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Application of artificial neural network for predicting hourly indoor air temperature and relative humidity in modern building in humid region

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ABSTRACT

The prediction of the air temperature (IT) and relative humidity (IH) in a building can help to reduce energy consumption for air conditioning. The purpose of this work was to apply the artificial neural network (ANNs) for an hourly prediction, 24–672 h in advance of (IT) and (IH) in buildings found in hot-humid region. The inputs used in the model are 12 last values of indoor and outdoor air temperature and relative humidity. The experimental building is built with cement hallow block in Douala-Cameroon. IT and IH were collected for 24 months. The experimental data were used to determine the optimal ANN structure with levenberg-marquardt algorithm using Matlab software. The optimal structure was the multilayer perceptron (MLP) with 36 input variables, 10 hidden neurons and two neurons in the output layer. The activation functions were respectively the hyperbolic tangent in the hidden layer and the linear function in the output layer. Moreover, the IT and IH results simulated by using the ANN model were strongly correlated with the experimental data, with the coefficient of correlation of 0.9850 for IT and 0.9853 for IH. These results testified that ANN can be used for hourly IT and IH prediction.

1. Introduction

Indoor thermal comfort conditions affect the amount of energy consumption in buildings [1,2] and they usually depend on the values of indoor air temperature and relative humidity [3]. The use of building energy simulation tools is an effective way in the estimation of the parameters of indoor thermal comfort. However, they necessitate several detailed input data such as properties of the building material, actual level of occupancy, energy produced by lights and equipment loadings [4]. Moreover, external unpredicted perturbations such as outdoor air temperature and relative humidity, soil temperature, radiation effects should also be taken into account [5]. The main barriers in using the current building simulation tools are the lengthy time required for simulations and complexity in the usage i.e. preparation of input data, execution and exploitation of results; unavailability and incompatibility of input data (weather conditions and the characteristics of building materials) [6]. Several techniques existing in literature reveal that nonlinear models are more effective than linear models for certain predictions [7]. As an easier alternative, the experimental data may be used to find out a black-box model or an empirical correlation defining the behavior of the thermal system. The limitation of this approach is that it requires assumption of the functional form of the proposed correlation [8]. The popular approach to analyze the steady and unsteady heat transfer problems is associated to the availability of non-linear empirical modeling methodologies, such as neural networks, inspired by the biological network of neurons in the brain [9–11]. Artificial neural networks (ANNs), which are increasingly being used in solving complex practical problems, are known as universal function approximators. They are capable of approximating any continuous nonlinear function to arbitrary accuracy [12]. Its applications are numerous in various fields including engineering, management, health, biology and even social sciences [13–17]. For the identification or analysis of heat transfer problems, a neural network approach has been attempted by many authors [18–20]. Singh et al. [21] used ANN for calculating thermal conductivity of rock. Various authors used neural networks for improved performance of built environment [22,23]. Alexiadis et al. [24] used ANN for the prediction of wind speed at six locations on the islands of the South and Central Aegean Sea in Greece. Some

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works were carried out on the prediction of surface air temperature in particular and other weather parameters by Njau [25,26].

Parishwad et al. [27] estimated the outdoor ambient temperature, relative humidity and air velocity in India using monthly–mean values of these parameters with developed correlations. The method can be used to predict the weather parameters at different locations of India.

Imran et al. [14] used ANN for the prediction of hourly mean values of outdoor ambient temperature 24 h in advance. This neural network is trained off-line using back propagation and batch learning scheme. The trained neural network was successfully tested on temperatures for years other than the one used for training. It requires a temperature value as input to predict the temperature of the following day for the same hour. Soleimani-Mohseni et al. [28] used nonlinear ANN models to estimate the operative temperature in a building by using other measurable variables, such as the indoor air temperature, electrical power use, outdoor temperature, time of the day, wall's temperature and ventilation flow rate. Lu and Viljanen [29] used an ANN model to predict either room air temperature or relative humidity. In that paper, the test house is a central ventilation control room. Measurements were taken from the test house in which indoor temperature and relative humidity were affected by ventilation machines. The experiment was carried for 30 days starting from January 2007. All the variables, temperatures and relative humidity indoor and outdoor, were collected within a 15 min interval. However, no outdoor relative humidity was available for outdoor temperatures below −10 °C. Satisfactory results with correlation coefficients 0.998 and 0.997 for indoor temperature and relative humidity were obtained in the testing stage. Mustafaraj et al. [30] investigates a neural network model to predict the indoor air temperature and relative humidity for the open-plan office positioned on the second floor in a modern commercial building in London. The data were collected for a period of nine months in the summer, autumn and winter seasons of 2005–2006 through the BMS's existing sensors. These data were used to build and validate the models. Kemajou et al. [31] predicted seven hours in advance the hourly indoor air temperature in modern building, by using an artificial neural network (ANNs) model, in hot-humid climate, using as inputs only the outdoor air temperature and the hourly values of indoor air temperature for the last six hours. The experimental building is built with cement hallow block in the town of Douala in Cameroon, and the experiment was carried out for six months. Similar works were carried out by Mba et al. [15]. Turkan et al. [3] predicted the daily mean indoor temperature (IT) and relative humidity values in an education building in Turkey by applying ANN. The city is located in a hot–humid region. The indoor air parameters, were collected between the 6th of June and 21st of September 2009, i.e. only for about four months via HOBO data logger. The R^2 values between predicted and actual values of indoor temperature and indoor relative humidity were computed as 0.94 and 0.96, respectively.

