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Artificial neural networks for predicting indoor temperature using roof passive cooling techniques in buildings in different climatic conditions

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ABSTRACT

Three passive cooling methods (e.g. roof pond, reflective roof cooling and using insulation over the roof) have been experimentally evaluated using an experimental test structure. The objective of this work is to train an artificial neural network (ANN) to learn and predict the indoor temperature of room with the different experimental data. Different training algorithms (traingd, traingdm, traingdx, trainrp, traincgp, traincgf, traincgb, trainscg, trainbfg, trainoss, trainlm, and trainbr) were used to create an ANN model. This study is helpful in finding the thermal comfort of building by applying different passive cooling techniques. The data presented as input were outside temperature, relative humidity, solar intensity and wind speed. The network output was indoor temperature. The advantages of this approach are (i) the speed of calculation, (ii) the simplicity, (iii) adaptive learning from examples and thus gradually improve its performance, (iv) self-organization and (vi) real time operation. Results proved highly satisfactory and provided enough confidence for the process to be extended to a larger solution space for which there is uneconomical and time consuming way of calculating the solution.

1. Introduction

Human thermal comfort is defined by ASHRAE as the state of mind that expresses satisfaction with the surrounding environment [1]. According to the ASHRAE standards the upper limit of comfortable temperature in living environments is 26 °C [2]. Energy expenditure and indoor environment are two very fundamental yet conflicting objectives of building design. Thermal comfort leads to high energy consumption. Poor thermal comfort affects the human's health adversely [3–5]. Most of the research work undertaken to-date in many countries involve continuing investigation, analysis and definition of the many complex thermal processes that can take place within a building structure, for the reason of quantifying the parameters necessary to achieve an energy-efficient built-environment with superior indoor 'comfort' climate [6–19]. After the crisis in 1970s, energy becomes one of the major topics in agendas of developed and developing countries which provide their energy needs from others [20]. Because of significant amounts of energy consumed in heating, ventilating and air-conditioning (HVAC) systems, there have been efforts to study energy use performance and promote good operational practice in buildings. In order to improve the operation of HVAC systems, it is necessary to have reliable optimization routines [21]. It is clear that in view of the technological developments, it will continue to keep its place there. Studies about minimizing energy consumption and using renewable energy sources speeded up with the reduction of fossil fuels and increasing of various environmental problems. If the lack of technology and materiality are taken into consideration, the wisest solution is to minimize the extravagant consumption with energy efficient buildings. The term energy efficiency in buildings can be defined as, providing comfort conditions with minimum energy consumption. The necessity of replacing the lost or excessive gains in order to protect the indoor comfort conditions makes it necessary to use energy in buildings. The energy load of a building is the amount of heating or cooling energy that must be taken on by heating and cooling systems. In recent years, the use of energy conservation in modern architecture for space heating/cooling has been reported frequently [22–25].

There is a lack of thermal comfort studies in India [26,27]. About 45% of the energy consumed in Indian residential buildings is used for achieving thermal comfort [28]. This is a large quantum of energy for India, given the population of the country. There are no thermal comfort standards in India. The national building code of India specifies two narrow ranges of temperatures for winter (21–23 °C) and for summer (23–26 °C). These are for air-conditioned buildings of any building type in any of the five climatic

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Nomenclature

$[A]$	weight matrix between input neurons and hidden neurons
$[B]$	weight matrix between hidden neurons and output neurons
g	gradient of curve
I_{Hp}	input to the pth hidden neuron
I_{oq}	input to the qth output neuron
X_1	nonlinear mapping provided by input layer
X_2	nonlinear mapping provided by hidden layer
X_3	nonlinear mapping provided by output layer
Net	neural network
O_{Hp}	the output of the pth hidden neuron
Ø	activation function/transfer function
O_{oq}	output of the qth output neuron
TestV	test data created by train
TR	initial training record created by train
TrainV	training data created by train
V	weight matrix or connectivity matrix between input neurons and hidden neurons
ValV	validation data created by train
A_{ij}	the weight of the arc between ith input neuron to jth hidden neuron
θ_{HP}	the threshold of the pth neuron
θ_{oq}	the threshold of the qth neuron
ξ	squashed-S function gain

