Simulation Studies in the Distribution of Gas Flow

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Abstract

This study describes the simulation of gas demand for greenhouses in the agricultural area. Using the data provided by an energy company providing gas to over 3600 individual greenhouses, several models are developed to predict the gas demand of an individual green house. Using these models peak smoothing strategies for the overall gas demand can be developed and tested. Three of such peak smoothing strategies are described, of which the one using a equilibration tank shows the best results.

1 Introduction

In the Netherlands, many greenhouses are used in the agricultural area. These greenhouses are all heated by gas, which is distributed by a number of companies. In recent years, a lot of effort has been spent to reduce costs of gas distribution. The largest problem is the variability in gas demand. Gas companies need an enormous over-capacity and very costly storage facilities to be able to guarantee gas supply during peak time. For example, early morning heating to raise greenhouse temperature from night climate to day climate results in an enormous peak in gas demand. Spreading this heating over a longer period will result in peak smoothing and as a consequence in cost reduction.

Gas demand varies greatly over seasons, weeks, and even days. The gas demand curve of individual greenhouses is highly skewed as it shows many peaks and valleys. Gas demand is influenced by a great number of parameters of which most are beyond human control. A fundamental question in reducing gas costs is how good gas demand can be predicted based on parameters describing the greenhouses. As can be expected, the functional relation between gas demand and these parameters is highly non–linear. In this study, we try to simulate gas demand by applying neural networks.

The peak smoothing problem is common to all companies distributing energy and water. Several strategies can be used to smooth peaks. In this study, different peak smoothing strategies have been simulated.

2 Data

The data used in this study was provided by an energy company which distributed about 1.5 billion Nm^3 gas over 3600 individual greenhouses, located in an area of over 200 km^2. Every 5 minutes, the cumulative gas demand was recorded as well as some weather data like temperature, light intensity, humidity, wind speed, wind direction, and air pressure. The weather data was recorded on a central located weather station.

As a sample of this data, the total gas demand during the first 10 days of January 1993 is plotted in figure 1. The correlation between gas demand and weather parameters is plotted in figure 2. By visual inspection, one can see that gas demand and outside temperature are correlated to some degree.

3 Model

A model of the gas demand of an average greenhouse is needed, to study the total gas demand

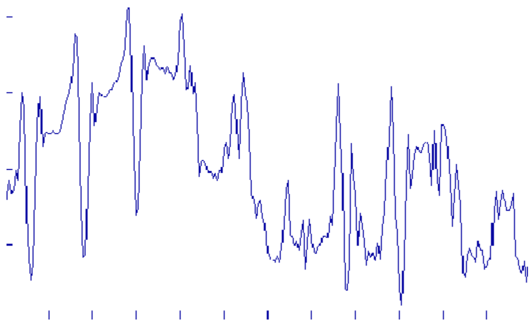

Figure 1: Gas demand in January 1993

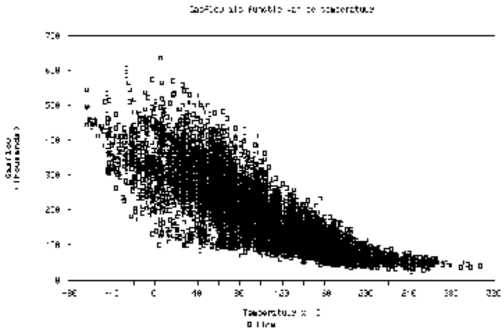

Figure 2: Correlating gas flow and temperature

requested from the energy company. This individual demand is influenced by many parameters:

- characteristics of the greenhouse: volume, glass surface, and isolation,
- climate in the greenhouse (tropical, moderate, or cold climate),
- weather characteristics: temperature, light intensity, humidity, wind speed, wind direction, air pressure,
- time and date,
- random processes, like human influence.

All these parameters have their effect on the individual gas demand. Some general observations can be made. A seasonal effect is expected to be present in gas demand, as well as a 24 hour cycle due to day/night rhythm. However, random processes have a great impact and make forecasting very complex. Each day will have its characteristic curve of gas demand. A sudden shower during daytime will result in an unexpected peak.

3.1 Fixed–time model

We listed some parameters which influence the gas demand on a fixed time. The relation between these parameters and the demand is however complex. Several problems occur when modeling gas demand using a fixed time model:

- There is some delay in time between the parameter value changes take place and the resulting gas demand. The rate of change and the length of the time delay is variable.
- Designers of greenhouses use only global models themselves, because of complexity and missing underlying theory.
- The human factors and set–up of climate computers in the greenhouses are difficult to model.
- The list of parameters is probably not complete and the assessment of the parameters is too global.

