THE COST EFFECTIVENESS OF TYPICAL MATERIALS IN RELATION TO INDOOR COMFORT OF PASSIVE COOLING STRATEGIES APPROPRIATE FOR SMALL ONE STORY HOUSE IN CHIANG MAI, THAILAND

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Abstract. This study suggests that the appropriate building materials are those most common in a given locale considering simple appropriate natural passive cooling strategies for a typical small one story house to apply toward traditional living. Two different weather conditions, hot-dry and hot-humid, were selected representing seasonal climates. Computer simulations on thermal effect and ventilation were processed by CFD software, FLOVENT 6.1. Ordinary building materials have been chosen to compare relationship between outdoor-indoor temperature differences and their costs. It was found that natural cross ventilation is the best solution for a small one-story house with additional assistance of thermal mass effect. The most effective typical wall and roof materials are the conventional 10cm brick wall and 5mm corrugated fibrous cement roof which give the best performance for comfort at a unit investment cost. Simulated results also showed that the same house with typical horizontal ceiling presents better comfort than non-ceiling case.

Keywords. Cost effectiveness; Construction materials; Passive cooling; Chiang Mai house; Comfort

1 Introduction

Chiang Mai is a rapidly growing city. People in the city have a wide range of incomes: some can easily afford to purchase a luxurious house, but some can hardly afford a small, comfortable house. Several government housing charity projects have appeared on many small pieces of land creating dense, inappropriately designed communities in many sub-districts within the city of Chiang Mai.

The upper part of Thailand has the potential to allow the application of passive cooling strategies because in the summer the ambient daytime air temperature can reach 40 C then fall to 23 C during the night-time, which makes it possible to reduce indoor temperature.

The objectives of this research are firstly to find the typical low cost materials that are suitable for a passive cooling strategy for Chiang Mai's climate and secondly to suggest appropriate passive cooling techniques for a small one-storey house in this city and nearby provinces. Initially, the Computational Fluid Dynamics (CFD) software is selected for economic reasons to analyze all thermal and ventilation conditions in stead of constructing and measuring a real house.

2 . Thermal Transmission through Building Materials

2.1 . CONDUCTION

The conduction rate depends on the thermal conductivity values. Every material has a different thermal conductivity value so the higher the value, the faster the heat will be transmitted by conduction. Expression of heat conduction is:

$$Q_c = k \quad A \quad t/d \quad (1)$$

Where Q_c is heat transfer by conduction in Watts (W); k is thermal conductivity in W/m C, A is area of surface in m^2; and t is the temperature difference in C that the heat passes across the distance (d) in meters of material.

2.2 . CONVECTION

Convection is the transmission of heat, by thermal expansion effects both naturally and artificially, from one fluid through a solid surface or another fluid. In natural convection, the size, shape and orientation variously influence the amount of convective heat transmission to or from the building's fabric. The scientific formula for the convection process is:

$$Q_{cv} = h_c \quad A \quad t \qquad (2)$$

Where Q_{cv} is heat transfer by convection in Watts (W); h_c is the heat transfer coefficient by convection in W/m^2 C; A is area of surface in m^2 and t is the temperature difference between the object and the air (C).

2.3 . RADIATION

Radiation is the flow of energy through any transparent substances due to the travel of electromagnetic waves. Thermal, presented in this case, is the electromagnetic wave in the band containing infrared. All objects naturally emit thermal radiation. One object at a higher temperature value always radiates heat to the lower until an energy balance occurs between both objects. Size and emissivity are involved in radiative quantity. Therefore:

$$Q_r = \qquad A \quad T^4 \qquad (3)$$

Where Q_r is heat transfer by radiation in Watts (W); is the Stefan-Boltzmann constant, i.e. 5.67 10^{-8} $W/m^2 K^4$; is the emissivity of the surface (dimensionless); A is area of surface in m^2 and T is the Absolute Temperature of object (K).

