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PREDICTION OF HEATING ENERGY CONSUMPTION IN UNIVERSITY BUILDINGS BASED ON SIMPLIFIED ARTIFICIAL NEURAL NETWORKS

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ABSTRACT
In this paper, the main objective is to predict heating energy consumption using a simple artificial neural network. For training and testing the network daily consumption for NTNU University campus Gløshaugen and mean outside temperatures were used. Training of the network was performed by using Levenberg–Marquardt (LM) feed-forward backpropagation algorithms. Different indices of the prediction accuracy were calculated for training and testing. Simplified model showed that it can predict heating consumption with adequate accuracy. Creating a model of energy use helps in future building planning; it can provide useful information about most probable energy consumption for similar buildings, or predict energy use in different conditions.
Keywords: heating energy consumption, prediction, artificial neuron network

1. INTRODUCTION
The study of the building energy demand has become a topic of great importance, because of the significant increase of interest in energy sustainability. In Europe, buildings account for 40% of total energy use and 36% of total CO_2 emission [1]. University campuses represent specific groups of diverse buildings, with significant energy consumption. They consist of many different buildings, representing small-scale town for itself. Therefore, they provide an excellent testbed to characterize and understand energy consumption of group of „mixed use“ buildings. Scientists and engineers are lately moving from calculating energy demand toward analyzing the real energy consumption of buildings. One of the reasons is that non-calibrated models cannot predict well building energy use, so there is a need for real time image of energy use in buildings (using measured and analyzed data).
In this paper thermal energy consumption for university campus is predicted. Actual recorded input and output data that influence thermal energy consumption were used for training, validation and testing.

2. STATISTICAL ANALYSIS FOR ENERGY USE PREDICTION
The classic approach to evaluate the building`s energy use is based on the application of a model with known system structure and proprieties as well as forcing variables (forward approach). The forward approach requires a detailed knowledge of the physical phenomena affecting the system behavior, and the building system operating mode [2].
A different approach for building energy analysis is based on the so called inverse or data-driven models. In recent years, considerable attention has been given to data-driven based methods [1]. By a data driven approach (inverse modeling) an empirical analysis is carried out on the building energy behavior, and its relationship to one or more driving forces or parameters. To develop an inverse model, it is necessary to carry out a mathematical description of the building or system, and then identify the parameters of interest using statistical analyses. The input and output variables are known

and measured, and the goal is to determine a mathematical description of the relationship between the independent variables and the dependent one. In contrast to the forward approach, the data-driven approach is useful when the building (or a system) has been built (that is, the building or system exists and works) and actual performance data are available for model development and/or identification.

3. ARTIFICIAL NEURAL NETWORK

Artificial neural network (ANN) has been widely used for a range of applications in different engineering areas, such as industry processes [3], and also in energy modeling [4]. In the building energy modeling the ANNs are used as surrogate of analytic computer codes to evaluate the energy flow and system performance, i.e. they are useful for forecasting and modeling. The ANNs learn from key information patterns allowing discovering complex relationships between the variables. Several studies have shown that in some cases forecasting models for energy consumption based on neural networks are more accurate. ANN is a computational structure inspired by a biological neural system, which consists of very simple and highly interconnected processors called neurons. They are usually arranged in an input layer, an output layer, and one or more hidden layers. The output of a specific neuron is a function of the weighted input, the bias of the neuron and the transfer function. Figure 1 shows presentation of a basic artificial neuron. In its simple form, each single neuron is connected to other neurons of a previous layer through adaptable synaptic weights. The output of any neuron is given by:

$$y_i = f(v_i), \quad v_i = \sum_{j=1}^{n} w_{ij} x_j + b_i \tag{1}$$

The neural network training process simply involves modification of weights until the predicted output is in close agreement with the actual output. Defined relations between the input layers, the hidden layers and the output layers determine a particular neural network model. Three types of networks used most commonly in ANN applications are feedforward networks, competitive networks and recurrent associative memory networks. Multi-layer, feedforward ANN with backpropagation learning method is used throughout this study. The backpropagation algorithm utilizes a generalization of the least mean square algorithm. It uses a gradient descent technique to minimize the cost function which is the mean square difference between the desired and the actual network outputs.