From the plots of gas demand as a function of time and weather, we might expect that the relation between gas demand and parameters is non–linear. Therefore, the neural network approach was chosen to model the greenhouse (see figure 3 and section 6).

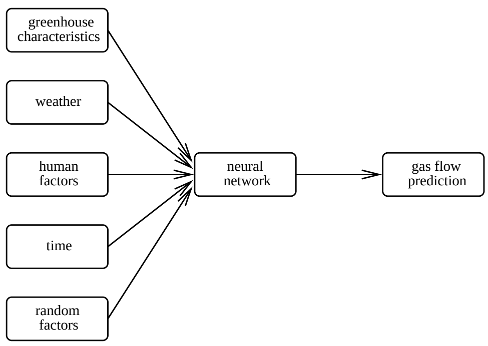

Figure 3: Neural network model of gas demand

3.2 Variable–time model

A model of gas demand as a function of the time is needed, to study the effects of different control strategies. Different approaches can be used to develop such a model. A bottom–up approach starts with modeling all individual greenhouses and describes the resulting gas demand statistically. However, models of individual greenhouses are not available and a top–down approach has to be chosen. Therefore, the gas demand distribution function of individual greenhouses is modeled using the total gas demand (see figure 4).

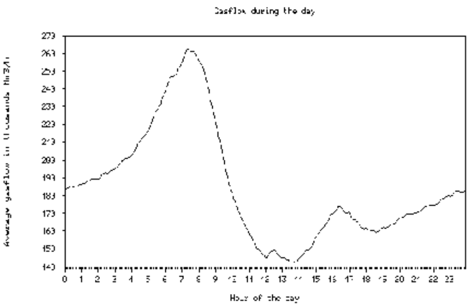

Figure 4: Gas demand during the day

This function is used to simulate the gas demand of an average greenhouse. A low value for the distribution function indicates a short heating period with long periods between heating.

4 Peak smoothing

In greenhouses a day/night rhythm can be observed. During the night the temperature is kept at a lower level than during daytime. In the morning, greenhouses are heated to daytime level. As a result, one can observe an enormous peak in gas demand shortly after sunrise. As the morning progresses, natural energy sources take over heating and the gas demand drops. At the end of the day, a small peak can be observed as natural heating drops when temperature still has to be kept at daytime level.

The temperature in the greenhouse is regulated by an automated system. When the temperature passes a first threshold, the greenhouse needs heating. When temperature passes a second threshold, heating is stopped. A controlling schema is used for controlling these thresholds to make optimal use of energy. The parameters are changing continuously.

4.1 Strategies

The goal of all gas stream controlling strategies is to smooth peaks on the overall gas flow curve and to reduce gas consumption in the peak time when the gas is most expensive. From figure 1, we see that the curve of total gas demand has a lot of peaks and valleys. The ultimate goal is a constant demand. However, our goal is to minimise random fluctuations present in the average gas demand.

When a sudden rise occurs in the demand, a peak can be expected, shortly followed by a valley. The exact height and duration of the peak are not known in advance. The first two strategies try to spread the peak more evenly over the near future. The third strategy tries to eliminate the occurrence of such peaks by using equilibration tanks.

4.1.1 Controlling gas streams by a randomising algorithm

Using a randomising algorithm, gas demand during a rise is delayed for a random period of time. The delay increases with 5 minute intervals and has a maximum of 20 minutes.

4.1.2 Controlling gas streams by a retentive algorithm

The basic idea of applying a retentive algorithm is to retain the gas stream which exceed an extrapolation line through the few last points.

4.1.3 Controlling gas streams by tank control

Tank control is based on an equilibration tank present at the greenhouse. When a peak in the gas demand occurs, the control system retrieves gas from this equilibration tank. When a drop in gas demand occurs, the equilibration tank is filled by the control system.

Such a control system can be realised by using an extrapolation line with a variable tangent coefficient. If the gas flow is above the extrapolation line, the difference is supplied by the gas tank. If the gas flow is below the extrapolation line, the gas flow is kept at the last reference point and the difference is supplied to the gas tank.

The tangent of the extrapolation line depends on the amount of gas in the equilibration tank. When the tank is almost filled, the tangent is almost zero. When the amount of gas passes a minimum threshold, the tangent is set to infinity. The tangent is a continuous function of the amount of gas in the tank and varies between both extreme values.