3. Passive Cooling and Applicability

Passive cooling covers all natural occurring processes and techniques of heat dissipation and modulation, including heat protection and related building design techniques. Some passive cooling techniques that relate to human comfort do not increase the cooling effect but extend the thermal comfort boundary of humans.

3.1 . NATURAL VENTILATION

Natural ventilation creates air movement to cool occupants and gives an effective air exchange in the room. Unfortunately, natural breezes cannot be scheduled therefore some additionally active air movement systems should be installed to maintain the occupants' indoor comfort. Natural ventilation strategies require the building to be opened the whole day to allow comfort airflow. In a region where the temperature normally exceeds thermal comfort with an obviously small diurnal range, the air movement around the human skin can shift up a few degrees of temperature above the upper comfort limit accelerating the moisture evaporation from the body.

3.2 . RADIANT COOLING

Thermal radiation happens everywhere depending on the temperature difference. A fast cooling rate of a building's fabrics makes the building cool in the early night hours. When direct and indirect sunlight falls on the outside surfaces of building especially the roof, it reflects and absorbs heat at the same moment. The radiant effects naturally occur at night depending on sky temperature, which is the product of the sky emissivity and dry bulb temperature. Calculation of sky temperature requires the values of sky's emissivity (Berdahl and Fromberg, 1982).

3.3. MASS EFFECTS

A building material, considered as a thermal mass, is actually known as a mass that influences its own thermo-physical condition and air volume inside the building. Density, thickness, conductivity and the specific heat of materials produce thermal effects on comfort. These properties lead to a difference of heat storage in materials during daytime and nighttime caused by air temperature, moisture content, solar radiation, sky components and surroundings.

4 . Thermal Comfort

The thermal balance of the body is dependent upon how much heat gain or loss occurs. There are 6 main factors influencing human comfort: air temperature, relative humidity, air velocity, mean radiant temperature (MRT), clothing and activity. Determination of comfort has been determined with the Psychrometric chart or the Bioclimatic chart. It was assumed that people wear light clothes during hot period in their house.

4.1 ENVIRONMENTAL TEMPERATURE

The air temperature and mean radiant temperature have been used as a comfort indicator. When two factors are approximately combined together, the Environment Temperature (T_{env}) in Equation 4 has been weighted significantly to MRT more than the dry bulb air temperature so it is suitable to be a comfort indicator in warm to hot climates:

$$T_{env} = (2/3)MRT + (1/3)DBT \quad (4)$$

Where T_{env} is the environmental temperature. It is noted that differences between MRT and DBT should not exceed 3 C to be considered close to comfort level (Szokolay, 2004).

4.2 . THAI'S COMFORT

For Bangkok, the comfort range for natural ventilation buildings conducted by a field survey showed that the comfort temperature was found within the range of 25.5 C to 30.5 C since the neutral temperature was at 28.0 C (Rangsiraksa, 2006).

Thiengburanathum and Assawamartbunlue have studied on dwelling in Chiang Mai with regard to life-cycle assessments. They found that the comfort upper limit could be extended to 30 C by utilizing a ceiling fan according to ASHRAE (1997)'s comfort zone.

5. The Chiang Mai Climate

Chiang Mai is a province in the northern part of Thailand. Chiang Mai City is situated at 18.8 north latitude and 99.0 east longitude. It is at 312 meters above the mean sea level.

In the winter period, November to February, the average minimum and maximum temperature is about 16 C and 30 C respectively. The relative humidity is moderate.

Chiang Mai's dry summer is influenced by a prevailing wind from the south-east. The ambient outdoor air is very hot with strong sunlight in the afternoon. The average minimum and maximum temperature is about 22 C and 35 C respectively. Humidity is low. Air speed is 1.68m/s.

In the humid season, the air is cooler than the summer in daytime, which creates a narrow diurnal range. Average minimum and maximum temperature is about 23 C and 31 C respectively. Air speed is 1.17m/s.

