FORECAST MODEL OF HEAT DEMAND

Abstract: The paper deals with the utilization of time series prediction for control of technological process in real time. An improvement of technological process control level can be achieved by time series analysis in order to prediction of their future behaviour. We can find an application of this prediction also by the control in the Centralized Heat Supply System (CHSS), especially for the control of hot water piping heat output. Due to the large operational costs involved, efficient operation control of the production sources and production units in a district heating system is desirable. Knowledge of heat demand is the base for input data for operation preparation of CHSS. Term “heat demand” is instantaneous required heat output or instantaneous consumed heat output by consumers. The course of heat demand can be demonstrated by means of heat demand diagrams. Most important is daily diagram of heat demand (DDHD), which demonstrates the course of requisite heat output during the day. This diagram is most important for technical and economic consideration. Therefore forecast of this diagram course is significant for short-term and long-term planning of heat production. In this paper we propose the forecast model of DDHD based on the Box-Jenkins methodology. The model is based on the assumption that the course of DDHD can be described sufficiently well as a function of the outdoor temperature and the weather independent component (social components). Time of the day affects the social components. The time dependence of the load reflects the existence of a daily heat demand pattern, which may vary for different week days and seasons. Forecast of social component is realized by means of Box-Jenkins methodology. The complete forecast algorithm with inclusion of outdoor temperature is described. Finally is presented some computational results and conclusions.

Key words: Prediction, District Heating Control, Box-Jenkins, Control algorithms, Time series analysis.

1 Introduction

Improvement of technological process control level can be achieved by the time series analysis in order to predict their future behaviour. We can find applications of this prediction also in the control of the Centralized Heat Supply System (CHSS), especially for the control of hot water piping heat output. Knowledge of heat demand is the base for input data for the operation preparation of CHSS. The term “heat demand” means an instantaneous heat output demanded or instantaneous heat output consumed by consumers. The term “heat demand” relates to the term “heat consumption”. It expresses heat energy which is supplied to the customer in a specific time interval (generally a day or a year). The course of heat demand and heat consumption can be demonstrated by means of heat demand diagrams. The most important one is the Daily Diagram of Heat Demand (DDHD) which demonstrates the course of requisite heat output during the day (See Fig. 1). These heat demand diagrams are of essential importance for technical and economic considerations. Therefore forecast of these diagrams course is significant for short-term and long-term planning of heat production. It is possible to judge the question of peak sources and particularly the question of optimal load distribution between the cooperative production sources and production units inside these sources according to the time course of heat demand. The forecast of DDHD is used in this case (Balátě, 1982).