Despite the efforts these works made, very little studies have been carried out in the simultaneous prediction of the temperature and relative humidity in the literature. In hot and humid climate region, the most recent work was done by Turkan et al. [3]. This study was limited to a daily prediction of indoor air temperature and relative humidity, and authors used only four months of data collection in an experimental building. These data were used to build and validate the models.

In the present report, we present an ANN-based approach for predicting one day to one month in advance, the hourly indoor air temperature and relative humidity of a modern building with cement hallow block envelope in hot-humid climate region, using as input the last 12 hourly values of indoor air temperature and relative humidity, the last 12 hourly values of outdoor air relative humidity. Moreover, this study undertakes an overall analysis for a period of 24 months of the predictions of a room air temperature and relative humidity.

2. Material and methods

2.1. Climatic data of study area

The work is carried out in the town of Douala, the economic capital of the republic of Cameroon, situated in the heart of Africa. This town is about 24 km from the sea, on the left bank of the Wouri River and dominated by Mount Cameroon, West Africa's highest mountain (4095 m). Douala is located at 09°44 longitudes east and 04°01 latitude south. The height above the sea level is 5 m [32,33]. Average monthly data are collected over a period of nearly twenty years by the national meteorology of Cameroon [34]. Some data are presented on Fig. 1 below.

Fig. 1 shows the evolution of outdoor air relative humidity (a) and temperature (b). From Fig. 1a, monthly, the average of maximum relative humidity (OHmax) remains constant throughout the year and is approximately 97%, while the average of minimum relative humidity (OHmin) monthly varies between 59% and 77%. In Fig. 1b, the ambient air temperatures do not vary by an extreme amount. Monthly, the average maximum air temperatures during the day are between 28 °C and 33 °C and the average of daily minimum air temperature are between 23 °C and 24 °C. The highest of the monthly-mean maximum air temperatures reaches 33 °C in February and the lowest of the monthly-mean minimum air temperatures is 23 °C in August. Solar radiation is high. The annual global radiation reaches 4065 kWh/m^2 per day. The monthly average duration of sunshine collected between 1993 and 2013 varies between 68 h and 175 h [34]. The prevailing wind comes from the

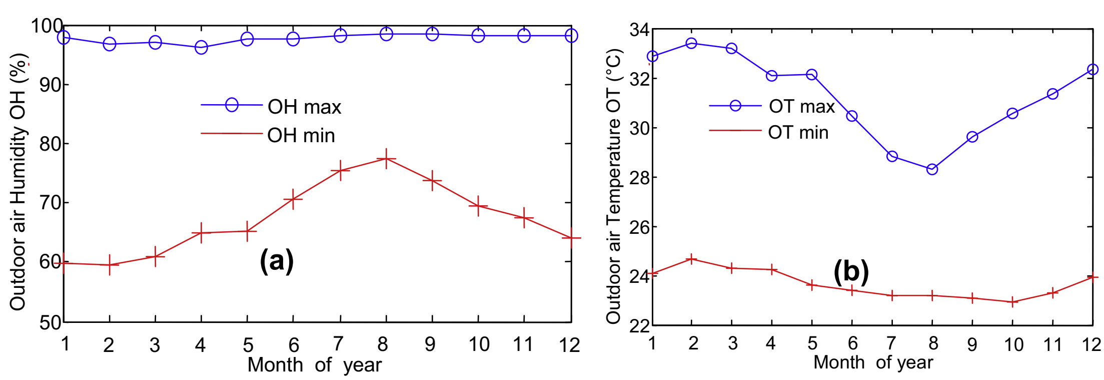

Fig. 1. Monthly average of outdoor air relative humidity and temperature.