4.2 Simulations of peak smoothing strategies

We modeled the gas distribution in a region of N greenhouses to test our simulation strategies. We tested different smoothing strategies for different parameter settings in the gas demand model.

The tank control algorithm shows the best results in peak smoothing. The smoothing level depends on the capacity of the tank. All peaks but the morning peak can be smoothed with a tank capacity of 10 % of the daily gas consumption. The randomising and retentive algorithm have only a minimal peak smoothing effect. The delay period of 20 minutes is too short for good results. A delay period of 1 hour would give good results, but is unrealistic with respect to the assumption that it can take one hour before a request for gas can be fullfilled. Temperature can fall to unacceptable temperatures with such a long delay time.

5 Model used in forecasting

The energy company was interested in a simulation model to forecast the gas demand 1 to 24 hours ahead. A statistical technique to forecast time series is the well known ARIMA-model of Box and Jenkins [Pankratz, 1983]. Forecasting the gas demand k hour ahead was done by using the gas demand of the past d hours and the weather forecast of the past d hours (see figure 5).

5.1 Forecasting using neural networks

A probabilistic neural network was used to predict the gas demand one hour in advance. The data came from the simulation of gas flow, using controlled or uncontrolled strategies. In table 1, the results are presented. The control strategy with the equilibration gas tank can be best predicted.

As mentioned earlier, the gas tank strategy produces the best results in peak smoothing. Curve fitting by neural networks gives better results in the case of smooth curves instead of noisy curves. This explains the better performance of the gas tank strategy with respect to forecasting.

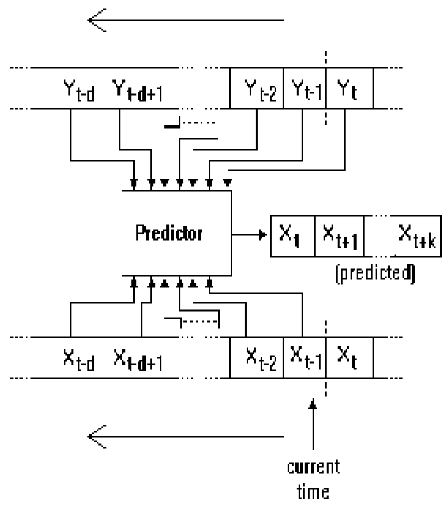

Figure 5: Multivariate model with weather forecast

	avg. relative error	mean square error
uncontrolled	16.6 %	37.5 %
random	17.3 %	48.4 %
retentive	19.1 %	59.7 %
tank	12.5 %	42.6 %

Table 1: Prediction results

6 Simulation of gas demand by neural networks

In figure 4 the gas demand is displayed as a function of time for a certain day. The gas demand of N days ($N = 365$) results in a density cloud of points. Non–linear regression techniques can be used to compute the average gas demand over the whole year as a function of time. An alternative method for non–linear regressions is to train a neural network on the gas demand data. A feedforward network trained with the backpropagation algorithm produced a global error of about 10 %. The trained neural network was used as a model for daily gas demand in the simulation studies.

7 Conclusions

The impact of the used simulation strategies on peak smoothing depends strongly on the delay time used to spread the gas demand over the next period of time. A delay time of 20 minutes has a significant smoothing effect on the curve of the gas demand. Looking at the morning peak in gas demand, a short relay time has not a significant effect, because the peak lasts about two hours. For a significant effect, a delay time of at least one hour is necessary. However, the delay time between two heating periods is limited to 20 minutes.

Another possibility is to start heating before sunrise. In combination with a random distribution of the starting points of individual greenhouses, this results in significant peak smoothing. If we split the group of greenhouses in subgroups with different starting points, we get in fact overlapping morning peaks but shifted in time. This results in a broad, but smoothed peak compared to the current morning peak.

The strategy with an equilibration tank shows best results. All the peaks but the morning peak can be smoothed with a tank capacity of 10 % of the daily gas demand.

The proposed methods are no solution for the peaks caused by sudden weather changes. Using a good weather forecasting system it is possible to anticipate peaks in gas demand and start heating in time. Recent results in weather forecasting with use of artificial neural networks are promising. However, it is necessary to have an information system containing the actual temperatures in the greenhouses to make optimal use of weather forecasting. Using this information, a peak in the gas demand can be anticipated. Greenhouses close to the minimal temperature can be informed to start heating. A prototype is under development.

In section 5.1 we concluded that forecasting using neural networks gives the best results when applied to the equilibration tank strategy. A better forecasting of gas demand can be used to predict peaks and valleys and as a result we can start peak smoothing strategies long before peaks arrive.

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