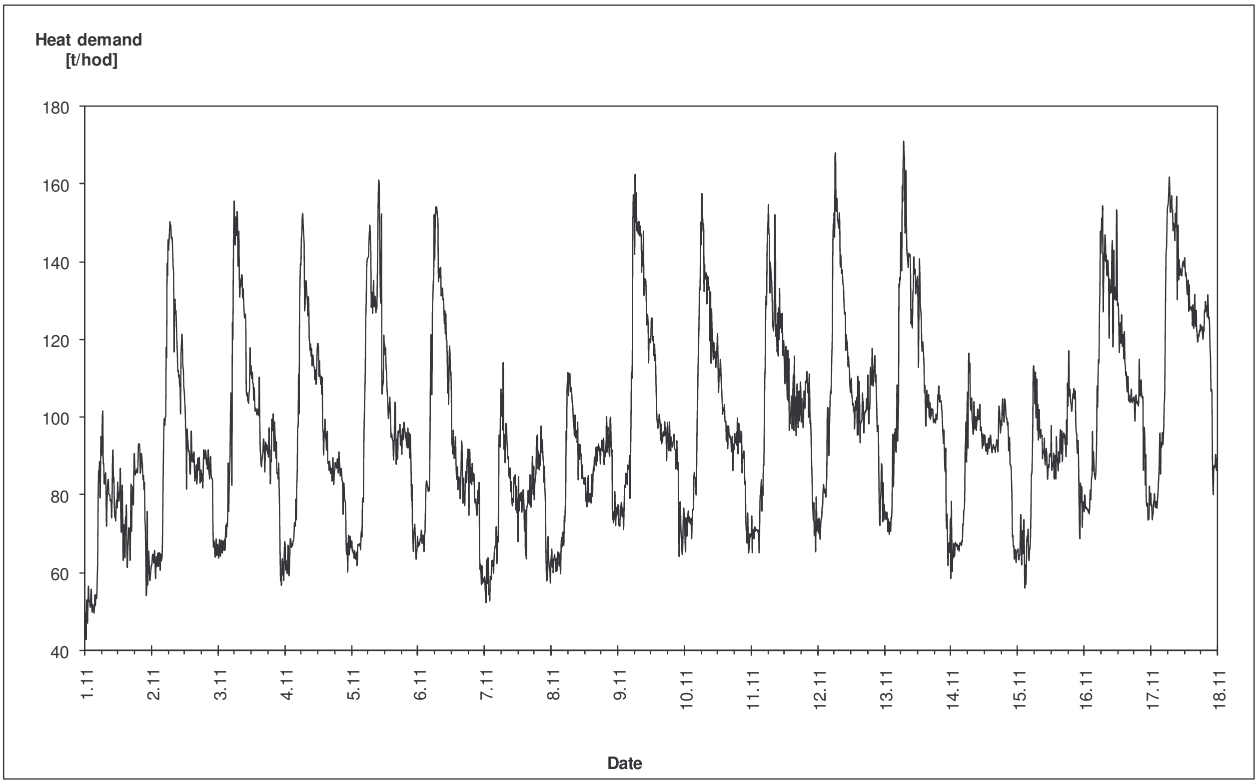

Fig. 1: DDHD from the concrete locality

2 Forecast method for concrete time series of heat demand

It is possible to use different solution methods for the calculation of time series forecast. (For example: solution by means of linear models, solution by means of non-linear models, spectral analysis method, neural networks etc.). In the past, lots of works were created which solved the prediction of DDHD and its use for controlling the District Heating System (DHS). Most of these works are based on mass data processing. Nevertheless, these methods have a big disadvantage that may result in out-of-date real data. From this point of view it is suitable to use the forecast methods according to the Box – Jenkins methodology (Box and Jenkins, 1976). As this method achieves very good results in practice, it was chosen for the calculation of DDHD forecast.

This paper is dealing with the identification of a model of concrete time series of the DDHD and then the inclusion of outdoor temperature influence in calculation of prediction of DDHD is presented.

3 Identification of a model of DDHD

Identification of time series model parameters is the most important and the most difficult phase in the time series analysis. We have particularly focused on determination of difference degree as well as on obtaining a suitable order of autoregressive process and order of moving average process. Differencing the time series consists in reduction of nonstationary time series to stationary time series and also it means to determine a degree of seasonal differencing in the case of periodic behaviour of time series.

A number of possibilities for determination of difference degree exist.

1. It is possible to use a plot of the time series, for visual inspection of its stationarity. In case of doubts, the plot of the first or second differencing of time series is drawn. Then we review stationarity of these series.
2. Investigation of estimated autocorrelation function (ACF) of time series is a more objective method.
3. Anderson (Anderson, 1976) prefers to use the behaviour of the variances of successive differenced series as a criterion for taking a decision on the difference degree required.

Many observed non-stationary time series exhibit certain homogeneity and can be accounted for by a simple modification of the ARMA model, the autoregressive integrated moving average (ARIMA) model. Determination of a degree of differencing d is the main problem of ARIMA model building. In practice, it seldom appears necessary to difference more than twice. That means that stationary time series are produced by means of the first or second differencing.

In practice, many time series have seasonal components. These series exhibit periodic behaviour with a period s. Therefore it is necessary to determine a degree of seasonal differencing - *D*. The seasonal differencing is marked by ∇_s^D. In seasonal models, necessity of differencing more than once occurs very seldom. That means *D=0* or *D=1*.

An example of the determination of the difference degree for our time series of DDHD is shown in this part of paper. The course of time series of DDHD contains two periodic components (daily and weekly periods). The daily period presents increase and decrease in heat demand during the day. Heat demand drop at the weekend forms the weekly period of DDHD. The general model according to Box-Jenkins enables to describe only one periodic component. We can propose two eventual approaches to calculation of forecast to describe both periodic components (Dostál, 1986).

- *The method that uses the model with double filtration*
- *The method – superposition of models*

For time series analysis we will further consider only time series of the DDHD without Saturday and Sunday values. This time series exhibits an evident non-stationarity (see Fig. 2). It is necessary to difference.