4. APPLICATION STUDY

In this paper heating energy consumption of one University campus has been analyzed. Norwegian University of Science and Technology (NTNU) campus Gløshaugen (Figure 2) consists of 35 buildings, with total area of approximately 300,000 m^2. Depending on their purpose, building types are: office, educational, laboratory workshop and sport facilities. Building and Energy Management System (BEMS) and web-based Energy Monitoring System (Energy Remote Monitoring – ERM) are available at NTNU [5]. Hourly heating and electricity consumption can be collected on ERM. District heating net in university campus is organized in form of a ring, while the Main heater is installed in the Old Electric building.

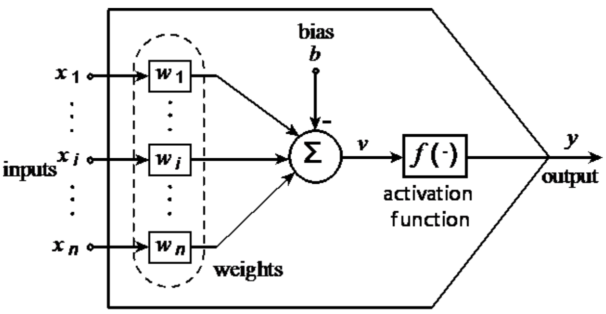

Figure 1. Model of neuron

Figure 2. District heating net in NTNU campus Gløshaugen

The Main meter is installed by the district heating supplier (Trønderenergi), so it is taken as relevant. In this study, the daily heating energy consumption values for the years 2008–2010, gathered from the

Main meter and mean daily outside temperatures obtained from the local meteorological station were used to train and test the model.

The input parameters of the neural network model were mean daily temperature, day of the week and month of the year. Model presented in this paper is simplified, without taking into account other meteorological parameters (wind speed, solar radiation, etc.), occupancy, etc. Input parameters day of the week and month of the year are coded, using numbers 1 to 7 and 1 to 12 respectively.

To ensure that no special factor is dominant over the others, all inputs and outputs are normalized to the interval (0, 1) by a linear scaling function:

$$x_i' = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}, \quad i = 1,\ldots,N \tag{2}$$

where $x_{\max}$ and $x_{\min}$ are the expected maximum and minimum values of the concerned variable, and N is the number of data points collected for a given input variable. Two data sets were created: daily heating energy consumption for years 2008 and 2009 were used for training the ANN, and 2010 for testing the network.

5. RESULTS AND DISCUSSION

The ANN model used in this study is a three-layer feedforward neural network composed of one input layer, one output layer and one hidden layer, because it has been established that such structure can approximate any function of interest [6]. In the model Levenberg–Marquardt (LM) learning algorithm, which is a variant of feedforward backpropagation was used. In the hidden layer and output layer logistic sigmoid (logsig) and linear (purelin) activation functions were used. During the application study many different values of hidden neurons were examined and the best results were achieved with one hidden layer with 7 neurons. The prediction accuracy is measured by the coefficient of determination (R^2), root mean square error (RMSE), as well as the coefficient of variation (CV) and mean absolute percentage error (MAPE), used in the ASHRAE context [7], defined respectively as follows:

$$\text{CV}=\frac{\sqrt{\frac{1}{N}\sum_{k=1}^{N}(y_k-\hat{y}_k)^2}}{\bar{y}}, \qquad \text{MAPE}=\frac{1}{N}\sqrt{\sum_{k=1}^{N}\frac{|y_k-\hat{y}_k|}{y_k}}\cdot 100 \tag{3}$$

where y_k and $\hat{y}_k$ are the target and output value for the k-th pattern respectively, while $\bar{y}$ is mean value of y and N is the total number of patterns.

