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APPLICATION OF ARTIFICIAL INTELLIGENCEIN ENERGY EFFICIENT H.V.A.C. SYSTEM DESIGN: A CASE STUDY

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ABSTRACT

Artificial intelligence (Artificial Neural Network-ANN, Fuzzy Expert System - FES, Genetic Algorithm - GA etc.) are widely accepted as a technology offering an alternative way to tackle complex and ill-defined problems. They can learn from examples, are fault tolerant in the sense that they can handle noisy and incomplete data are able to deal with non-linear problems and, once trained, can perform prediction and generalisation at high speed. They have been used in diverse applications in control, robotics, pattern recognition, forecasting, medicine, power systems, manufacturing, optimisation, signal processing and social/psychological sciences. They are particularly useful in system modelling, such as in implementing complex mappings and system identification. This study presents application of ANN in HVAC system design problem. It can also be used for the estimation of cooling or heating loads of buildings. In all those models, multiple hidden layer architecture has-been used. Errors reported in these models are well within acceptable limits, which clearly suggest that artificial intelligence (ANN) can be used for modelling other fields of energy too. To the best of the author's knowledge these novel approaches for application of Artificial Intelligence or Artificial Neural Network (ANN) in energy efficient HVAC system design is absent in thermal engineering or fluid mechanics literature due to its assessment complexity.

Keywords: artificial intelligence, artificial neural network, HVAC, air conditioning, refrigeration.

1. INTRODUCTION

The efficiency of the appliances and equipment used in homes and businesses has increased greatly over the past three decades. However, there is still much that can be done to reduce the amount and slow the growth of energy consumption in residential and commercial buildings. As much as half of the energy used in our home goes to heating and cooling.

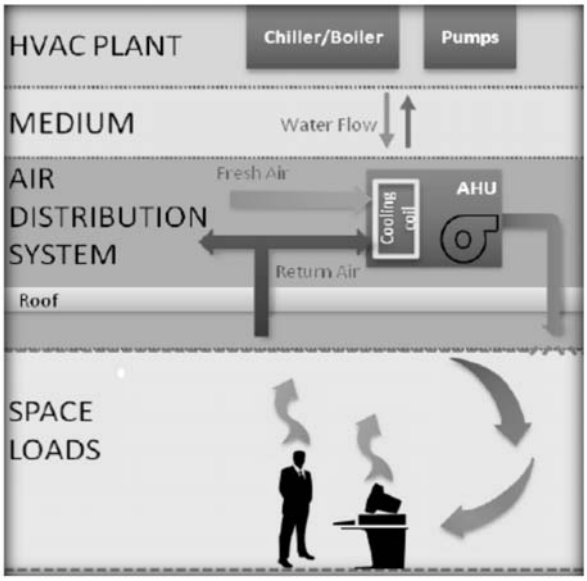

Figure-1. HVAC system components.

So, making smart decisions about Heating, Ventilating, and Air Conditioning (HVAC) system can have a big effect on utility bills and comfort. A typical HVAC system consists of plant equipment (chillers, AHUs, Pumps etc.) which transfer energy via air, water or a refrigerant to air distribution systems. Air is warmed or cooled as it flows over the heating or cooling coils in the air distribution system. The main thermal loads in a commercial building are a combination of:

- Heat produced by people
- Heat generated by electronic equipment's
- Solar radiation through glass windows
- Heat conduction through glass windows
- Heat conduction through wallsand roof
- Heat generated by lighting etc.

To provide comfortable indoor conditions, an amount of fresh outdoor air must be supplied to the building. The quantity is proportional to the number of people in the space. Conditioning this fresh air increases the load on the system. Generally, air is transported through ductwork while water and refrigerants are distributed through pipe work. The entire process is energy intensive - the main users of this energy being the HVAC plant: chillers, AHUs, FCUs, fans and pumps.

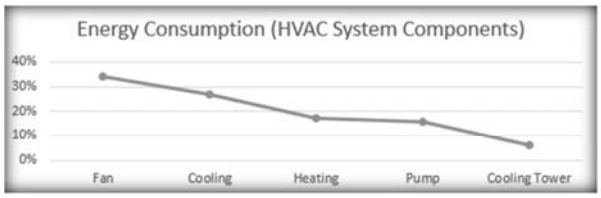

Figure-2. Energy consumption in HVAC systems.

