is, it has a pitched roof with large overhangs that shade the numerous openings (Ling and Beng 1998). However, the modern style is to use heavier materials, such as brick and concrete, for the walls.

The above design approaches have been applied for a long time and proven to provide comfort for people who live in those buildings. The question is whether they can always be applied in most locations in the tropical countries. In reality, too many people in the tropical Asian countries do not have the luxury or the money to own a large piece of land with abundant trees, where the building can be built far enough from the neighbours and the streets. In the suburbs and cities, each housing lot is usually limited in size. Having too many openings can also be quite bothersome, as the openings will introduce more dust and noise from the streets and neighbours (Soebarto and Handjarinto 1998). Further, most people no longer favour lightweight construction because it does not offer the same durability, stability, security and social status as heavyweight construction does.

It is not the intention of this paper to oppose the common suggestions by the previous publications. Rather, the study presented in this paper is intended to search for the most critical strategies that can improve the thermal performance of residential buildings that are located in the more common setting: a lot surrounded by or nearby other buildings or streets. The performance of heavyweight construction is analysed and compared to that of the lightweight construction. The study also questions whether continuously opening the windows, as suggested by literature, is always necessary to maintain comfort, considering the dust and noise problems that will result.

2 Methodology

The analyses were mainly conducted through simulation. Monitoring results of a case study building were also used to confirm the analyses. An hourly simulation program, ENER-WIN (Soebarto and Degelman 1995), was used to predict the indoor temperature when each strategy was applied. This program performs an hourly simulation for all 8760 hours in a year using a modified TETD/ TA (Total Equivalent Temperature Difference/Time Averaging) methodology (McQuiston and Spitler 1992). The program takes into account the outside conditions (hourly temperature, humidity, solar radiation and wind), the thermal properties of the building envelope (thermal time lag, conduction, and radiation exchanges of the opaque surfaces and conduction, solar and visible transmissivity of the transparent surfaces) and the internal loads (people and electric loads). The program is supported with a weather generator that produces hourly dry-bulb and dew-point temperature, wind speed, cloud cover fraction, and direct and diffuse insolation. Inputs to the weather model consist of monthly means and standard deviations derived from 30-year statistical summaries. Recorded weather data from a particular year can also be used in lieu of the simulated weather data. Further discussions about the program and the weather data generator can be found in previous publications (Soebarto & Degelman 1995, Degelman et al. 1997, Degelman 1991).

2.1 Simulated building

The building simulated was a typical 3-bedroom single story house located in an urban housing lot in Jakarta, Indonesia (6.1 SL, 106.5 East Longitude). As in many other places in the tropics, there is a little variation between day and night temperature and in the entire year. The temperature ranges from around 24 to 32 degrees Celsius. The average relative humidity is between 50 and 90%.

The bedrooms were in the left and right zones, the living and dining areas occupied the middle zone, and the service areas were in the left or right zone. The building had plastered single brick walls, tile flooring on a concrete slab, and uninsulated clay tile roofing with plasterboard ceiling. The U-values of the wall and roof assembly were estimated using the method developed by Mackey and Wright (1945). The windows glazing was single pane and operable.

The building's total floor area was 120.m^2. and the ceiling height was 3 m. The building layout is adapted from many modern houses in this area The bedrooms were in the left and right zones, the living and dining areas occupied the middle zone, and the service areas were in the left or right zone.

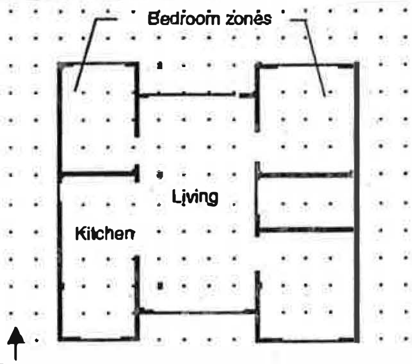

Fig.1 Floor plan of simulated building

The building had plastered single brick walls, tile flooring on a concrete slab, and uninsulated clay tile roofing with plasterboard ceiling. The U-values of the wall and roof assembly were estimated using the method developed by Mackey and Wright (1945). The windows glazing was single pane and operable.

