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MODEL BUILDING FOR PREDICTION OF HEAT SUPPLY DAILY DIAGRAM

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ABSTRACT
The paper deals with analysis of time series of heat demand course. The course of heat demand and heat consumption can be demonstrated by means of heat demand diagrams. Most important are Heat Supply Daily Diagram (HSDD), which demonstrates the course of requisite heat output during the day. This analysis is utilized for building of prediction model of HSDD. Forecast of this demand course is significant for short-term and long-term planning of heat production. This forecast is most important for technical and economic consideration. The solved prediction is specially determined for qualitative-quantitative method of hot-water piping heat output control – Balátě system which enables to eliminate transport delay. Importance of it is increased namely for controlled systems having great time constants and great transport delay. We focus on determination of difference order, autoregressive process order and moving average process order.
Keywords: Prediction, District Heating Control, Box-Jenkins, Control algorithms, Time series analysis

1. INTRODUCTION
An improvement of technological process control level can be achieved by time series analysis in order to prediction of their future behavior. 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.

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. Term “heat demand” relates to term “heat consumption”. It express heat energy, which is the customer

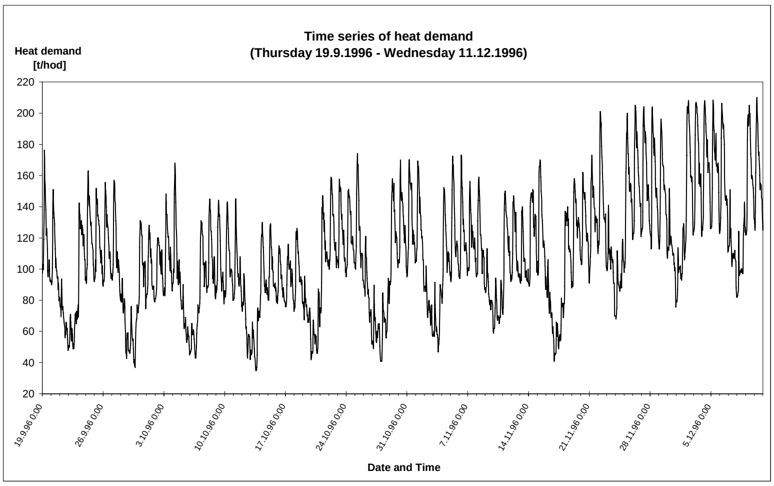


Figure 1. Heat Supply Daily Diagram for concrete locality

supplied in a specific time interval (generally day or year).

The course of heat demand and heat consumption can be demonstrated by means of heat demand diagrams. Most important are:

- **heat supply daily diagram**, which demonstrates the course of requisite heat output during the day. (See fig.1)
- **duration heat demand diagram** - Y-coordinates represent heat demand and distance from zero represents duration of corresponding heat demand. At present there are known duration heat demand diagrams daily and yearly

These diagrams are most important for technical and economic consideration. 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 namely the question of optimal distribution loading between cooperative production sources and production units inside these sources according to time course of heat demand. The forecast of heat supply daily diagram (HSDD) is used in this case.

2. METHODS OF FORECAST – BOX-JENKINS METHOD

It is possible to use different solving methods for calculation of time series forecast. (For example: solving by means of linear models, solving by means of non-linear models, spectral analysis method, neural networks etc.). In former times was created a lot of works, which solve the prediction of HSDD and its use for control of District Heating System (DHS). Most of these works are based on mass data processing. But these methods have a big disadvantage. It consists in out of date of real data. From this point of view is available to use the forecast methods according to the methodology of Box – Jenkinse [2]. This method works with fixed number of values, which are update for each sampling period. This methodology is based on the correlation analysis of time series and it works with stochastic models, which enable to give a true picture of trend component and also of periodic components. Because this method achieves very good results in practice, it was chosen for calculation of HSDD forecast.

3. BUILDING OF MODEL FOR CONCRETE TIME SERIES OF HEAT DEMAND

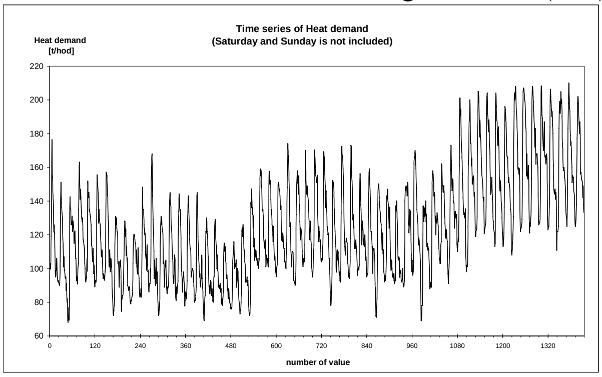
The identification of parameters of time series model is most important and most difficult at the time series analysis. This paper deals with identification of model of concrete time series of HSDD. We focus namely on determination of difference degree and obtaining the suitable order of autoregressive process and order of moving average process.