Hence, making smart decisions with artificial intelligence on heating, ventilating, and air conditioning (HVAC) system can have a big effect on our utility billsand comfort. Artificial Intelligence represents a significant paradigm shift in the aims of computing, which reflects the fact that the human mind, unlike present day computers, possesses a remarkable ability to store and process information which is imprecise and uncertain. The principal constituents of Artificial Intelligence or Soft Computing (SC) are: Fuzzy Expert Systems (FES), including Fuzzy Logic (FL); Neural Networks (NN), including Neural Computing (NC); Genetic Algorithms (GA); Machine Learning (ML); Probabilistic Reasoning (PR) etc. [1-9].

2. METHODOLOGY ADOPTED

For estimation of the flow of energy and the performance of systems, analytic computer codes are often used. The algorithms employed are usually complicated, involving the solution of complex differential equations. These programs usually require large computing power and need a lot of time to give accurate predictions. Instead of complex rules and mathematical routines, artificial neural networks can learn the key information patterns within a multidimensional information domain. In addition, neural networks are fast, fault tolerant, robust and noise immune.

ANNs have been used successfully in several applications namely: classification, forecasting, control systems, optimization and decision making etc. In the brain, there is a flow of coded information (using electrochemical media, the so-called neurotransmitters) from the synapses towards the axon. The axon of each neuron transmits information to several other neurons. The neuron receives information at the synapses from many other neurons. It is estimated that each neuron may receive stimuli from as many as 10,000 other neurons. Groups of neurons are organised into subsystems and the integration of these subsystems forms the brain. It is estimated that the human brain has got around 100 billion interconnected neurons.

An ANN is a group of interconnected artificial neurons, interacting with one another in a concerted manner. In such a system, excitation is applied to the input of the network. Following some suitable operation, it results in a desired output. At the synapses, there is an accumulation of some potential, which in the case of the artificial neurons, is modelled as a connection weight. These weights are continuously modified, based on suitable learning rules.

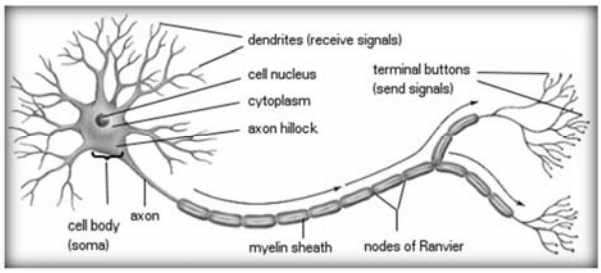

Figure-3. Abiological neuron.

A neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. It resembles the human brain in two respects; the knowledge is acquired by the network through learning process, and inter-neuron connection strengths known as synaptic weights are used to store the knowledge.

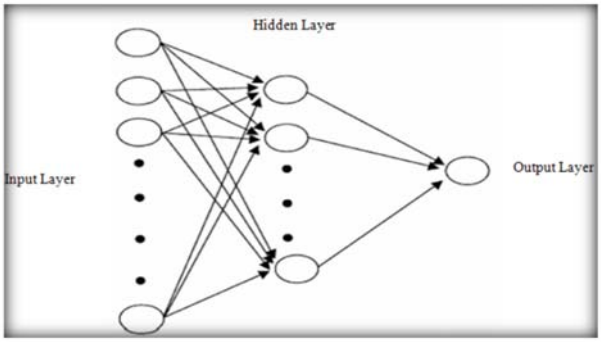

Figure-4. Multilayer feed forward neural network.

3. THEORY AND CALCULATION

Artificial neural network (ANN) models may be used as an alternative method in engineering analysis and predictions. ANNs mimic somewhat the learning process of a human brain. They operate as a ``black box" model, requiring no detailed information about the system. Instead, they learn the relationship between the input parameters and the controlled and uncontrolled variables by studying previously recorded data, like the way a non-linear regression might perform. Another advantage of using ANNs is their ability to handle large and complex systems with many interrelated parameters. They seem simply to ignore excess data that are of minimal significance and concentrate instead on the more important inputs. The typical multilayer feed forward neural network usually consists of an input layer, some hidden layers and an output layer. In its simple form, each single neuron is connected to other neurons of a previous layer through adaptable synaptic weights as shown below. Knowledge is usually stored as a set of connections weights (presumably corresponding to synapse efficacy in biological neural systems).Training is the process of modifying the connection weights in some orderly fashion using a suitable learning method. The network uses a learning mode, in which an input is presented to the network along with the desired output, and the weights are adjusted so

that the network attempts to produce the desired output. The weights after training contain meaningful information, whereas before training, they are random and have no meaning. The node receives weighted activation of other nodes through its incoming connections. First, these are added (summation).

