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Experimental and numerical studies of reducing cooling load of lecture hall

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ABSTRACT

In this paper, the cooling load of a lecture hall in a hot, humid climate requiring sustainable energy consumption is investigated experimentally and numerically. The polyethylene aluminium single bubble (PASB) is used as an insulating material placed on the external wall for the lecture hall with dimensions (15 m × 12 m × 6.6 m) at University Putra Malaysia (UPM), Selangor, Malaysia. The measurements of air temperature, air velocity, relative humidity and the number of students using the lecture hall for the whole month of April 2012 were used as input parameters for the three-dimensional computation of fluid dynamics (CFD). The results show that the potential temperature reduction inside the lecture hall was around 3 °C when using the (PASB) as insulating material, leading to a potential saving of 500 USD per month.

1. Introduction

Many researchers have studied how to decrease the air conditioning cooling load while maintaining a comfortable indoor environment including, Chu et al. [1], Cheong et al. [2], Gan [3], Pan et al. [4], Stamou and Sun [5], Daghigh [6], Dahlan [7], Wahhad [8] and Wong [9]. However, Sookchaiya et al. [10] who conducted a study on buildings in Thailand recommended that the Thai Building Code be modified to suit an integrated approach for all building life cycle phases since this will improve the energy consumption of the buildings while preserving natural resources through recycling building materials Gheewala and Kofoworola [11]. Mahlia et al. [12] compared cooling loads on buildings fitted with insulation and those without insulation, on a mathematical basis for buildings in selected Malaysian cities. Their results showed that the cooling costs were affected by the increments in the fibreglass insulation thickness.

Fuller et al. [13] showed the application of a concrete insulated wall could maintain the required temperature of wine in a cellar. Yongson et al. [14] found the direction of airflow in an air conditioned room changed path in accordance with the components of the room and its occupants. This means that the occupants should feel cooler if they were positioned on a plane that was closer to the air-conditioning unit blower.

Samuel et al. [15] researched the effects of dynamic insulation and found that it had the potential to save 9% of heating energy for a house and that there was an additional 5% recovered from the air-to-air heat exchanger. Synnefa et al. [16] focussed on the need for passive solutions to reduce the energy consumption of the cooling units and improvement of the indoor thermal conditions. They found that applying solar reflections on the ceiling helped in reducing the incoming outdoor heat, thus reducing the energy loads on the indoor thermal requirements. However, the insulation has to be applied to enhance the thermal condition inside the new and existing houses or buildings, especially those undergoing major renovation, as one practical step, among others to achieving improved building energy-efficiency [21–23].

Aldawi et al. [24] analysed the energy saving potential and thermal performance of three varying configurations of a concrete wall system under different climates in Australia. The outcomes were compared with a conventional brick veneer wall system. The concrete wall designs showed heating and cooling energy reductions of about 10% to over 47% depending on the configuration and climate zone.

One of the methods to envelope the building is with insulated building walls, which also protect occupants from extreme weather conditions and can damp down large fluctuations in temperature. As such, to reach to the thermal comfort condition and reduce the energy consumption for heating and cooling, it should provide

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occupants with necessary thermal condition. This is can be done through increasing the thermal resistance of this envelope and, hence, reducing transmission loads. Therefore, the addition of thermal insulation is important, particularly in regions with extreme climates [25].

The location of insulation to minimise heat gains and losses in the building walls was also analysed by Ozel and Pihtili [26] focusing on three different climatic locations in Turkey. The study showed that the different climate conditions did not have a noticeable effect on the insulation location.

The objective of this paper is to evaluate the reduction of the cooling load temperature for a lecture hall with and without PASB insulation experimentally and numerically.

2. Experimental work

2.1. Test room (LH)

Data on the air temperature, relative humidity, air velocity and the number of students who occupy the 50 classrooms from 9:00 to 17:00 were collected over a four-month period. The results led to the selection of the lecture hall with the highest cooling load due to number of occupants and its location. The front wall has covered by PASB insulation which is exposed to the sun for most of the day. The hall size was (15 m length × 12 m width × 6.6 m height) as displayed in Fig. 1. The data was collected in the hall for one month (April 2012).

