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Improving the residential natural gas consumption forecasting models by using solar radiation

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ABSTRACT

Natural gas is known as a clean energy source used for space heating in residential buildings. Residential sector is a major natural gas consumer that usually demands significant amount of total natural gas supplied in distribution systems. Since demands of all consumers should be satisfied and distribution systems have limited capacity, accurate planning and forecasting in high seasons has become critical and important. In this paper, the influence of solar radiation on forecasting residential natural gas consumption was investigated. Solar radiation impact was tested on two data sets, namely on natural gas consumption data of a model house, and on natural gas consumption data of a local distribution company. Various forecasting models with one day ahead forecasting horizon were compared in this study, including linear models (auto-regressive model with exogenous inputs, stepwise regression) and nonlinear models (neural networks, support vector regression). Results confirmed that solar radiation clearly influences natural gas consumption, and included as input variable in the forecasting model improves the forecasting results. Consequently it is recommended to use solar radiation as input variable in building forecasting models.

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1. Introduction

Forecasting natural gas consumption is a tool commonly used for balancing the supply and demand of natural gas. This area is usually regulated by government or by natural gas supply contracts. These regulations usually demand forecasting the future consumption inside the tolerance interval. Otherwise, penalty system is applied. Therefore local distribution companies require accurate forecasting models.

Forecasting natural gas consumption has been investigated in several different areas, on world level [1], national level [2–5], on gas distribution system level [6], in commercial and residential sectors [7–10], and finally, on individual customer level [11]. The authors used various data in building forecasting models such as economic parameters, weather data, past natural gas consumption data, past energy consumption data, mathematical and engineering calculations, software simulation data, survey data of households and other various parameters, such as day of week, holidays, etc. Forecasting horizons vary from a few hours ahead to a few decades ahead. A recent overview of various forecasting approaches in the field of natural gas consumption was published in Soldo [12]. Natural gas forecasting approaches can be divided into two groups with respect to the use of weather parameters as influential variables.

In the first group, forecasting without weather data, we can find a number of papers where authors did not consider the influence of weather parameters on natural gas consumption at all [1–5]. Instead of weather data they proposed various forecasting methods and other relevant input data in order to forecast natural gas consumption. Usually they forecasted natural gas consumption at national level or higher, and as input variables they used past consumption data, gross domestic product (GDP), growth rate, production rate, total ultimate recovery, cumulative production, future recoverable, etc.

In the second group of papers, forecasting with weather data, the authors investigated influence of weather conditions on natural gas consumption [6–11,13–15]. Since the natural gas consumption in summer period is significantly lower than in winter period, it is obvious that most of the consumed natural gas in residential buildings is used for space heating in cold weather. The second group of authors recognized and investigated the strong relationship between weather and natural gas consumption. The authors used weather parameters such as outside temperature or derived variable heating degree day, wind speed and relative humidity. Investigation of natural gas consumption in residential buildings was described in two recent papers [16,17]. Since the past natural gas consumption data and the weather parameters data could

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not provide sufficient forecasting accuracy, the authors have used a variety of additional input data in order to predict human behavior, which also has a great influence on natural gas consumption in residential buildings. These human actions could be predicted by using input variables such as heating program (day or night. . .), working days–weekends, holidays, natural gas price, index of income, etc. These parameters, in real everyday environment, improve forecasting models and its forecasting results.

The literature overview reveals that the influence of solar radiation has not been considered yet in building forecasting models. Solar radiation influences the heat gain when passing through the glazed window parts of the building, and this effect was investigated in the several recent papers [18–20] but not in relation to natural gas consumption. The author's objective is to investigate the influence of solar radiation on improving natural gas consumption forecasting models. Two natural gas consumption systems of different scales are observed: an individual house and the residential sector of local distribution company. Various forecasting models are developed and analyzed in order to study the influence of solar radiation in improving the short-term natural gas forecasting.

This paper is organized as following: the objectives of this research are described in the next section. Section 3 describes the data acquisition process and presents the collected data. Section 4 describes basic relations of the data, feature extraction and data preparation for application in the forecasting models. These models are described in Section 5 while Section 6 describes models training and testing procedures and performance measures. Section 7 presents the comparison and evaluation of obtained forecasting results with indication of the best forecasting results. Guidelines for the future research and the key findings of this research are given at the end of the paper in Section 8.