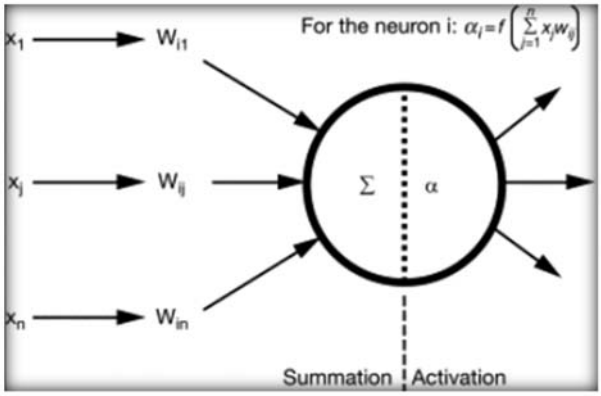

Figure-5. Information processing in ANN unit.

The result is then passed through an activation function, the outcome being activation of the node. For each of the outgoing connections, this activation value is multiplied with the specific weight and transferred to the next node. A training set is a group of matched input and output patterns used for training the network, usually by suitable adaptation of the synaptic weights. The outputs are the dependent variables that the network produces for the corresponding input.

It is important that all the information the network needs to learn is supplied to the network as a data set. When each pattern is read, the network uses the input data to produce an output, which is then compared to the training pattern (the correct or desired output). If there is a difference, the connection weights (usually) are altered in such a direction that the error is decreased. After the network has run through all the input patterns, if the error is still greater than the maximum desired tolerance, the ANN runs again through all the input patterns repeatedly until all the errors are within the required tolerance. When the training reaches a satisfactory level, the network holds the weights constant and uses the trained network to make decisions, identify patterns, or define associations in new input data sets not used to train it. The feed forward back-propagation (FFBP) algorithm is one of the most popular and powerful learning algorithms in neural networks. The training of all patterns of a training data set is called an epoch. The error is expressed by the root-mean-square value (RMS) [10].

4. H.V.A.C. SYSTEM DESIGN: A CASE STUDY

Managing adequately the building energy demands has always been a struggle for facility managers. The proper use of the energy in a commercial building provides lower operational costs in two aspects. The first one is achieved by evaluating the energy end-uses (lighting, electrical equipment's and HVAC) and implementing actions to reduce the amount of energy for one or more of these end-uses. If the facility manager could anticipate the energy demand profile and the energy consumption of the building, he could implement actions to reduce one or both and, therefore, reduce the operational cost. Several inspections were made to evaluate the different types of internal loads (lighting, computers and occupancy) and their schedules. Some assumptions related to this profile were also made in this case study. A feed-forward approach for neural network (ANN) development was chosen for this work.

This study considered assessing the heating load and cooling load requirements of buildings (that is, energy efficiency) as a function of building parameters. The dataset comprises 768 samples and 08 attributes or features(Relative Compactness; Surface Area; Wall Area; Roof Area; Overall Height; Orientation; Glazing Area; Glazing Area Distribution)aiming to predict 02 real valued responses or outcomes(Heating Load; Cooling Load). The energy analysis was performed using 12 different building shapes.

5. RESULT AND DISCUSSIONS

From this study of assessing the heating load and cooling load requirements of a commercial building (that is, energy efficiency) as a function of building parameters, the results obtained in training and validation are considered good (r = 0.99) as shown below. Despite the disadvantages of ANN known as black box model, ANN can simulate the pattern. Based on the pattern recognition of input and output, ANN can model the nonlinear processes.

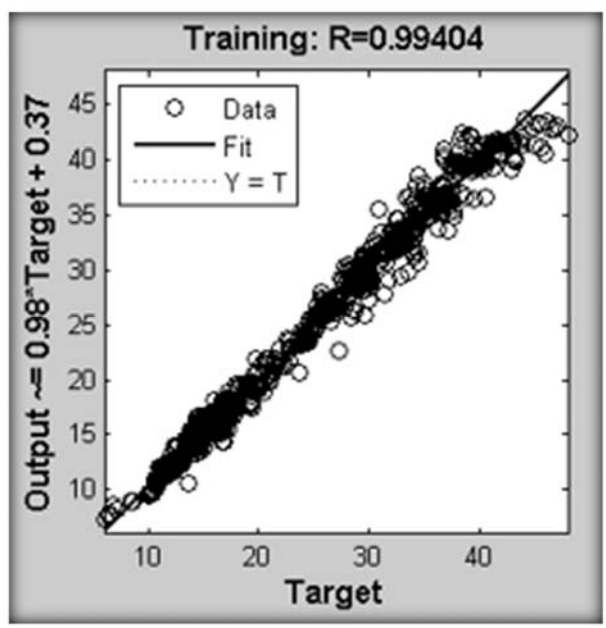

Figure-6. Training Dataset – ANN.