3.1. Determination of degree of differencing

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 degree of differencing ***d*** is the main problem of ARIMA model building. In practice it is found seldom necessary to difference more than twice. That means, stationary time series are produced by means of first or second differencing. Number of possibilities for determination of difference degree exists.

1. It is possible to use a plot of the time series, for visual inspection of its stationarity. In the case of obscurity the plot of first or second differencing of time series is draw. Then we review stationarity of these series.
2. Investigation of estimated autocorrelation function (ACF) of time series is more objective method. If the values of ACF have a gentle linear decline (not rapid geometric decline), an autoregressive zero approaching 1 and it is necessary to differencing.
3. Anderson [1] prefers to use the behaviour of the variances of successive differenced series as a criterion for deciding on the degree of differencing necessary. Degree of differencing ***d*** is given accordance with minimal value of variances $\sigma_z^2, \sigma_{\nabla z}^2, \sigma_{\nabla^2 z}^2 \ldots$.

Example of determination of difference degree for our time series of HSDD is shown in this part of paper. The course of time series of HSDD contains two periodic components (daily and weekly period). The general model according to Box-Jenkins enables to describe only one periodic component. From this point of view it is essential for finding the difference degree to use time series of HSDD without values of Saturday and Sunday. This time series (see Fig.2.) exhibits evident nonstationarity. It is necessary to difference. The course of time series of first differencing is shown in the Fig.3. The differenced series looks stationary. It is possible to use estimated ACF for confirmation or to compare the estimated variance of non-differenced and differenced series. In our case we obtain these results: $\hat{\sigma}_z^2 = 967{,}7;\ \hat{\sigma}_{\nabla z}^2 = 119{,}9;\ \hat{\sigma}_{\nabla^2 z}^2 = 168{,}2.$ From these results and figures below it is suitable to choose first differencing of HSDD (d=1).



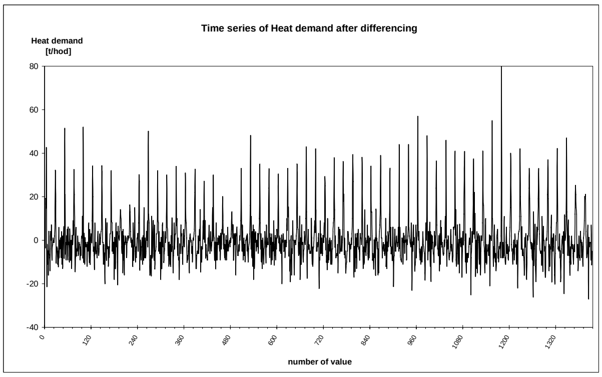


Figure 2. The course of HSDD without values of Saturday and Sunday

Figure 3. The course HSDD after first differencing

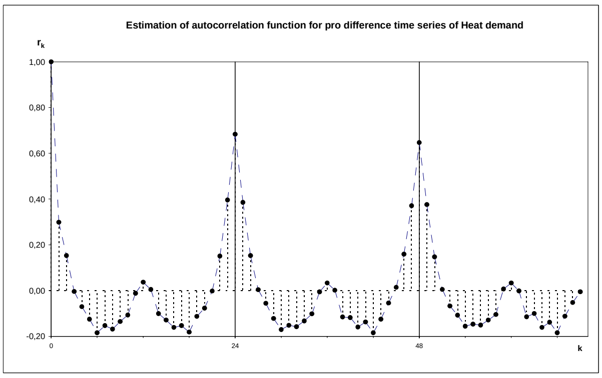
Many of time series from practice have seasonal components. These series exhibit periodic behaviour with period ***s***. Therefore it is necessary to determine degree of seasonal differencing - ***D***. The seasonal differencing is marked by ∇_s^D . In seasonal models it is occurred seldom necessary to difference more than one. That means D=0 or D=1. About degree of seasonal differencing it is possible to decide on the base of investigation of estimated ACF. If the values of ACF at lags ***k*s*** are local maximum, it is necessary to make a first seasonal differencing (D=1) in the form $\nabla_s z_t$.

Our time series of HSDD exhibits also obvious seasonal pattern. From this point of view it is necessary to make seasonal differencing of our time series. The course of estimated ACF evidence seasonal pattern (see Fig. 4). This function has local maximums at lags 24, 48, …. That represents seasonal period 24 hours by sampling period 1 hour.