2.2. Experimental setup

A thermo-hygrometer with accuracy of +5 °C was used to measure the air temperature in 50 rooms to find the hottest model for this study, but with this data accuracy the results were not accurate. Thus, the device was changed to the VELOMETER AVM 440 to record air velocity, air temperature and humidity. An infrared thermometer was used to confirm the results of the mentioned devices. The insulation material polyethylene aluminium single bubble PASB was selected and used to determine its potential for the reduction of heat entering a lecture hall. It was placed directly on the external wall of the lecture hall. The foil of 8 mm thick bubble comprised of a layer of polyethylene air bubbles sandwiched between two layers of 99% pure aluminium foil. The PASB is 99.9% pure aluminium with reflectivity at 97%, 0.03 emissivity and 0.275 mm thick. The thermal conductivity was 0.034 W/mK with density 85 kg/m^3. Table 1 presents the tools and devices used in this experiment.

Table 1
Tools and devices.

Item	Number	Function
Coating material	1	Polyethylene aluminium single bubble (PASB)
Screw or nail	6	To install the insulation
Fast response thermo-hygrometer	1	To measure air temperature and air humidity inside the hall
Velometer AVM 440	1	To measure air velocity High accuracy with maximum reading of 30 m/s
Infrared thermometer	1	To measure wall temperature
Infrared thermometer stand	1	To hold infrared thermometer
Computer	1	For software and data analyses
Digital camera	1	For taking photographs

3. Numerical simulation

3.1. Boundary conditions

A CFD programme, code Fluent 6.3 [17] was used to conduct all the simulations. The re-normalisation group (standard-enhance wall treatment) k–ε turbulence model was used in this study. The Y$^+$ limit had to be checked to ensure that there were enough cells in an area near the wall to make the equation of turbulence model able to solve changes in the inner wall region; the Y$^+$ for k–ϵ is acceptable from (0 to 5) when using the boundary layer, Fluent, Inc. [17]. The boundary conditions for air velocities ranged between 0.14 and 0.34 m/s for a supply diffuser with air temperature of 20 °C in the lecture hall. The surface temperature of the internal wall facing the front of the hall was set at 33 °C; the right side was set at 27 °C, the left side, rear walls, floor and ceiling were set at 24 °C. These fixed temperatures were measured by using the infrared thermometer that was used to profile the wall temperature. The air velocity was set at 0.1 m/s, with air temperature of 30 °C for the ceiling exhaust located at the end of the lecture hall. The 80 occupants were modelled to generate heat of 68 W/m^2 (ASHRAE) per person, while the power of 50 fluorescent lights was set at 225 W and 200 W from the projector (MS overhead 1525). More cells at the boundary layer were used to accommodate the existence of high temperature; a type of grid used to mesh the geometry was

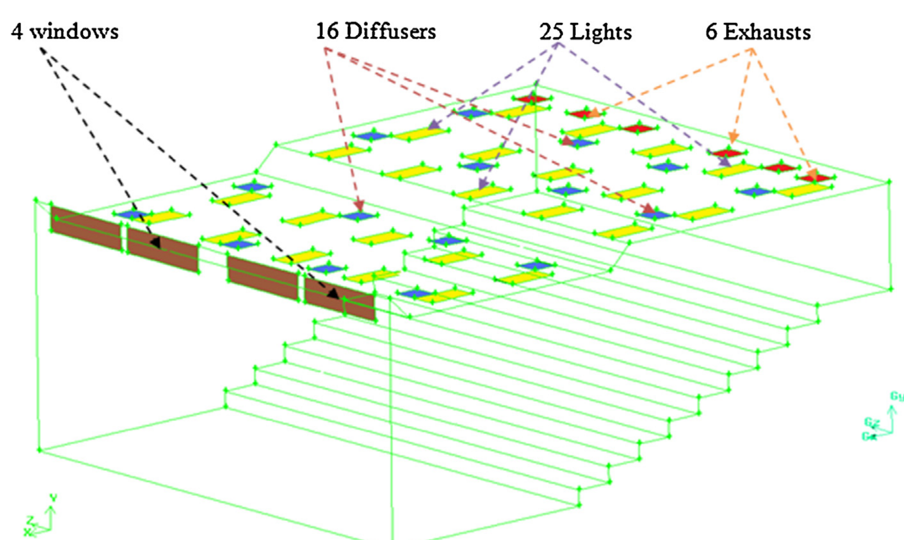

Fig. 1. Test room.