This study presents application of ANN in HVAC system design problem. It can also be used for the estimation of cooling or heating loads of buildings. In all

those models, multiple hidden layer architecture has been used. Errors reported in these models are well within acceptable limits. A fair agreement between forecasts by ANN and actual values are obtained as shown.

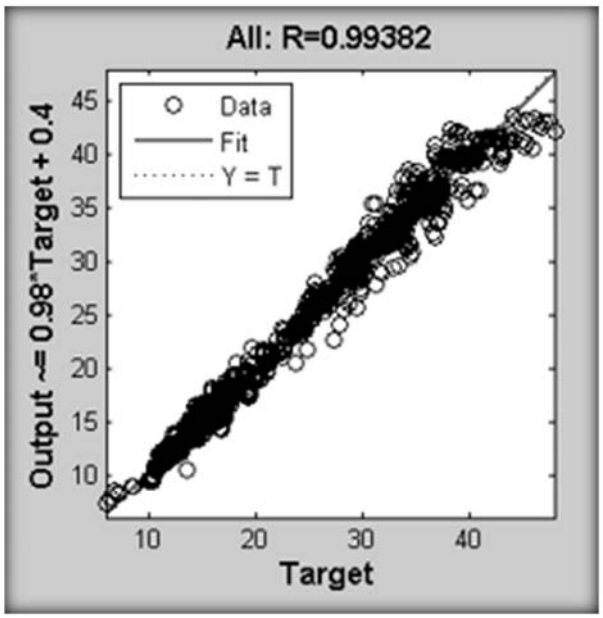

Figure-7. Training - validation - Test dataset – ANN.

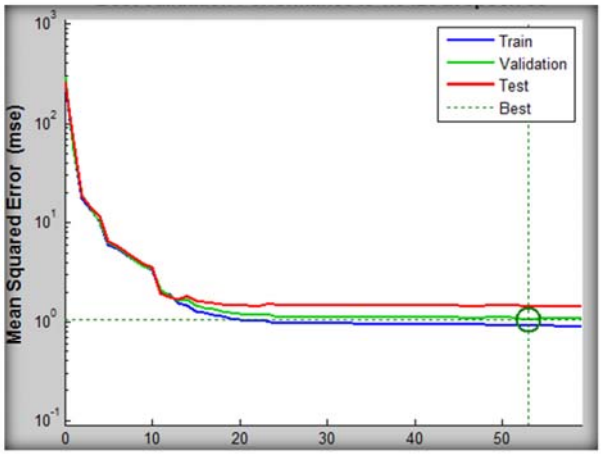

Figure-8. ANN Performance – MSE.

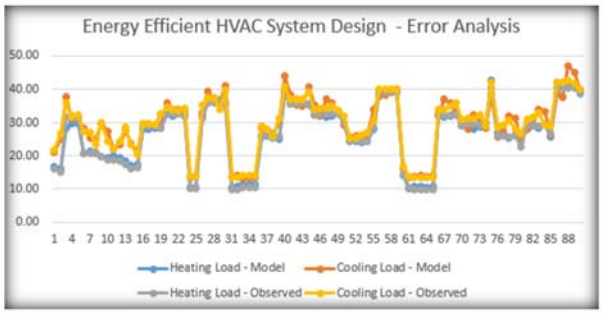

Figure-9. Error analysis (Actual vs ANN Prediction).

6. CONCLUSIONS

The ANN modelling presented here can predict the HVAC load of a building with acceptable accuracy. It is certainly more economical to be able to investigate the behaviour of energy consuming systems without having to construct and experiment on several systems or use expensive models. The application of ANNs have shown that it is possible to model such systems with a minimum amount of input data, thereby providing the designer of such systems with the flexibility to test several systems quickly. The significant reduction in estimation times is the major benefit of the present method. We are planning to extent the present work into other areas of the subject to create a much versatile simulation tool.

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