Overhangs shaded all windows, and the length of the overhangs was the same as the height from the windowsill to the bottom of the overhangs.

When the windows were opened the ventilation rate was estimated from the equation: $Q = C_v * A * v$, *where* C_v = effectiveness factor (0.5 if the wind is perpendicular to the openings and 0.3 if diagonal), A = area of inlet, and v = wind velocity (ASHRAE 1997). Each room had openings for both inlet and outlet. The wind velocity was estimated from the measurement in the case study.

There were five occupants in the building and it was assumed that four of them would leave the house during the day and return in late afternoon. The lighting was mostly incandescent with a load density of 10 W/m^2. Small equipment's load density was estimated to be 4 W/m^2. No air-conditioning system was used in the building.

The alternative strategies to be tested were those that could be applied within the constraints of the site. These included (1) varying the wall thickness and mass, (2) adding radiant barrier and roof insulation, (3) changing the schedule of opening the windows, (4) varying the building orientation, and (5) adding more shading to the building. However, due to the space limitation, only the first three results are presented in this paper.

2.2 Case study building

The case study building was a two-and-a-half story building also located in Jakarta. The building had a similar zoning as the simulated building. The main structure was reinforced concrete and the walls were plastered single bricks. Natural stones, adding 5 cm more to the thickness, covered the walls of one half of the house. No insulation was used in either the wall construction or under the clay tile roof. The floor was polished concrete slab. The windows, about 30% of the total wall area, were clear glazing, and mostly located on the north and south facing walls. Not all windows were operable, and during the period of the study only few windows were opened sometimes. The main inlets and outlets for natural ventilation were the permanent openings (i.e. screened holes), amounting to 20% of the total wall area. The average ceiling height was 3 m. The building was not air-conditioned.

Hourly monitoring was conducted during November and December 1997. Several calibrated data loggers were used to monitor the indoor and outdoor temperature and relative humidity in the family room (first floor), and the sitting room (second floor). The occupants' thermal sensations and preferences during the monitoring period were also recorded.

3 Simulation Results

3.1 Heavyweight vs. lightweight

The first simulation was to test the performance of heavyweight construction against the suggested lightweight construction. Four wall material assemblies were tested: single brick, double brick, uninsulated and insulated timber frames with timber sidings. Fig.2 shows that in the hottest week of January, the peak indoor temperatures in the living area of a house with single brick walls were about 3 K lower than with uninsulated timber framed walls.

Double brick walls, would perform the best during the day, but they would make the temperatures late in the evening and early in the morning the highest amongst the other alternatives due to the heat stored in the mass. Insulating the timber walls did not improve the performance of uninsulated timber walls as the insulation would trap the heat inside. In the whole year, however, with lightweight construction, there were 6118 hours when the indoor temperature in any zone reached above 27 °C, whereas with single brick walls there were 6334 hours.

The monitoring of the case study building reveals similar results. During the monitoring period, conducted in November 1997 in unusually hot days (allegedly an El Nino effect), the outdoor temperature reached about 36 degrees. The peak indoor temperature, however, only reached about 30 °C (Fig.3). The mass of this building was effective in retarding the external heat. Later in the evening and early in the morning, the indoor temperature was only slightly higher than the outdoor temperature. In previous work, Hyde and Docherty (1997) found similar results in their performance studies of various constructions of houses in the hot-humid tropics of Australia. They also found that to cool the mass some occupants chose to use some form of active system. In this work I do not propose the use of such mechanical system. Controlling the opening of the windows, as shown later, may eliminate the need for such system.