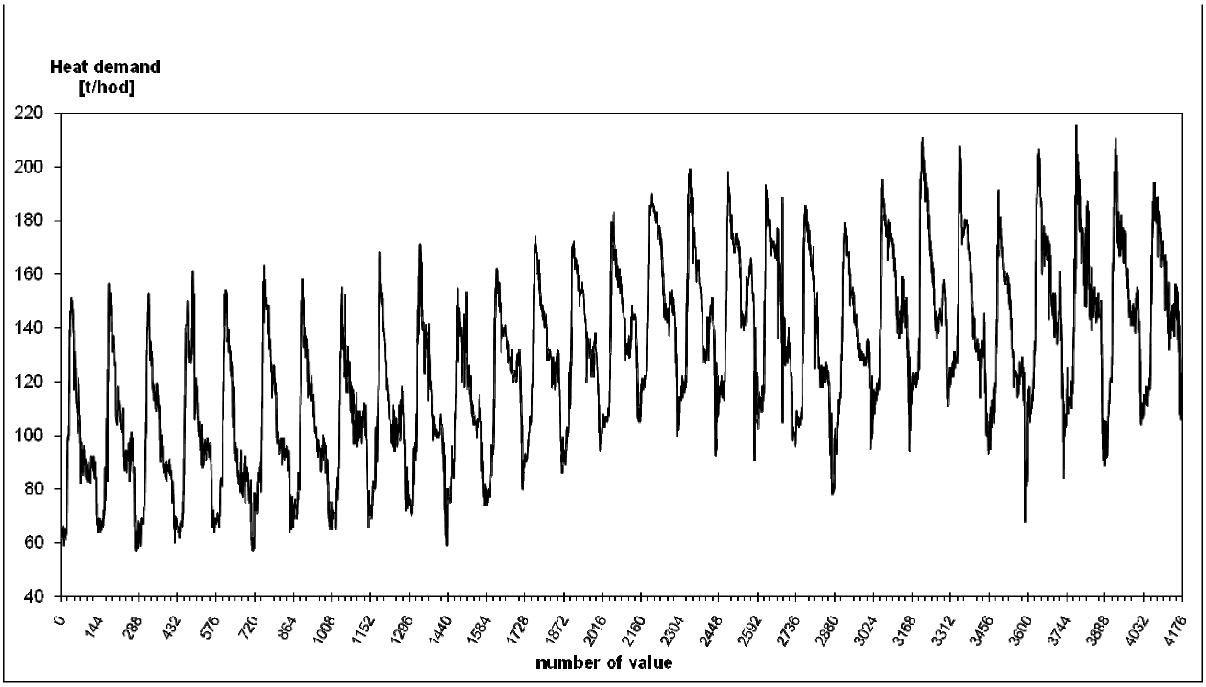

Fig. 2: The course of DDHD without Saturday and Sunday values

The course of time series of the first differencing is shown in Fig. 3. The differenced series looks stationary now. This fact is also confirmed by the sample ACF (see Fig. 4 and Fig. 5) and by the estimated variance of non-differenced and differenced series.

