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A fuzzy nearest neighbor neural network statistical model for predicting demand for natural gas and energy cost savings in public buildings

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ABSTRACT

This paper addresses the problem of predicting demand for natural gas for the purpose of realizing energy cost savings. Daily monitoring of a rooftop unit wireless sensor system provided feedback for a decision support system that supplied the demand for the required number of million cubic feet of natural gas used to control heating, ventilation, and air conditioning systems. The system was modeled with artificial neural networks (ANNs). Data on the consumption of the system were collected for 111 days beginning September 21, 2012. The input/output data were used to train the ANN. The ANN approximated the data very well, showing that it can be used to predict demand for natural gas. A fuzzy nearest neighbor neural network statistical model consisting of four components was used. The predictive models were implemented by comparing regression, fuzzy logic, nearest neighbor, and neural networks. In addition, to optimize natural gas demand, we used the fuzzy regression nearest neighbor ANN model cost function to investigate the variables of price, operating expenses, cost to drill new wells, cost to turn gas on, oil price and royalties.

1. Introduction

Natural gas is a clean energy source that can meet the demand for energy for heating and industry. Yet most research on energy technology has focused on improving the efficiency of either one subsystem of a building or one single building. The present study takes a more systematic approach by investigating a group of buildings in a mall that relay real-time demand for natural gas in their heating, ventilation, and air conditioning (HVAC) systems. This information can then be used as a decision support system to regulate the flow of natural gas from wells. The use of this decision support system not only increases cost effectiveness but protects the HVAC system against interruptions in the flow of natural gas. To test the system, we developed a hybrid model using artificial neural networks (ANNs). Data on the consumption of the system were collected for 111 days beginning September 21, 2012.

It is very important to forecast the natural gas demand in MCF in terms of supply and demand and it is the most important to compare this and other variables such as price to alternative energy sources, such as oil. This information is important for both customers and producers in order to maximize their profit and determine the requests for natural gas. Choosing the best method of demand forecasting is a crucial task in order to have the most accurate real time information. In this paper the demand forecasting for natural gas is accomplished based on different methods including nearest neighbor, artificial neural network (ANN) fuzzy logic and regression. The Fuzzy Neural Neighbor Statistical (FN2^2S) method is examined by using data from natural gas wells in the Western Pennsylvania market. The results of different methods are compared and the best method is chosen.

Despite significant progress in energy technology, about 2 billion people worldwide still lack access to electricity (Henao, Cherni, Jaramillo, & Dyner, 2012). Deciding which energy technology is most appropriate for supplying these areas is difficult, as existing energy decision support tools, though useful, are incomplete. This is because most research on energy technology focuses on the energy use of a single building, which limits its applicability to groups of buildings, as scenarios such as energy sharing and competition cannot be modeled (Hu, Weir, & Wu, 2012). However, emerging technology in net-zero buildings and smart grids is shifting researchers' focus from centralized operation decisions in a single building to decentralized decisions in groups of buildings.

Buildings consume about 40% of the world's energy (Xiao & Wang, 2009). As most of this energy is used by the building's HVAC system, the efficiency of this system is critical to the sustainability of the building. Building energy regulations emerged in the 1970s to help minimize consumption and maximize efficiency (Pérez-Lombard, Ortiz, Coronel, & Maestre, 2011). Such codes set the minimum requirements for energy-efficient design in new buildings.

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Building automation systems, standard in most modern buildings, provide automatic monitoring and control of building services systems, saving labor, time, and money.

Efficient HVAC control is often the most cost-effective option for improving the energy efficiency of a building. HVAC systems must be integrated with an efficient control scheme to maintain comfort under any load conditions (Canbay, Hepbasli, & Gokcenc, 2004). Several groups of researchers have studied the control of HVAC systems. For example, He, Cai, and Li (2005) developed a hierarchical multiple model predictive control strategy based on Takagi–Sugeno (T-S) fuzzy models to control the temperature of air-handling units in HVAC systems. Results of a simulation and real process testing showed that the approach was effective in HVAC system control applications. Soyguder, Karakose, and Alli (2009) used fuzzy sets to model the intelligent control of an expert variable flow-rate HVAC system with two different zones. Finally, Ferreira, Ruano, Silva, and Conceição (2012) used a discrete model-based predictive control methodology to study how best to control an HVAC system to maximize thermal comfort and minimize energy consumption. Energy savings resulting from the application of their method were estimated at more than 50%.