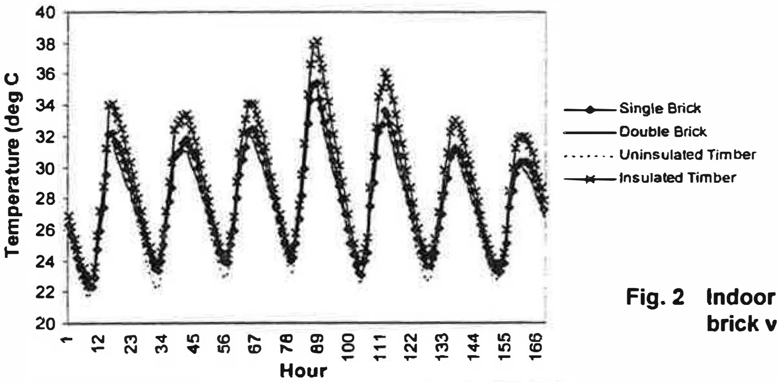

Fig. 2 Indoor temperature with brick vs. timber

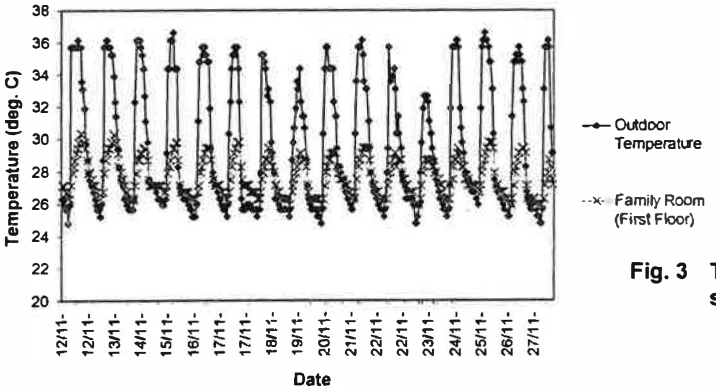

Fig. 3 Temperature of case study building

3.2 Adding radiant barrier and roof insulation

The simulation results also showed that during the peak hours most heat gains were from the roof, whereas the windows were the second source of heat gains. This is not surprising, since near the equator the sun is always at high angles during the day. In spite of this, the majority of houses' roofs in the tropics are not insulated even though lately there have been some houses with radiant barriers. Two tests were conducted to investigate the effect of radiant barriers and roof insulation. The first was to add only radiant barriers. To simulate this, the solar absorptance of the roof was changed from 0.75 (clay-tiled roof) to 0.10 (radiant barrier under the roof tiles), but the U-Value was not changed. Solar absorptance of 0.10 was estimated from the emittance of reflective foils. The second is to add roof insulation above the ceiling and radiant barrier under the roof tiles. The U-Value of the roof was changed from 2.59 W/m^{2}K to 0.54 W/m^{2}K, and the solar absorptance was also changed. The results as presented in Fig.4 show how installing radiant barrier could significantly improve the performance of the house. It reduced the indoor peak temperature by almost 7 K. Adding roof insulation, however, would increase the indoor temperature. As discussed previously, adding insulation in the house construction in these climates may be a disadvantage as the insulation would trap the heat.

3.3 Opening the windows

In the previous simulations 70% of the windows were assumed to be open all day and night to allow continuous cross ventilation. Realising that the outdoor temperature could reach 35 degrees or above, opening the windows all the time may actually become a disadvantage; therefore, regulating the window opening may improve the indoor temperature. In the next simulation 90% of the windows were assumed to be closed from 11 am to 5 pm and open for the rest of the hours. In the simulation this was done by applying a schedule for the natural ventilation rates. The building to be simulated was the single-brick with radiant barriers but no roof insulation. The results as presented in Fig.5 show an improvement of the indoor temperature. By closing most of the windows during the peak time of solar radiation, the indoor temperature could be 3 to 4 K lower than the outside temperature. Then fully opening the windows from 6 o'clock in the afternoon until the next morning would bring the indoor temperature close to the outdoor temperature, which would have dropped during the night. With this strategy, the number of hours in a year when the indoor temperature of any zone reached above 27°C decreased to only 3830 hours.