zones in India [29]. The ideal standard for thermal comfort can be defined by the indoor temperature. This is the average of the air dry-bulb temperature and of the mean radiant temperature at the given place in a room. In addition, there should be low air velocities and no 'drafts' little variation in the radiant temperatures from different directions in the room, and humidity within a comfortable range. It is well known that the radiant temperature in a space affects the thermal comfort at least as much as air temperature [30]. A room may feel comfortable at a low air temperature if the surfaces and objects radiate a lot of heat, while a room with higher air temperature may feel cold if the surfaces and the objects are cold. In order to discuss the thermal comfort in a space, the concept indoor temperature is important factor.

ANN-models have proven to be successful non-linear black box model structures in a number of estimation, recognition and prediction applications and they have fascinated an increasing significance in recent years [31–34]. There are many non-linear model structures that can be used for estimation, such as wavelet networks, recurrent networks, gray box models, fuzzy models and radial basis function networks, and. However, in this article, we will concentrate on feed forward backpropagation neural network models for this problem. ANN-models for prediction and/or estimation of indoor air temperature have been discussed in a number of papers [35–38]. However, none of these articles discusses estimation of indoor temperature using passive cooling techniques.

2. Assumptions

HVAC stands for heating, ventilation, and air-conditioning. There are many factors that affect the energy needs of buildings. Basically these factors can be divided into two groups as physical environmental and artificial designing parameters. The physical environmental parameters are; outdoor temperature (°C), the amount of the solar radiation (W), wind speed (m/s), etc. and the artificial designing parameters are; transparency ratio (%), building form factor, orientation, optical and thermo-physical properties of the materials used in building envelope and the distance between buildings [39]. In this article we only deal with physical environmental parameters. The research behind this report is based on the assumption that the indoor temperature in a building or a room can be estimated using measurements of other variables, such as the outdoor temperature, solar radiation intensity, wind velocity, and relative humidity in different buildings; different variables may be used to estimate the indoor temperature. It is also believed that such estimations can be used in HVAC systems in order to get better thermal comfort in spaces [40].

2.1. Experimental procedure

Two identical prototype rooms each having dimensions 1 m × 1 m × 1 m were fabricated. All the walls of rooms were constructed using brick work. Both rooms have one door of 0.5 m × 0.4 m and one window of 0.4 m × 0.3 m (Fig. 1). The roofs were constructed using reinforced cement concrete slab of 100 mm thickness. A major heat load in building is from the roof, so that only treatment on the roof was compared. Following three passive techniques were applied on one of the test rooms (room 1) while other test room was kept with bare reinforced cement concrete roof (room 2).

In first technique roof pond was built over the roof. Roof pond is a unique passive system that can be used for both passive heating during winter and passive cooling of buildings during summer.

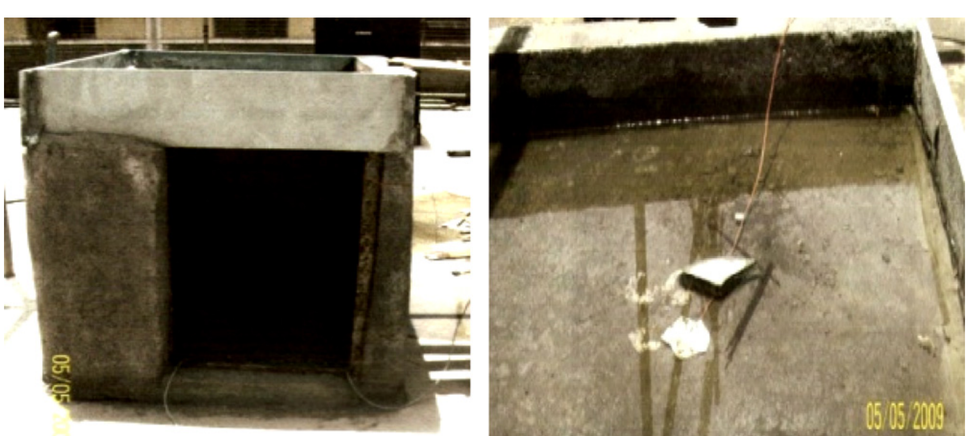

Fig. 1. Experimental setup.