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Sensitivity analysis of heat transfer rate for smart roof design by adaptive neuro-fuzzy technique

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ABSTRACT

Thermal comfort in the building is a major concern among the design expertise especially in tropical countries. Therefore, it is important to design a smart roof system to reduce the heat gain of the building and enhance the resident's thermal comfort. The leading feature of this system is using PVC tubes integrated with a layer of insulation material and fans and located at the underside of the roof to act as a moving-air path (MAP) system. Indoor experiment is carried out on the scale roof model and the heat transfer rate into the attic is determined using experimental data. Next, Adaptive Neuro Fuzzy Inference System (ANFIS) is applied as a soft-computing method determine the predominant variables that affecting the thermal comfort in the building. Training and testing data of the ANFIS model are collected from the experimental measurement. Mass flow rate, solar-air temperature, inlet air temperature, outlet air temperature and ambient temperature are the input parameters used to compute the output parameter which is the attic temperature. The results indicated that the combination of mass flow rate and ambient temperature is the primary factor and the best predictor accuracy for thermal comfort in the building.

1. Introduction

Thermal comfort in the building has always been a main concern for building occupants as well as architectures, engineers and interior designers. The local climate is one of the key factors decide the basic requirement for the thermal comfort in the residence. Most of the residential buildings do not have an air-conditioner installed in the building in the coastal areas and mild climate zones. So, the cooling system of the building is fully depended on the natural ventilation [1]. Therefore, it would be a terrible condition without proper ventilation system in the building during the summer and high rate of electricity consumption is used to cool the building. Moreover, in Malaysia, the relative humidity and the ambient air temperature lie in the ranges of 60–90% and 26–40 °C, respectively [2]. This climate will stimulate uncomfortable environment for human beings. Furthermore, in the low-rise residential building, the high intensity of heat is transmitted into the building through the building envelope. From the literature survey, it is shown that 70% of the heat gain of the building is through the roof [3]. Therefore, it is very important to find a sustainable technique to minimize the heat gain and electricity consumption by incorporating energy efficiency concept into the building design.

Attic ventilation has been a long period of application in the residential building, especially passive ventilation system which consumed less energy [4]. Adequate natural ventilation helps to replenish the air in the building with fresh air. Thus, moisture in the building can be maintained at a satisfactory level. However, natural ventilation heavily depends on the availability of wind flow. If the wind speed is low, then the alternative way is to introduce the buoyancy drive ventilation system. Buoyancy flow is caused by the difference of air density inside and outside of the house which is due to different level of moisture and temperature [5]. Indoor hot air is dissipated to the outer environment through buoyancy flow. Although buoyancy ventilation is more energy efficient, this process is slow and ineffective.

There are several studies on improving thermal comfort in the building through empirical study [2,6–9] and numerical modelling

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Nomenclature

A	Area of tube opening, m^2
A_F	Roof area, m^2
C_p	Specific heat capacity of air at constant pressure, $Jkg^{-1}K^{-1}$
Q_s	Radiation heat supplied by halogen bulbs, W
Q_A	Heat transfer to attic, W
Q_{ve}	Exhausted heat, W
T_{attic}	Attic air temperature, K
T_i	Inlet temperature, K
T_o	Outlet temperature, K
$T_{sol\text{-}air}$	Solar-air temperature, K
ρ	Air density, kgm^{-3}

Subscripts

cond	Conduction
cov	Convection
rad	Radiation

[10–12]. Ong [2] found out that insulation layer installed under the roof tile will help to reduce the temperature in the attic. Among six different types of passive roof designs, installation of roof solar collector (RSC) on the roof resulted significant attic temperature reduction which is around 13 °C less compared to the uninsulated roof design [2]. Gagliano et al. [6] emphasized on the position of the insulation layer is the key factor that influences the performance of the ventilated roof. Besides, heat gain of the building is depended on the roof surface temperature and the surface temperature is affected by the orientation and tilt angle of the roof design [7]. Hence, indoor heat gain and moisture content can be reduced remarkably by improving the ventilation system to achieve a low energy building [6]. Khedari et al. [8] and Hirunlabh et al. [9] investigated the performance of RSC under natural ventilation. The experimental results showed that the minimised length is less than 100 cm for the RSC and the tilt angle is 30° to circulate the natural ventilation of 0.08–0.15 $m^3 s^{-1} m^{-2}$ [8,9].