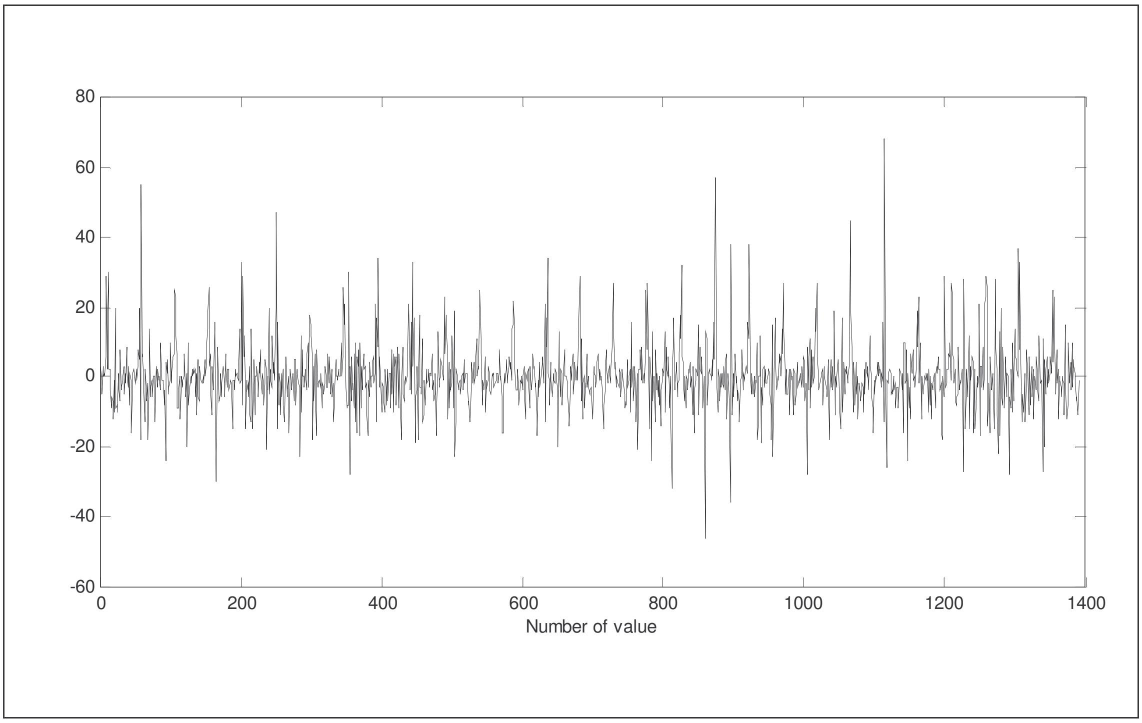

Fig. 3: Time series of heat demand after first differencing

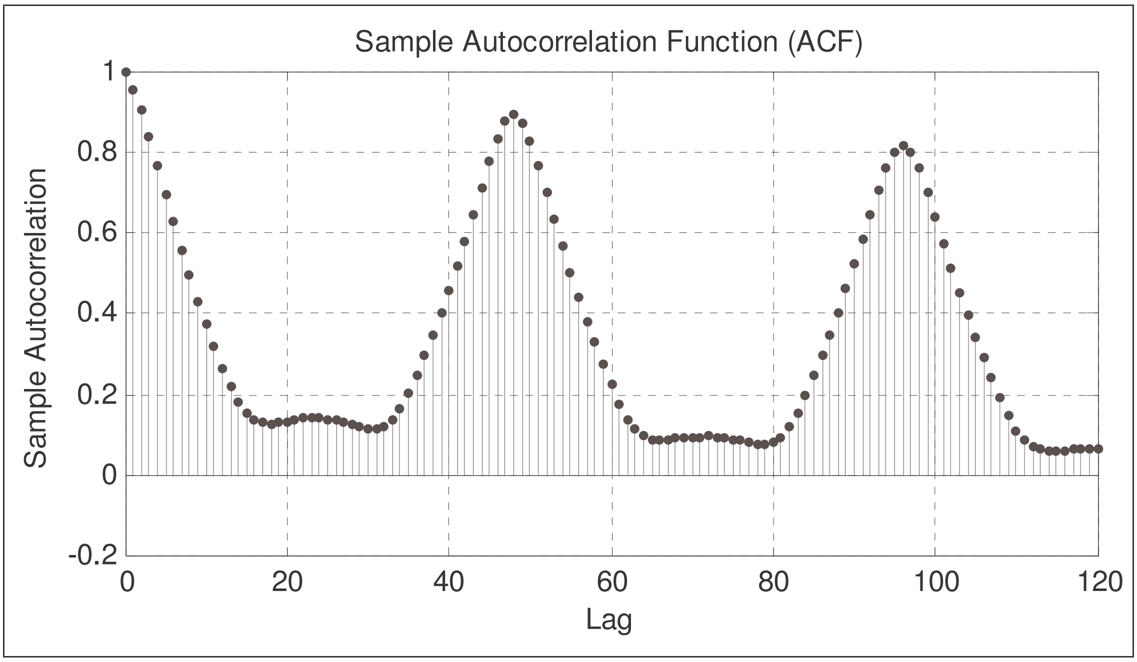

Fig. 4: The course of estimated ACF of DDHD

As our time series of the DDHD exhibits an obvious seasonal pattern, it is necessary to make an analysis of the seasonal differencing of our time series, as well. The course of the ACF sample evidences the seasonal pattern (see Fig. 4 or Fig. 5). These functions have their local maxima at lags 48, 96, etc. That represents a seasonal period of 24 hours by a sampling period of 30 minutes. On the basis of the executed analysis, it is necessary to make the first differencing and also the first seasonal differencing of the DDHD in the form (1).

