Corrections of the heating curve based on behavior in the consumption of the heat

Dolinay Viliam, Vasek Lubomir

Abstract— This article focuses on benefits of heat curve corrections. Large group of heat distributors use simple weather compensation heating curve to compute temperature of heating water in their supply systems. In such system the value of the water temperature is directly proportional to outside temperature. From the natural behavior of the system is evident that the heat requirements during the day change but not only depending on outside temperature but time has an important role. A typical example of this behavior is the morning rush hour. Regardless of the constancy of outside temperature, system consumes an increased amount of heat. The reason is simple in this case, consumer (house) loses heat during the night because the temperature at night is controlled to a lower value but when switching to the daily operation, it is a logical that heating system tries to attempt to supplement this heat deprivation. One possible solution would be to do intelligent appliances at the time of these changes and the distribution spread more in time. These methods, however, would require greater investment but that the most consumers are not in the current economic situation willing to accept. The second solution, presented in this article, leaves the current system of weather compensation curve and only complements correction terms. These corrections ensure that at critical moments, the system temperature will be increased/decreased and the system will better spread required heat flow between the quantity (mass flow) and quality (temperature).

Proposed method was applied on real heating system and subsequent behavior was closely monitored. Obtained results show improved behavior, which is evident from the reduction of shock and peaks in the system.

This article presents idea and practical attempt of heating curve modification, as an introduction for the future research.

Keywords— Equithermal curve, heating curve, heat consumption, prediction, simulation.

I. Introduction

PREPARING the heating curve is suitable in most task of heating system.

The aim is to determine the temperature of heating water to provide enough heat for the consumer but also to eliminate unnecessary losses in the pipeline net and at the same time use the minimum energy to transport the heat medium from source to consumer [1, 3]. Higher temperature increases the loss of heat during the transfer medium, vice versa medium with low temperature does not transfer as much energy and it is therefore necessary to increase its quantity. Increasing the quantity of course increases the cost associated with the transport [2]. Simple consideration mentioned above shows that in the determination (calculation) of suitable heating curve must be found the optimum ratio of the temperature of heating water and its quantity (the control parameters).

The above description is of course a considerable simplification, because the values of both parameters are also dependent on time and at especially the systems where the heat transfer medium is transported over long distances has timing an essential role.

In practice, the heating curve is often obtained experimentally and generalizes heat requirements in the system after a certain time of day, typically day and night.

In this article will be devote just to the systems with a fundamental heating curve, whose shape is directly proportional to the value of outdoor temperature. This type of heat curve management is usually called an equithermal, or weather-compensated control.

The aim of this paper will be to present improvements correcting curves depending on the specific periods of the day. Such period is usually morning or evening rush hours. Number of authors deals with system behavior prediction [4, 5]. It is not easy to determine suitable parameters, because heating consumption is effected by users behavior (house residents) and outside weather adds stochastic behavior as well. In the first part of the article the appropriate of modifying the basic heating curve will be presented. The simple experiment to confirm some basic links in the heat distribution system will be shown subsequently.

There are several algorithms modifying heating curve control. Some of them have already found a place in practical application [11]. Modified curves are for example used in modern boilers for heating of houses. The final heating water temperature is in this case usually calculated from outside temperature and current room temperature. More sophisticated solutions extend computation by the time factor (night, day, weekday, weekend, etc.) This methods are however hardly applicable on wide areas such as central heating system, which is the area on article focuses. Nevertheless, this ideas can be generalized and modified so that in central heating systems is also applicable.

In central heating systems, performs a number of variants of heat consumers. Certainly the heat consumption timing need is different than the school, house, shop or factory is supplied. The buildings, apart from the use are physically behaving the same, but people often significantly affect the consumption by their behavior and requirements.

If the focus is on the residential space, it is customary that the heat consumption decreases at night, usually called the night attenuation. The night attenuation has resulted in morning peak in consumption. Depending on the quality of building insulation, the consumption in the morning peak increase by more than 100%. For residential space heating can also be observed stagnation of consumption in the late morning and afternoon. First, at this time the outside temperature is higher, but this is able to compensate classic heating curve, but the apartments are also without residents and often controlled by the room temperature to a lower value.