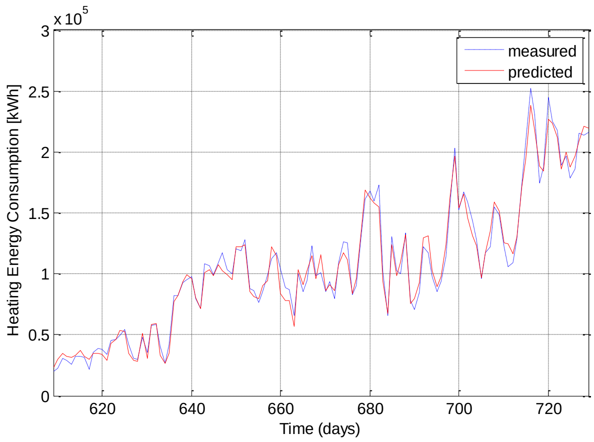

Figure 3. Measured and predicted values for September to December 2009: training results

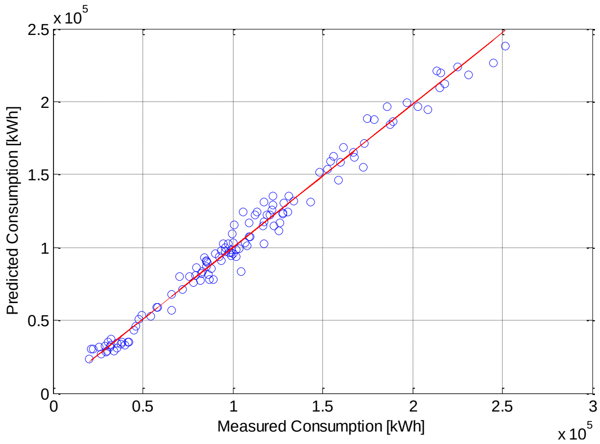

Figure 4. ANN model training results

Indicators for the prediction accuracy for training data (in total 729 samples for years 2008 and 2009) and testing data (364 samples for year 2010) are shown in Table 1. Part of the results for period September to December is presented in Figure 3 to Figure 6.

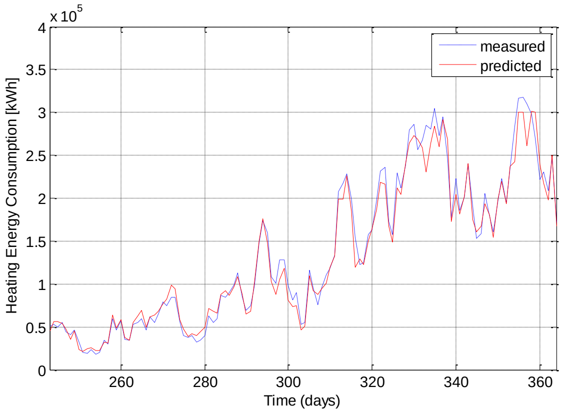

Figure 5. Measured and predicted values for September to December 2010: test results

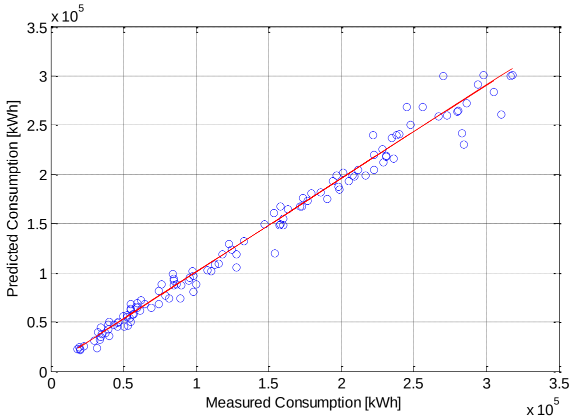

Figure 6. ANN model testing results

The results show that ANN is able to predict energy heating consumption with great accuracy, although output data range is wide (daily consumption varies from 100 kWh to 320 000 kWh).

Table 1. Comparison of the prediction error values for training and testing

Year/period	R^2 [-]	RMSE [kWh]	CV [-]	MAPE [-]
2008-2009; training period	0.9832	8099	0.0908	10.62
2010; testing period	0.9789	12411	0.1131	10.36

6. CONCLUSION

In the present paper, the simplified neural network model for heating energy consumption for University campus Gløshaugen was trained based on daily data for 2008 and 2009 and tested for the year 2010. Based on the evaluation indices, it is found that ANN is a very effective method for this type of predictions. Once an accurate ANN model is developed, engineers can easily apply this method to predict and evaluate building heating energy consumption without detailed knowledge of the ANN method, while using minimum data input (mean daily temperature). In future work, impact of different number of hidden layers, as well as additional meteorological parameters can be analyzed.

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