$$\nabla\nabla_{48} z_t = z_t - z_{t-1} - z_{t-48} + z_{t-49} \tag{1}$$

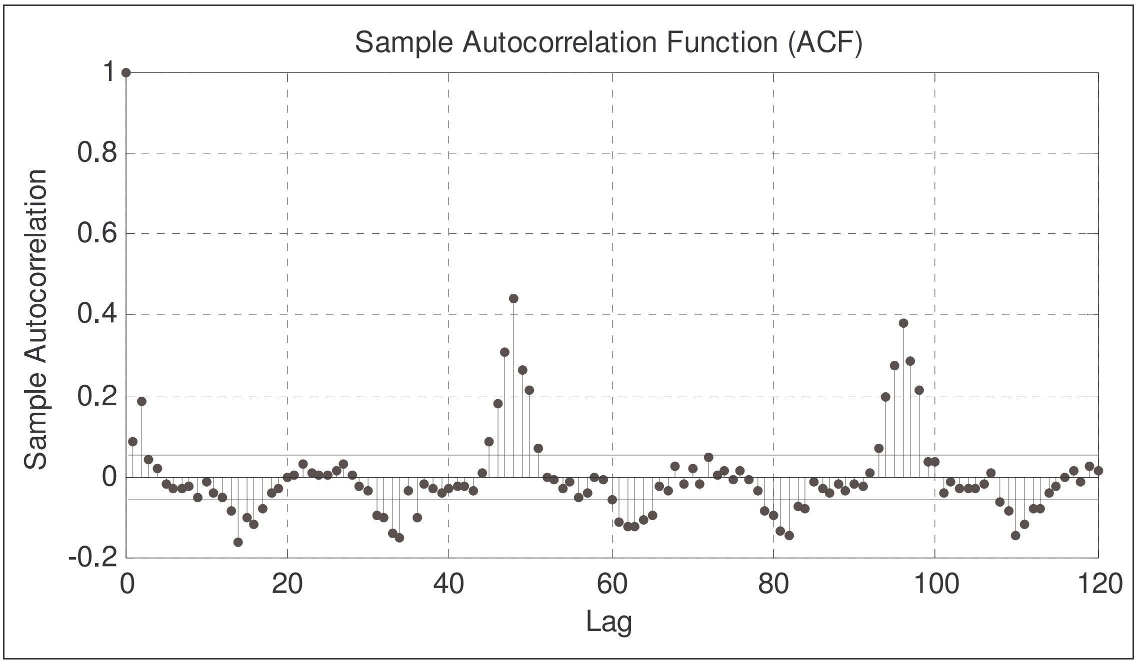

Fig. 5: The course of estimated ACF of the DDHD after the first differencing

3.1 Determination of AR process order and MA process order

After differencing the time series, we have to identify the order of autoregressive process AR(p) and order of moving average process MA(q). The traditional method consists in comparing the observed patterns of the sample autocorrelation and partial autocorrelation functions with the theoretical autocorrelation and partial autocorrelation function patterns.

The order of model is usually difficult to determine on the basis of the ACF and PACF. This method of identification requires a lot of experience in building up models. From this point of view it is more suitable to use the objective methods for the tests of the model order.

A number of procedures and methods exist for testing the model order (Cromwell, 1994). These methods are based on the comparison of the residuals of various models by means of special statistics. In our case, the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Schwarz test are used for testing. Adequacy of the suggested model is examined by means of Portmanteau test.

4 Inclusion of outdoor temperature influence

Above mentioned methods do not describe sudden fluctuation of meteorological influences. In this case we have to include these influences in calculation of prediction.

Previous works on heat load forecasting [Arvastson, 2001], show that the outdoor temperature has the greatest influence on DDHD (with respect to meteorological influences). Other weather conditions like wind, sunshine and so on have less effect and they are parts of stochastic component.

For inclusion of outdoor temperature influence in calculation of prediction of DDHD was proposed this general plan:

a) The influence of outdoor temperature filter off from time series of DDHD by means of heating characteristic (function that describes the temperature-dependent part of heat consumption)

b) Prediction of DDHD by means of Box-Jenkins method for this filtered time series

c) Filtration of predicted values for the reason of inclusion of outdoor temperature influence (on the base of weather forecast)

From the previous plan is evident that the principal aim is to derive an explicit expression for the temperature-dependent part of the heat load. It is obvious that the temperature dependence is non-linear. For relatively high outdoor temperatures, the temperature has less influence. For example, the load will almost be the same for 25 °C and 27 °C. A corresponding conclusion is also true for relatively low temperatures, e.g. whether the outdoor temperature is -28 °C or -30 °C does not matter, the production units will produce at their maximum rate anyway.