On the base of executed analysis it is necessary to make first differencing and also first seasonal differencing of HSDD in the form (1).

$$\nabla\nabla_{24} z_t = z_t - z_{t-1} - z_{t-24} + z_{t-25} \quad . (1)$$

The course of differenced HSDD in the form (1) is shown on the figure 5. For comparing it is possible to calculate the variances of time series and differenced series according Anderson[1]. The results are $\hat{\sigma}_z^2 = 967{,}7;\ \hat{\sigma}_{\nabla z}^2 = 119{,}9;\ \hat{\sigma}_{\nabla^2 z}^2 = 168{,}2; \hat{\sigma}_{\nabla_{24} z}^2 = 150{,}5; \hat{\sigma}_{\nabla\nabla_{24} z}^2 = 72{,}7$.



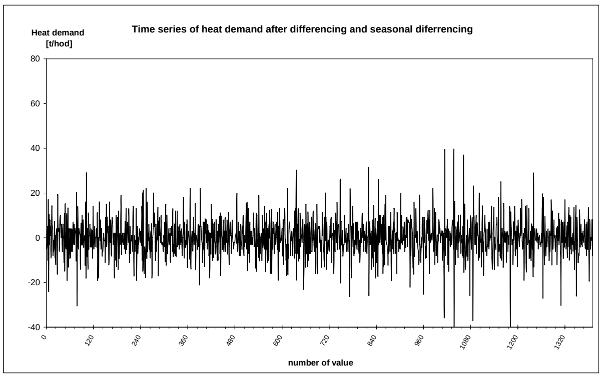


Figure 4. The course of estimated ACF of HSDD

Figure 5. The course HSDD after first differencing and after first seasonal differencing

3.2. Criterions for determination of autoregressive process order and moving average process order

After differencing of time series we have to identification of ARMA model. Order of autoregressive operator $\phi_p(B)$ - $\boldsymbol{p}$ and order of moving average operator $\theta_q(B)$ - $\boldsymbol{q}$ is the first results of this identification. A number of procedures and methods exist for testing of model order [3]. These methods are based on comparing the residuals of various models by means of special statistics.

The results of testing for model order of HSDD are presents on the next tables (see tab.1 and tab.2). We have chosen the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for testing. Tables represent the values of the particular criterion in dependence on model order (p, q).

Table 1. Values of Akaike Information Criterion

p \ q	0	1	2	3	4	5	6	7
1	4,9407	4,9487	4,9477	4,9408	4,9506	4,9437	5,1471	4,9516
2	4,9492	8,2673	4,94	4,9504	10,8561	5,0701	5,4884	4,9549
3	**4,9352**	4,9448	4,951	9,6548	6,3356	4,9465	32,0275	4,9667
4	4,9448	12,6404	7,5348	5,4233	5,242	10	6,0874	4,9747
5	4,9531	7,5066	9,7629	5,2236	7,9804	4,9977	4,9866	8,0104
6	4,946	4,9473	4,9909	4,9615	4,9643	4,9827	9,0348	7,4573
7	4,9454	4,9589	7,4783	4,971	5,8989	7,7497	6,6514	6,8525

Table 2. Values of Bayesian Information Criterion

p \ q	0	1	2	3	4	5	6	7
1	**1034**	1040,6	1044,9	1047,6	1053,5	1055,8	1100,1	1064,4
2	1040,7	1728,2	1047,4	1053,5	2273,1	1084,7	1171	1068,4
3	1042,3	1048,4	1053,6	2022,9	1335,8	1063,4	6680,8	1073,9
4	1048,4	2642,8	1575,9	1155,2	1122,1	2000	1292,9	1078,6
5	1054	1569,7	2046,8	1118,5	1673,8	1080	1081	1681,2
6	1056,3	1060,1	1072,2	1069,7	1073,5	1080,2	1899,1	1554,9
7	1059,8	1065,9	1563	1074,8	1258,4	1623,8	1401,8	1436,3

Results for our time series are ambiguous. The minimal value of AIC is for p=3 and q=0 whereas the minimal value of BIC is for p=1 and q=0. From table 1 it is clear that value of AIC for p=3 and q=0 is close to minimum and the same situation is on the table 2 for p=1 and q=0. From this point of view it is possible to use both model for prediction. The general theorem – small value of model order results from tables. Small values of AIC, BIC show evidence of this theorem.

4. CONCLUSION

The paper presented a method for inclusion of outdoor temperature influence in calculation of HSDD prediction. This prediction of HSDD is necessary for qualitative-quantitative control method of hot-water piping heat output – Balátě system.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] Anderson, O. D. (1976). *Time Series Analysis and Forecasting – The Box-Jenkins aprroach*.London and Boston: Butterworths, 180 p., ISBN: 0-408-70926-X.

[2] Box G.E.P., Jenkins G.M. (1976). *Time Series Analysis-Forecasting and Control*. USA: Holden Day, 575 p., ISBN 0-8162-1104-3.

[3] Cromwell, J.B., Labys, W.S., Terraza, M. (1994). *Univariate Tests for Time Series Models*. SAGE Publication, ISBN 0-8039-4991-X, Thousand Oaks, California.