6. Materials and Cost

Low to middle income people usually search for available low cost materials without carefully considering their properties. Table 1 gives examples of typical material prices in Chiang Mai.

TABLE 1. *Typical material prices (Ministry of Commerce: April 2006)*

Materials	Unit Price (Baht)	Construction cost includes labor cost per unit area (Baht/m^2)
Brick 7x16x3.5 cm	0.87	420 (rendered)
Concrete block 7x39x19 cm	6.54	380 (rendered)
Fibrous cement panel 0.8x400x20 cm	140	250 (structure included)
Hard wood panel 2x400x15 cm	390	870 (structure included)
Aerated concrete block 7.5x20x60 cm	19.8	422 (rendered)
Corrugated fibrous cement 0.5x120x50 cm	40.19	215 (structure included)
Concrete roof tile 12x42x33 cm	12.15	340 (structure included)
Gypsum board 120x240x0.9 cm	146.73	220 (frame included)

7. Computational Fluid Dynamics (CFD)

FLOVENT version 6.1 software was used to analyze airflow and thermal transmission. Achieving simulation results, the process in Figure 1 must be followed:

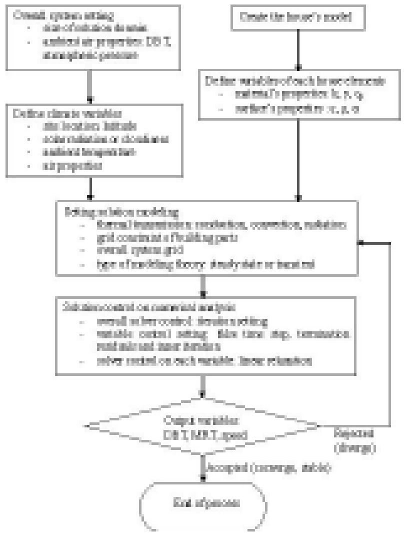

Figure 1. Simulation procedures in FLOVENT 6.1

8. Selection of Passive Cooling Strategies

Changes of season show obviously different diurnal range of outdoor air temperature. Figure 2 shows monthly climate plot in the psychrometric chart, which is partly a tool in climatic analysis and guideline for passive thermal design of ARCHIPAK 5.1 software (Szokolay, 2005). It shows Chiang Mai's climate in the extension of comfort control potential zone according to ventilative cooling strategy at 1.5 m/s of air speed. Applicability of mass effect strategy would be concerned additionally on MRT results.

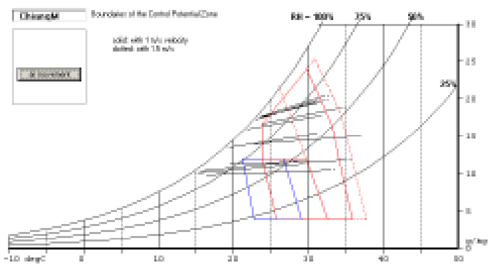

Figure 2. Boundaries of control potential zone from air movement 1 and 1.5 m/s

9. The Sample House Model

A typical sample house represented in this study was designed as shown in the floor plan and roof plan from figures 3. The research is concerned with the opportunity of low to middle income people to possess a more comfortable house than those existing choices throughout the property market. So, the design should not use heavy mass, which might incur a larger expense for the house's owners.

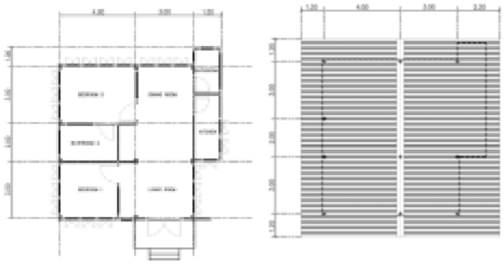

Figure 3. Floor plan and roof plan of the sample house

10. Results

10.1 . COMFORT VENTILATION

In this simulation, wind was assumed to be from a southerly direction at 0.5 m/s, which was approximately 30 percent of average wind velocity in the climatic data. All windows were set to open but the front door (north) and kitchen door (west) were closed. Every opening was installed with a mosquito net, which assumed a 60 percent opening area. The average air speed was found at 0.26 m/s, which means 52 percent of the exterior breeze.

