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Thermal performance and cost effectiveness of massive walls under thai climate

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ABSTRACT

In Thailand, traditional houses and public buildings were constructed from materials of low thermal mass. Windows and doors in such buildings are well shaded. Open windows, doors, and even gaps in the raised floor allow all interior spaces in a building to be naturally ventilated. Prior to the introduction of air-conditioning, concrete began to replace wood as walling material. New large air-conditioned buildings have glazed and closed windows so all interior spaces require air-conditioning and forced ventilation. Under the present situation, there is a tendency to believe in the merit of thermally massive walls. This paper presents results from an experimental and simulation study on comparative energy and economic performance of thermally light and massive walls that are used to enclose air-conditioned spaces. The spaces are assumed to serve three residential functions and three commercial functions. Results related to residential functions reaffirm the merits of vernacular architecture. Results related to commercial functions are mixed. However, very massive walls are not economical.

1. Introduction

Thailand is located in a tropical zone. Most locations in Thailand have very low wind speed and natural ventilation is not effective in large buildings. For most days of a year, the condition in building interior is too warm for comfort. Air-conditioning has been introduced into Thailand since fifty years ago and has been increasingly used in consonant with the increase in disposable income. It has reached saturation in commercial buildings.

In urban areas, it is expected that air-conditioning has penetrated to a significant proportion of households. Air conditioning load accounts for over 70% of total electric load in a small household.

In air-conditioned buildings, heat gain through building envelope or due to building envelope can contribute significant load to air-conditioning systems. During daytime, solar radiation is the main force that drives heat gain through building envelopes. Heat is transferred through an opaque wall by conduction. The rate of heat transfer is influenced mainly by thermal resistance of a wall, the wall thermal mass and the wall solar absorptance. Additionally, the coefficient of convection heat transfer and thermal emittance exert certain influence.

In a review of vernacular architecture, Zhai and Previtali [1], identify local climate and cultural heritage as the main influence on ancient architecture of a location. The authors assert that for tropical region, houses were constructed from materials that offer good insulation and of low thermal mass, as evidenced by those of vernacular houses in two locations in Indonesia. Lindberg et al. [2], describes measured temperatures in walls of 6 test buildings in Tampere University of Technology. It was observed that for massive walls, heat could be transferred into the room during some periods when exterior temperature was falling. Thomsen et al. [3], refers to 12 houses in a project of the International Energy Agency (IEA) Task 13 that were designed to mainly demonstrate the effect of insulation, and of which 5 houses comprise massive walls. The overall results were considered successful in demonstrating low energy houses. Zhou et al. [4], considers appropriate size of internal mass for various types of external walls enclosing naturally ventilated spaces. Gregory et al. used a computer program developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) for rating of energy performance of residential buildings to simulate the effects of massive internal walls of a room module comprising four wall compositions under the climate of Newcastle in Australia [5]. The configuration that results in lowest cooling and heating energy comprises an external wall constructed from a single layer of brick and an external insulation layer that encloses a room with internal massive wall. The mass of this external wall is lower than the one with two layers of brick and higher than another one that comprises timber stud and insulation. Kalogirou et al. used TRYSYS, a well-known simula-

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tion program, to simulate heating and cooling energy consumption for a room module that comprised a massive internal wall behind a glazed window with overhang [6]. The results show that heating energy as well as cooling energy decrease with increasing wall thickness. The same TRNSYS program was used by Florides et al. [7], to simulate energy consumption of four room modules, each oriented in a different cardinal direction. Among many measures to reduce heating and cooling energy, wall mass and roof mass as well as insulation were tested simultaneously. The authors conclude that roof and wall insulation have significant effect on energy consumption. The results of studies on the effect of wall mass most relevant to the present paper is reported in [8] by Zhu et al. Two identical houses were constructed in Las Vegas. The walls of the baseline house were insulated to give an *R*-value of 2.15 ($m^2\,K\,W^{-1}$) with standard wall composition, while those of the so-called Zero Energy House (ZEH) comprised thick reinforced concrete with insulation that rendered an *R*-value of 2.06 ($m^2\,K\,W^{-1}$). In both cases, no shading device was used. Measurements of wall surface temperatures during heating, cooling, and transitional (no heating nor cooling) seasons show that wall temperatures of the massive wall fluctuate much less when ambient air temperature fluctuates diurnally in all seasons. Further more, the massive wall was able to store heat sufficiently during winter daytime that no heat flux flowed into interior wall surfaces even during nighttime, indicating that there was no heat loss. Computer energy simulation using Energy 10 shows much lower heating energy but slightly higher cooling energy consumption from the ZEH.