Regarding to previous consideration we can used the temperature-dependent part of heat consumption in the form (2):

$$z_t^{kor} = x_1 \cdot T_t^3 - x_2 \cdot T_t \quad (2)$$

where: z_t^{kor} is correction value of heat consumption in time t including outdoor temperature influence, T_t is real value of outdoor temperature in time t , x_1, x_2 are constants

The course of heating characteristic for constants $x_1 = 0.002$, $x_2 = 3.5$ is shown in the Fig. 6.

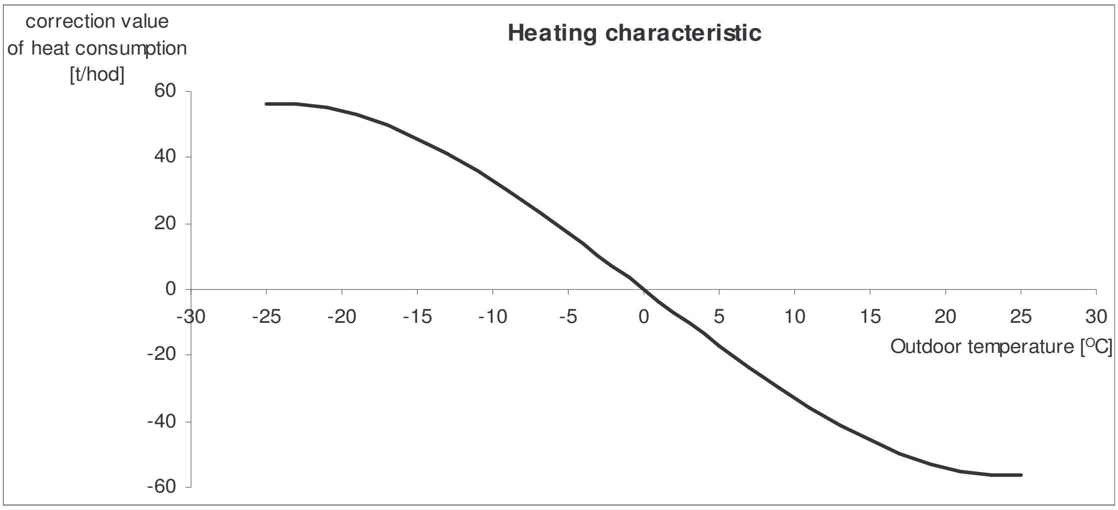

Fig. 6: The sample of heating characteristic (cubic function)

The temperature dependent part can assumed to vary as a piecewise linear function, see the illustrating example in Fig. 7 (Dotzauer, 2002). Here a function with five segments is used, but the number of segments can of course be chosen arbitrarily.

Given the number of segments as a N_s. and the temperature levels as $\tau_i, i = 1,...,N_s + 1$. Now we can consider the temperature-dependent part of heat consumption in the form (3):

$$z_t^{kor} = \alpha_i \cdot T_i + \beta_i \quad (3)$$

where: z_t^{kor} is correction value of heat consumption in time t including outdoor temperature influence, T_t is real value of outdoor temperature in time t ,α_i is the slope of i-th segment, β_i is absolute equation term of i-th segment. Constants (x_1, x_2 and ,α_I, β_i) have to be determined for concrete locality empirically.

Filtration time series of DDHD that inputs in prediction model is defined in the form (4).

$$z_t^{filtr} = z_t - z_t^{kor} \quad (4)$$

where: z_t^{filtr} is heat consumption in time t with filtering off the influence of outdoor temperature, z_t^{kor} is correction value of heat consumption in time t including outdoor temperature influence, z_t is real value of heat consumption in time t