Figure 4 shows air movement direction at 150 cm above the floor level. It can be seen that windward windows allow external wind into the house. The wind passes entirely through every room and has obviously higher speed close to the windows.

10.2 . MASS EFFECT

It was assumed that outdoor radiant air temperature is always equal to ambient temperature. Brick and concrete blocks are the main materials for walls. Wood and fibrous cement panels were selected to simulate the light-mass effect. Fibrous cement corrugated roof and concrete tile are the typical roofing materials. Output variables from simulation are the average of dry bulb air temperature, MRT, and T_{env} in each room. Figure 4 shows an example of simulation result on mean radiant temperature at 150 cm level.

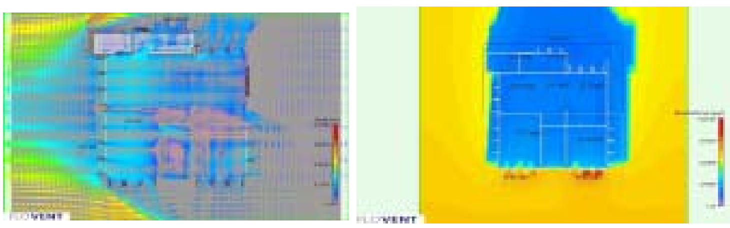

Figure 4. Simulated horizontal wind direction at 150 cm from the floor (left) and MRT for April 8am (right)

10.3. COST EFFECTIVENESS DUE TO MATERIALS AND

Ambient temperature is used as the reference level for each experiment by the following equation,

$$dT_{amb} = T_{env} - T_{ao} \quad (5)$$

Where dT_{amb} is the difference between calculated environmental temperature (T_{env}) and outdoor temperature (T_{ao})

The total cost of the wall and roof would set to divide the dT_{amb} values, forming the ratio of the ambient difference to the net wall and roof cost, expressed in C per 10,000 Baht, called here 'dT_{amb}/cost ratio' (dT_{amb}/Cost) x 10,000). In Figure 5 is shown the smaller the ratio the better regards with the thermal-cost effectiveness on each construction type.

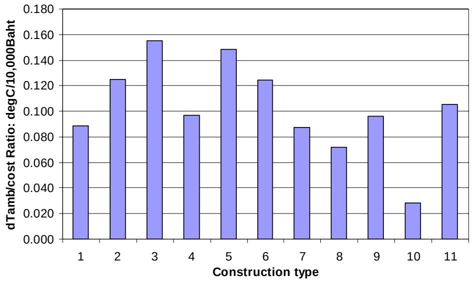

Figure 5. dTamb/cost ratio of chosen simulated construction types

11. Conclusion

In summer, the simulation results showed good distribution of air movement. The southerly wind at only 0.5 m/s can give air movement with the average of 0.2 m/s indoor at 1.50 m level. At this speed the excessive heat gain to the body would be relieved due to skin evaporation. People in traditional living always wear light clothes, which are responsive to a hot climate in summer. During calm hours the wind does not continuously blow, so some active air movement techniques are useful to maintain an occupant's comfort.

Mass effect on the typical materials does not show any improvement of comfort over typical construction. With typical thickness of brick, concrete block and fibre cement panel wall, simulations show temperatures during daytime peak hours below the outside by about two degrees. However, these materials show effects on heat storage during sleeping hours, at night, with a difference in temperature of almost 3 degrees Celsius from outdoor temperature. Wood materials give a close temperature to ambient air outside at night time, but people may feel very hot during daytime hours because of its small thickness.

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