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Evaluating thermal effects of internal courtyard in a tropical terrace house by computational simulation

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ABSTRACT

Thermal comfort conditions in residential buildings vary according to the designs, modifications of the house and adaptations of the occupants. The purpose of this paper is to examine thermal performance of terrace housing in tropical climate by exploiting internal courtyard. A case study of a terrace house was chosen, where field measurement was conducted during a three-day recording in naturally ventilated spaces of the house. Results from field measurement were used to develop a baseline model for computational experiment. Subsequently, the effects of introducing an internal courtyard on thermal comfort performance of the building were investigated using ECOTECT software. The results from simulation analysis indicate that, applying internal courtyard in the terrace house will improve natural ventilation and thermal comfort in spaces with openings to the outside environment. It shows that the influence of the internal courtyard on the thermal condition has a strong reliance on the envelop openings. This study suggests that the internal courtyard of a terrace house can affect improvements in thermal conditions of the courtyard's surrounding spaces, provided sufficient and efficient openings with shading devices are suitably incorporated.

1. Introduction

The concerns over global warming and need for reduction of high emission of greenhouse gases, demand the utilization of strategies for indoor climate modification in promoting comfortable indoor environment [1]. In warm humid tropics overheated building interior are common due to solar penetration through the building envelope and windows, and lack of ventilation [2]. Terrace houses, as one of the most common typologies of residential buildings in Malaysia, are also faced with these problems. Because of the high density of the building blocks and the crowded dwellings, a large number of buildings do not fulfill the requirements for thermally comfortable environment. Several studies have been undertaken by researchers in tropical climates in relation to thermal comfort in residential buildings [3,4], in which the main scope of the studies was to find the neutral temperature appropriate to the warm-humid climate. Findings revealed a higher comfort temperature exists in comparison with those recommended by international standards, whereby in naturally ventilated buildings the upper range of comfort can be stretched with the aid of higher natural air movement. Many bioclimatic design strategies for improving the natural ventilation have been proposed in different studies and some of them are also used in practice [5]. One of the suggested strategies is to include internal courtyard in the house in order to optimize the climatic source according to its thermal mass effects. On the other hand, solar radiation which is received by the courtyard surfaces will affect the thermal performance of the internal spaces especially in areas adjacent to the courtyard. The amount of heat gain through radiation depends on climatic conditions, the time of the year and configuration of the courtyard [6].

Courtyards are commonly used in terrace houses in Malaysia to provide ventilation and/or natural lighting to interior rooms. The same principle has been used in many traditional urban shop houses, mostly found in Malacca and Penang. So far, thermal performance of courtyard building has been investigated by several researchers [2,7–9]. These studies have mainly evaluated detached buildings, such as bungalows, where there is no limitation of land size and opening. Therefore, this study is intended to investigate the influence and effectiveness of internal courtyard on thermal performance of terrace houses in a warm-humid climate, in order to explore its advantages and to offer recommendations. The two main objectives of the current research are as follows:

(1) To investigate the thermal performance of an existing terrace house under warm-humid climate.

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(2) To examine the effects of introducing an internal courtyard on the indoor thermal condition.

To this end, a field measurement exercise was conducted in the selected terrace house, followed by computer modeling work using 'ECOTECT' software to simulate thermal performance of the building. Subsequently, the calculated values from field measurement and the simulation results were compared for validation purposes.

1.1. Ambient climate

The study area is located in Kuala Lumpur, Malaysia, which is situated at latitude 3°7′N and longitude 101°33′E. Being close to the equator, the hot and humid conditions are emphasized with heavy rain fall and sunshine throughout the year. It has a yearly mean air temperature of about 27 °C and relative humidity (RH) of 70–90% throughout the year [3]. Moreover, the monthly mean of maximum air temperatures ranged from 33.5 °C in March and April to 31.9 °C in December, while monthly mean of minimum temperatures ranged from 23.1 °C in January to 24.3 °C in May [10]. On the average, Malaysia receives about 6 h of sunshine per day, when in most places recorded solar radiation ranging from 14 to 16 MJ m^{-2} per day. Rainfall distribution pattern over the country is recorded from 2500 mm to 3500 mm which is the result of seasonal wind flow patterns coupled with the local topographic features.

In fact Malaysia experiences uniform high temperature and high humidity throughout the year, accompanied by heavy rainfall and weak wind velocity. Heat and humidity are the main issues that need to be considered for achieving comfort in this climate.