This paper first describes an observation on the climate of Thailand and Thai vernacular architecture and the recent trend in building design. It then briefly describes results of an experiment conducted in two identical experimental rooms. The results were used to validate results from a computer simulation program. The paper then presents and discusses results of computer simulation of a generic building model when the spaces in the rooms are consequentially assumed to serve three residential functions and three commercial functions. Two cases of wall mass variations are considered. In the first case, the density of the wall varies while its thickness and other material properties remain unchanged. In the second case, the wall thickness varies while all material properties remain unchanged. The paper then reports on economic analysis undertaken for the second case.

2. Thermal environment and building design

Traditional practice of housing construction normally is influenced by and reflects the climate of the location and cultural heritage [1]. Prior to the advent of air-conditioning, buildings in Thailand were designed for natural ventilation.

2.1. Thermal environment of Thailand

Fig. 1 illustrates the variation of dry-bulb temperature of the central region of Thailand.

The temperature varies from 25° to 35 °C over a daily range of about 10°C for every day except those in the cooler period of November to January. Daily range of relative humidity is 40–80%. Fig. 2(a) shows plots of climate data of a chosen day in late rainy season. The value of relative humidity shown is subtracted by 30%, so actual value ranges from 40 to 95%.

Fig. 2(b) shows monthly average hourly temperatures. Hourly temperatures of the four months of November to February exhibits distinct pattern of the cooler season where the values during the night to the early morning period are lower than those of all other months. The four overlapping graphs of the four months show lower values and are clearly distinct from those of the other months. The sky is clearer and radiation from the sun is much stronger than radiation from the sky during the cool season. The two months immediately following the cool season when radiation from the sun is strongest are hot and dry. Typical daily insolation is 18.5 MJ. The sky temperature of the central region is almost always above 20 °C and may even exceed air temperature for some hours during the rainy season, as exhibited in Fig. 2(a) where global radiation, Eglobal, is also shown. The temperature of soil beneath ground is close to monthly average air temperature.

2.2. Traditional houses and buildings

Traditional Thai buildings are constructed from materials of low thermal mass and rely on good shading and natural ventilation to achieve thermal comfort. This applies to individual houses and public buildings. In rural area, thatched roof and walls lined with dry broad tree leaves were commonly used. As noted in [1], the low thermal mass construction allows the interior air temperature to follow that of the cooling ambient air as evening approaches.

Unlike traditional construction practice in temperate and arid regions that utilizes mass to moderate interior environment, traditional Thai practice is the opposite.

2.3. Modern buildings

The architecture of large modern buildings in Thailand may no longer be distinguished from those of other countries. The floor is wide and the large glazed windows cannot be opened. Such buildings now fully rely on conventional air-conditioning to achieve thermal comfort. Two decades ago and earlier, walls of such buildings were constructed from local lightweight bricks that were plastered on both sides with cement mortar to a total thickness of 0.1 m. Concrete blocks, pre-casted concrete slabs and lightweight concrete blocks are now more commonly used.

Studies made since 1980 concluded that air-conditioning accounted for up to 60% of energy use and heat gain through walls accounted for up to 60% of load of the air-conditioning system of a commercial building [9], underscoring the importance of walls.

3. Experiment and calculation results

A set of experiments in two experimental rooms were conducted at a site about 100 km north of Bangkok. The results are used as baseline values for reference purpose and for use in comparison with results calculated from a computer program.

3.1. Experimental setup and facilities

Two experimental rooms were constructed on an open area of a factory located in Saraburi province, Thailand. The site is at latitude 14.3°N and longitude 100.55°E. The two rooms are identical (and are designated Room A and Room B). A station was also erected to measure solar radiation (global and diffuse), wind speed, ambient temperature, and relative humidity at the location. Fig. 3 shows the rooms and the station. Each is a single storey room with a pitched roof. The pitch angle is 30° with respect to the horizon. The roof ridge is aligned along the north-south direction. Under each roof, there is an attic chamber that is well insulated. The external dimensions of each room are 4 m wide by 4 m long and 2.8 m high. The station is situated between the two rooms.

The walls of the rooms are constructed of plastered lightweight concrete. There is a window on each wall and a door in each room. The interior and exterior surfaces of all walls were painted white. Each room is served by a fan coil to keep the air temperature to required level, with chilled water supplied from a small chiller of 3 refrigeration tons. For the purpose of validation of the calculation