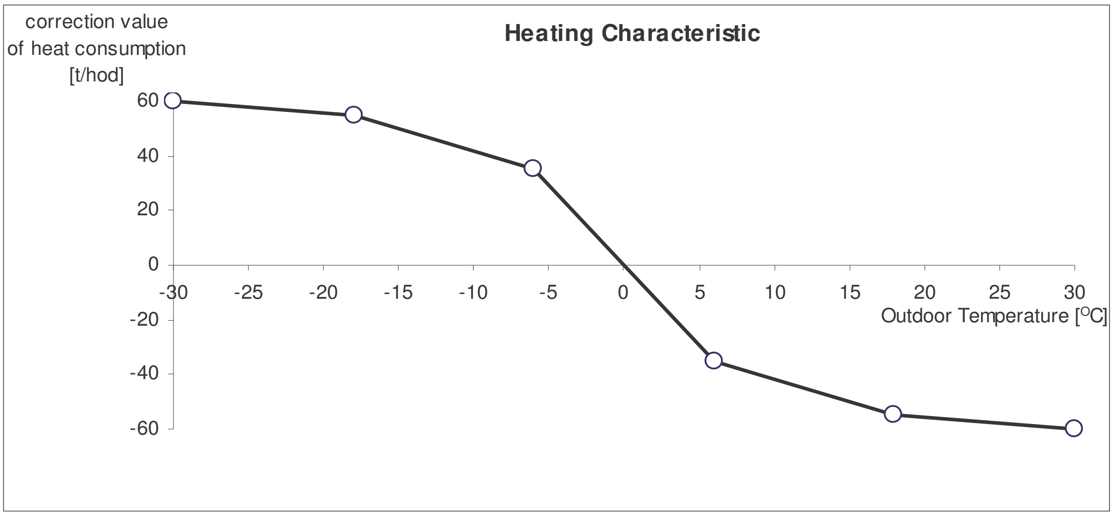

Fig. 7: The sample of heating characteristic (piecewise linear function)

After prediction calculation of filtering off time series is necessary to filtrate the predicted values for the reason of inclusion of outdoor temperature influence (on the base of weather forecast). We can define this operation in the form (5).

$$z_t^{+} = z_t^{filtr^{+}} + z_t^{kor} \tag{5}$$

where: $z_t^{filtr^{+}}$ is predicted value of filter off time series of heat consumption in time t, z_t^{kor} is correction value of heat consumption in time t including outdoor temperature influence, z_t^{+} is predicted value of heat consumption in time t.

The value z_t^{kor} is obtained by application of the equation (2) or (3) for this operation. We use weather forecast (temperature forecast).

5 Concrete Results of DDHD prediction

We use real data measured in concrete locality (in our case in the city Olomouc and Zlin) for calculation. In this case we realized the calculation of DDHD prediction for date 23.11. 1998. In this time the sudden fluctuation of outdoor temperature was observed (see Fig. 8). The samples of results of DDHD prediction are shown in the Fig. 9 and Fig. 10.