Ozel and Pihtili [10] used numerical models to determine the ideal configuration and position of the insulation layers in the roofing system. The simulation results concluded that 3 pieces of insulation material placed on the inner, middle and outside roof surface are needed to achieve the best load levelling on the 20 cm thick roof structures [10]. However, the results are based on simulation and did not validate with experimental measurements. Jayasinghe et al. [11] observed the influence of the orientations of roof, materials and colours of the roof surface on the inside temperature of the building in tropical climate. They suggested that the thermal performance of the clay tiles as a roof covering material is better than that of the cement fibre sheets. Besides, aluminium foil with/without polystyrene could be used as an insulation material to improve the occupants comfort inside the building. In addition, light colour of the roof surface is an alternative way to enhance the indoor thermal comfort during hot climates [11]. Kumar and Suman [12] used numerical models to determine the thermal conductance coefficient, U factor and thermal resistance, R value of different sorts of building insulation materials. Those materials are available in the India and validated with experimental results. Among 112 samples of study, only 50 mm of Elastospray material satisfied the requirement of the Energy Code and Building Code of India. Most of the research are focused on improving the performance of the passive ventilation system and relatively little attention is paid on the active ventilation system. Hence, this leads to recognition of critical gaps in building ventilation system design, which is not filled with current ventilation strategies.

Recently, artificial intelligent (AI) method adopts to real system in order to create an intelligent system that understand, think, learn and behave like human beings [13]. Nowadays, artificial intelligent has been widely used in solving engineering problems as well as predicting the energy demand of a building and other applications like wind turbine [14,15]. Yokoyama et al. [16] applied the neural network in order to predict the demand of cooling for the building and the modal trimming method is adopted to find the parameters of model. Although additional input variables such as relative humidity and air temperature could improve the accuracy of identification process for the model parameter in the neural network. It also affects on the building cooling demand's prediction. Ekici and Aksoy [17] applied back propagation three layered Artificial Neural Network (ANN) for the estimation of the heating energy requirement of three different types of building with the same footprint but at different building orientations varies from 0° to 80°. The results are compared with numerical simulation and the accuracy is above 90%. The design of the building ventilation system

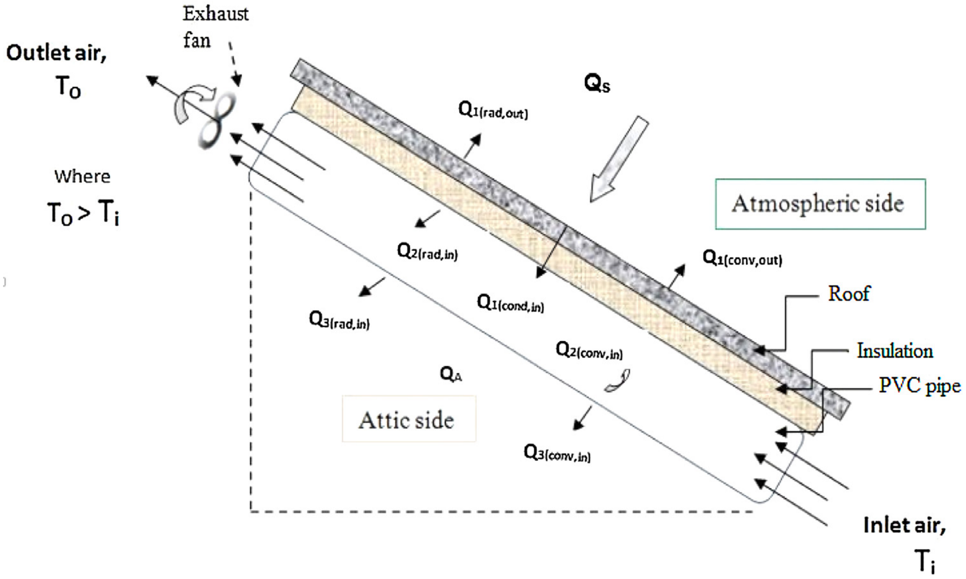

Fig. 1. Schematic diagram of the smart roof model.