2. Objectives

The HEP-Plin, Ltd. is a local distribution company (LDC) that is obligated to forecast and nominate the amount of the natural gas they will consume in the following day. LDC needs accurate forecasting tool in order to avoid penalty rule. This research has been initiated to determine whether further improvements of the existing forecasting models could be made.

The main objective of this paper is to forecast residential natural gas consumption on daily basis and to determine whether the use of solar radiation can improve the accuracy of forecasting models. Forecasting horizon is one day ahead. The influence and predictive importance of solar radiation is investigated by creating two groups of models. In one group, solar radiation is excluded from forecasting models, and in another group, it is included in forecasting models as input variable. The difference in the results of these two groups of models indicates the predictive importance of solar radiation influence in building the forecasting models. In order to achieve the given objective, the following forecasting models are examined:

- Benchmark models: temperature correlation (TC), random walk (RW).
- Linear models: auto-regressive model with exogenous inputs (ARX), stepwise regression.
- Nonlinear models: neural networks (NN), support vector regression (SVR).

Temperature correlation and random walk models are simple benchmarks models presented for comparison only. We expect any reasonable model to perform better than these two simple models. Linear models (stepwise regression, ARX) have been commonly used in solving forecasting problems [11,21–23]. Suggested nonlinear models have also been widely used in the area of forecasting natural gas consumption as in many others areas [5,10,15,24–28].

3. Data

This study is based on weather data (outside temperature and solar radiation) and two different sets of the natural gas consumption data. The first set of natural gas consumption data is from a model house, and the second one from the local distribution company. Measurements of natural gas consumption and meteorological data were carried out through two heating seasons 2011/2012 and 2012/2013 as follows:

(1) Season 1: from 6th November 2011 till 27th April 2012.
(2) Season 2: from 8th November 2012 till 1st April 2013.

3.1. Weather data

Weather data were collected in a weather station with hourly reading, located at N 45° 41.170', E 18° 24.200' and 3.5 km away from the model house. Weather station is located inside of the observed natural gas distribution area. In the first observed period (heating season 2011/2012) the temperature stretched from −21.1 to +26 °C, with the mean value 4.3 °C. Solar radiation was in the range from 0 to 844 W/m^2 with mean of 87 W/m^2. In the second observed period (heating season 2012/2013), the temperature stretched from −11.8 to +19.3 °C. The mean value was 3.7 °C. Solar radiation was in the range from 0 to 775 W/m^2 with mean of 60 W/m^2.

3.2. Model house data

For this research the authors created an environment with minimal human influence on natural gas consumption: the model house. The house is located at N 45° 39.720′, E 18° 25.970′. It has only one floor and the heated space covers approx. 100 m^2. The model house is heated by natural gas boiler with central heating system. In order to exclude human interference as much as possible, natural gas is used only for space heating. Hot water is prepared with solar panels and extra heated with electrical energy, which is also used for cooking. Other influential parameters of the human interference on space heating, and thus on the natural gas consumption, like thermal influence of electrical appliances (television, oven, fridge, dishwasher, lamps, microwave oven, etc.), human thermal influence, etc., are excluded from this research. Central heating system has a programmable unit and is programmed to heat the living space at 22 °C for 24 h a day, every day, during the whole heating season. The main objective of this particular heating regime is to collect the natural gas consumption data dependable only on weather conditions, as much as possible.

For this experiment, several measuring devices have been developed and installed in the model house. Natural gas data are measured by a natural gas meter with hourly reading. Each full hour date, time and the natural gas consumption values are stored by a unique electronic device created for this research only.

In the first observed period the consumption stretched from 0 to 1850 [10^{-3} m^3] with the mean value of 355. In the second season data (heating season 2012–2013), the consumption stretched from 0 to 1320 [10^{-3} m^3] with the mean value of 382.

3.3. Local distribution company data

In the observed natural gas distribution area, the local distribution company delivers natural gas to two small cities with total of 4314 customers. There are only twelve customers with technological natural gas consumption in production process, while the

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