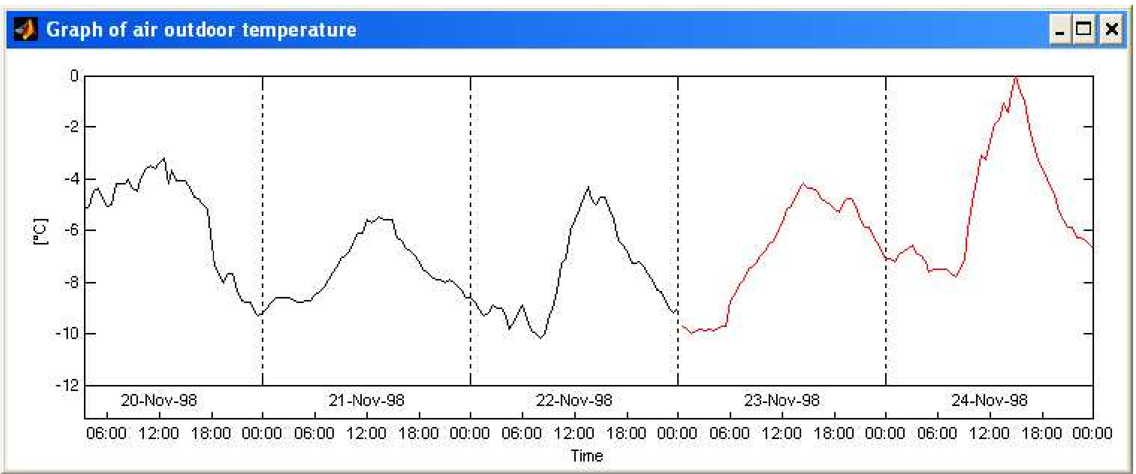

Fig. 8: The course of outdoor temperature

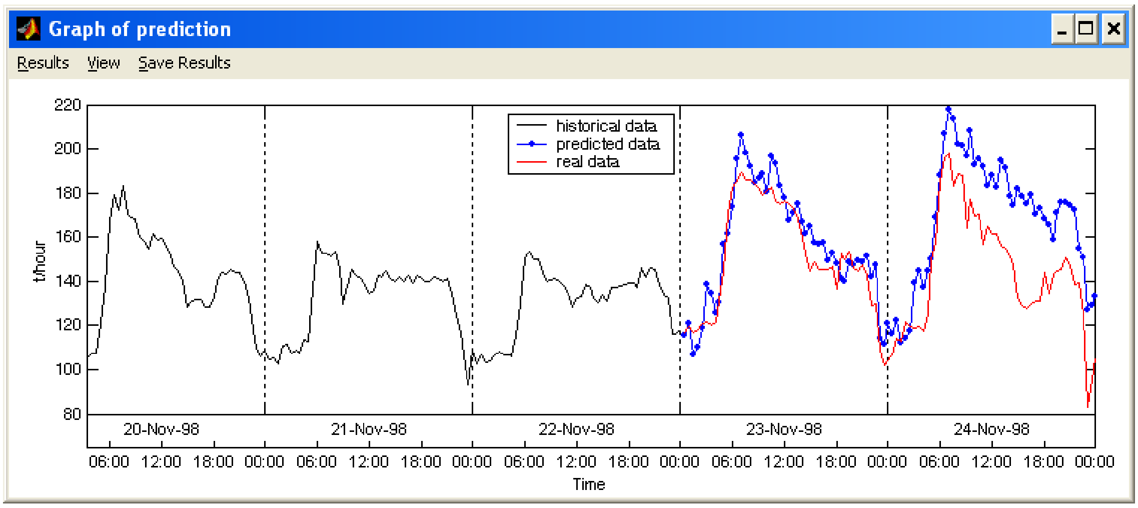

Fig. 9: The course of DDHD prediction without inclusion of outdoor temperature influence

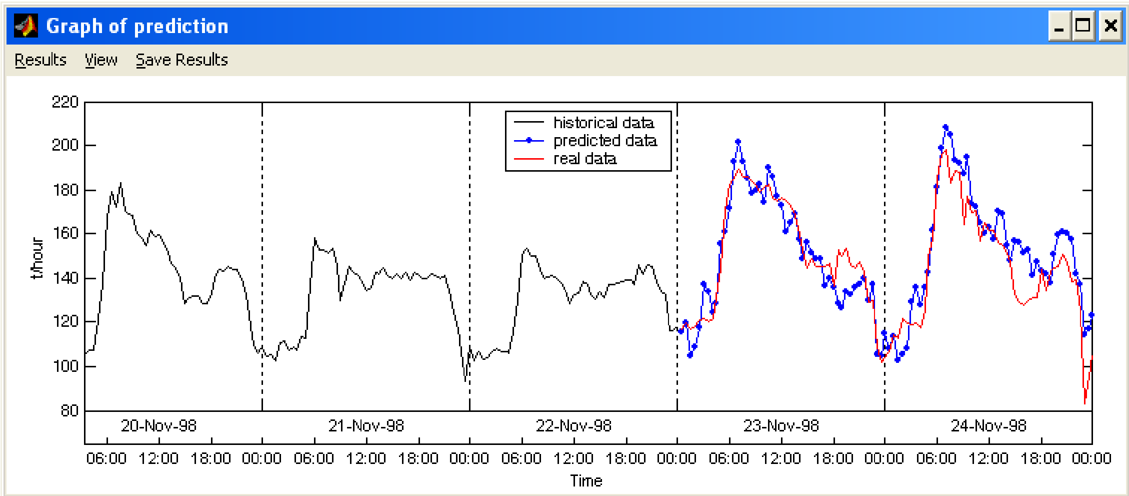

Fig. 10: The course of DDHD with inclusion of outdoor temperature influence

6 Conclusion

This paper presents the method for building up the model of time series of DDHD and the possibility of improvement of this forecast model with help of inclusion of outdoor temperature influence. The modelling is based on the Box-Jenkins methodology. The time series analysis was made for the DDHD from the concrete locality. This prediction of DDHD is necessary for the control in the Centralized Heat Supply System (CHSS), especially for the qualitative-quantitative control method of hot-water piping heat output – the Balátě System (Balátě, 1982).