Accurate energy investment planning is critical to preventing excessive energy consumption. Ekici and Aksoy (2011) had success using an adaptive network-based inference system model to forecast energy consumption in buildings in a cold region. Taspınar, Celebi, and Tutkun (2013) used a multilayer perceptron with the ANNs with time series approach to forecast short-term natural gas consumption in Turkey. Although the amount of data used was small, the algorithm was able to forecast consumption, with encouraging and meaningful outcomes for future energy investment policy. Finally, Connolly, Lund, Mathiesen, and Leahy (2010) reviewed 37 computer tools for their usefulness in analyzing the integration of renewable energy into various energy systems. They found that no one energy tool addresses all issues related to integrating renewable energy; rather, the ideal tool depends on the specific objectives that must be fulfilled.

Decision support systems can be used to improve the performance of an energy system. For example, Neves, Dias, Antunes, and Martins (2009) used a problem-structuring method, soft systems methodology, to structure a multicriteria decision analysis to appraise energy efficiency initiatives. This methodology was useful in defining the decision problem context and the main actors involved, as well as unveiling the objectives of each stakeholder. In addition, Ashhab (2008) used ANNs to determine the operating conditions under which a photovoltaic solar-integrated system would be most efficient. The ANNs approximated the data well, showing promise as a method of predicting system performance (i.e., system efficiencies).

The nearest neighbor method is widely used alone as well as in combination with other methods to forecast avalanches. Yet forecasters often have difficulty determining the number of real neighbors on the present day. Singh and Ganju (2004) proposed an alternative method that uses the same database and parameter vector space as is used for the nearest neighbor method. The output, when analyzed against the backdrop of nearest neighbor method output on the same data, helps forecasters fine-tune their decisions.

According to García-Pedrajas and Ortiz-Boyer (2009), the k-nearest neighbors (k-NN) classifier is one of the most widely used methods of classification because of its good generalization and easy implementation. However, no successful method of boosting k-NN has yet been reported. Ensemble methods rely on the instability of the classifiers to improve their performance; as k-NN is fairly stable with respect to resampling, these methods fail in their attempt to improve the performance of k-NN classifier. However, k-NN is very sensitive to input selection. Thus, ensembles based on subspace methods are able to improve the performance of single k-NN classifiers.

k-NN and Bayesian methods are effective methods of machine learning (Aci & Avci, 2011). Expectation maximization is an effective Bayesian classifier. Aci and Avci (2011) proposed a data elimination approach that could be used to improve data clustering. The proposed method was based on hybridization of k-NN and expectation maximization algorithms. The k-NN algorithm is considered the preprocessor for the expectation maximization algorithm to reduce the amount of training data.

The present paper is organized as follows. Section 2 introduces an integrated building natural gas decision support system. Section 3 formulates fuzzy nearest neighbor neural network statistical ($FN2^2S$) methodologies and the natural gas decision model. The experimental results presented in Section 4 demonstrate how the proposed framework can be used for decision making and cost savings. Finally, conclusions are drawn in Section 5.

2. Integrated building natural gas decision support system

CONTOUR has developed a control system that both connects rooftop HVAC units to the end user via wireless technology and the Internet as well as provides state-of-the-art lighting control on the same wireless network. This three-component system operates via a two-way wireless connection between the CONTOUR Network Operations Center (NOC) and a master control unit (P1800). This unit contains a two-way radio that operates on a nationwide commercial radio band, providing a wireless link between the rooftop and the CONTOUR NOC (Fig. 1).

Communication between the CONTOUR NOC and the end user's personal computer is via the Internet and a secure password-encrypted login procedure. The end user has direct access to each P1810 installation and the associated control functions through the Internet. The most sophisticated piece of equipment needed to control heating, cooling, and lighting is a telephone. End users can also communicate with a field P1810 through CONTOUR's Cus-

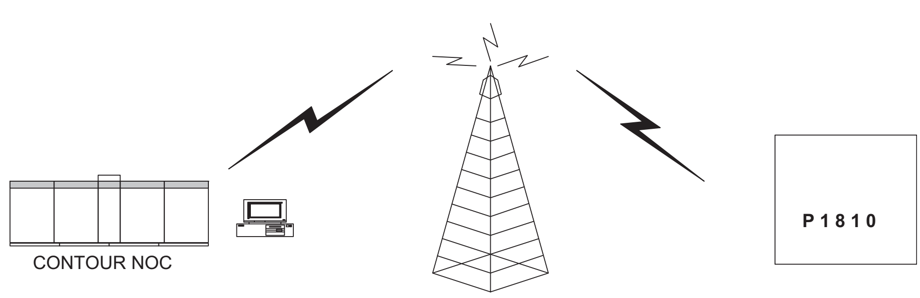

Fig. 1. Two-way wireless connection between the CONTOUR Network Operations Center (NOC) and a master control unit (P1800).