As discussed in the beginning of this paper, opening the windows may create other problems such as noise and dust. However, in this investigation the windows were opened in the evening and early in the morning. This is the time when the outdoor noise levels and activities have slowed down. Therefore, the author believes that this simple strategy can still be applied.

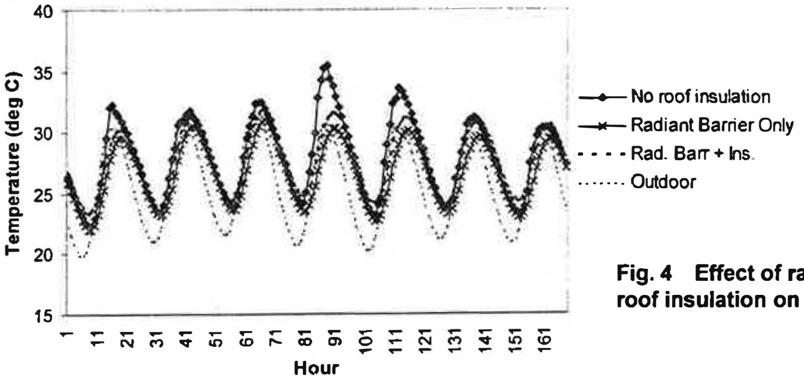

Fig. 4 Effect of radiant barrier and roof insulation on indoor temperature

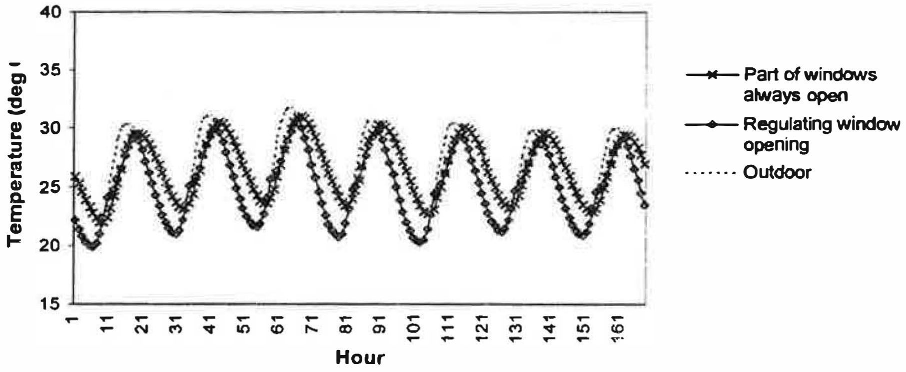

Fig.5 Effect on indoor temperature of regulating window opening

3.4 Discussion and conclusions

The traditional approach for buildings in the tropics suggests the use of a lightweight and breathable construction to allow air movement in the space. However, the results, supported with measurements from a real house, suggest that a high thermal mass construction can have a similar performance, as long as there are adequate openings at the right wind direction to let the heated air out in the evening. During the day it is suggested that most of the windows be closed to help reducing the heat gains through the openings, and at the same time preventing the external noise and dust from entering the house. In this condition, air movement can still be promoted through the use of fans. The most significant finding of this study is the effect of applying radiant barriers to the underside of the roof. Adding radiant barriers showed a reduction in the peak temperatures of 7 K from the house without radiant barriers.

These studies have demonstrated three critical passive strategies for tropical residential buildings located in a limited lot. Adding radiant barriers is very important, and it is a strategy that can easily be applied. The currently preferred construction, high thermal mass with operable windows, will not only reduce the noise and dust problems but also offer a good thermal performance. Finally, whenever possible, the building and the openings should be oriented to avoid low angles of afternoon sun, and at the same time catch the breeze to allow cross ventilation.

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