1.2. Thermal comfort

Thermal sensation is affected by environmental factors, namely air temperature, mean radiant temperature, air movement, humidity as well as the clothing worn and the activity being performed [11]. Producing a unified means of assessing thermal comfort by taking into account some or all of these factors into a single index was the major concern of researchers previously. An elaborate prediction of thermal comfort at steady-state conditions has been carried out by Fanger [11]. Even though his experiments were conducted in temperate climate, Fanger proposed that PMV (predicted mean vote) can be used for the tropics by applying the method on the findings of Ellis [12]. In his work Ellis investigated European and Asian subjects in Singapore and the thermal neutrality established was found to be similar to the value proposed by PMV.

While several field studies seem to agree with the results obtained by using the Fanger's PMV, some have found discrepancies with it [13]. deDear found that PMV can predict the comfort temperature for air-conditioned buildings more accurately, in comparison with naturally ventilated buildings, since people in free-running buildings will accept higher internal temperatures. These new trends caused Fanger to propose an extension of the PMV model for naturally ventilated buildings in warm climates [14]. In their study, an expectancy factor has been proposed for non-air-conditioned buildings, which will be multiplied with PMV value. The current study applied the expectancy factor of 0.9 for PMV calculation.

2. Methodology

Field measurement has been conducted to investigate the thermal conditions in an existing naturally ventilated terrace house under warm humid conditions. The field measurement information was then used to develop the baseline model for the computer simulation work. ECOTECT software was applied to build a model for the case study building. Accordingly, thermal evaluation of the model was conducted for two different conditions which were: the existing house and the thermal effects of introducing an internal courtyard in the house.

2.1. Field investigation

2.1.1. The terrace house

A double storey terrace house with a built-up area of 219 m2 was selected as the case study. As Fig. 1 illustrates, the ground floor consists of family areas (kitchen, living area, dining area and utility) and the first floor consists of bedrooms and bathrooms.

The building openings are oriented in Northwest Southeast direction, where the front façade (NW) has large windows to enhance cross-ventilation as well as admitting natural lighting in the building (refer to Fig. 2).

2.1.2. Field measurement

In Malaysia, April has been recognized as a month with higher air temperatures [10]. Hence, the field measurement was conducted during three days in April of 2007. Under each boundary configuration air temperature, relative humidity, air velocity and globe temperature were monitored using 'Thermal comfort data logger INNOVA'. The data logger was placed at the central part of the family area (in the middle of living and dining area on the ground floor) at

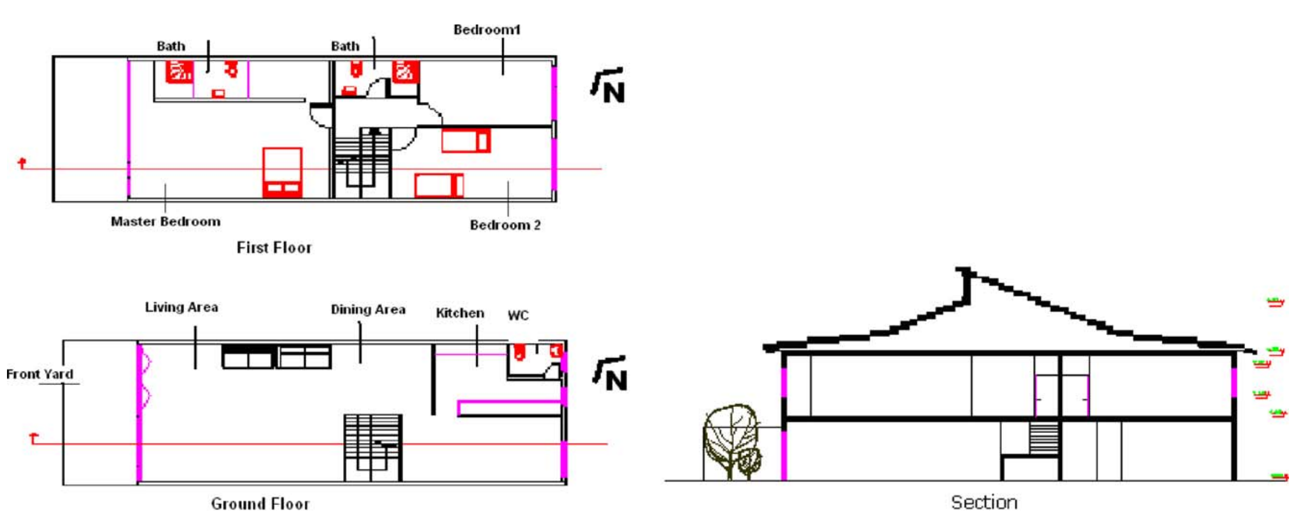

Fig. 1. Floors plans and longitudinal section of the case study terrace house.