Like night attenuation, the day stagnation has resulted in an increase in consumption in the subsequent hours. If the temperature is suppressed in the apartment during the day, to fetch the temperature to normal will require increased consumption and thus arises the evening rush hour. If pump load balance is required, in view of the above mentioned is necessary to adapt the system input parameters. In the hot-water heating systems the amount of heat is controlled by the outlet water temperature and its mass flow. Water temperature is usually kept at the lowest possible value and in the modern systems is almost without fluctuation. Possibility to influence change in heat by mass flow is limited, differential pressure in the system must be kept. Inappropriate reduction in pressure would result in insufficient supply to the furthest stations, while the excessive increase would increase the costs associated with pumping and excessive work load of the system. In systems which slew this article is the pressure (flow) "untouchable". The pressure is kept to a minimum differential pressure by the independent controller. Although the possibility to intervene in the system was limited to changing the temperature of heating water to these experiments is predominantly achieved by a balanced flow. Quantities are obviously linked and therefore change any of them directly affect the remaining two.

A brief example:

Let's enter to the system at the moment the balance, there are no peaks and output temperature is without variations.

- We will now increase the water temperature a few degrees (the output of the heat exchangers)
- In our system after a few minutes the water reaches house station of the monitored building
- Water temperature in the house circuit is set to a level which does not interfere. This temperature is kept at the desired value using three-way mixing valve (mixing input water with water on the return)

Note: Input water flow is controlled by an automatic servo valve.

- Increase in the temperature causes an increase in the input of cold water from the return pipe to the input (mixing).
- Increase the proportion of return water incorporation into the input (automatically closing the valve) will increase the pressure which is compensated by reducing the flow (the amount taken from the heat exchangers decrease).

Arrangement of valves and pipes is shown in the diagram in Figure 2.

This simplified example showed indirect way how the affect flow by the change in temperature.

It must be always bear in mind, changing one of the variables affects the others and always take into account all physical limitations of each variable in the system.

II. System Description

A. Equithermal regulation

Heat loss of the house depends on the outdoor temperature and the radiator area is there for each outdoor temperature of heating water, which currently provides the required room temperature. This dependence is called the heating curve.

Equithermal regulation, also called weather compensation sets heating water temperature by the outside temperature; used electrically operated valve that reduces the temperature of hot water rising from the source by the incorporation of cooled water that returns from the radiators. Heating water than has at all times the temperature, ensuring the performance of heaters needed to cover the heat losses. When outdoor temperature is lower, the warmer water is driven to the circulation, if it is warmer outside, the heating water temperature decreases. This performance is continually changing the heating system depending on outdoor temperature.

The advantage of the equithermal regulation is that only one controller is needed for the whole house. The disadvantage is that it does not take into account the different heat gains or losses in individual rooms. Therefore, it is not used separately, but combined, for example, with thermostatic valves [10].

Figure 1 shows example of heating curve which is used for equithermal regulation.

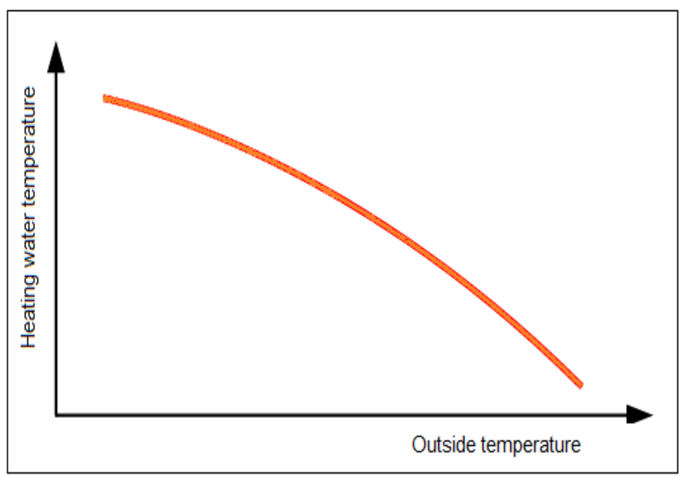

Fig. 1 Heating curve

B. Thermal attenuation

In completely isolated houses with large heat accumulation capacity are generally lower regulation requirements than in the light construction. This is because the wall material acts as a "battery" (compensates outside temperature differences), and the room temperature therefore varies only slowly. There is therefore enough time for any manual correction. But it also means that it is hardly possible to somehow significantly affect heat loss by reducing the temperature at the time when no one is in the building.

On the other side, in houses with small heat capacity (for example wooden buildings or poorly insulated houses) will be suitable to use the controller with a time schedule that enables the heat in the rooms only when there are residents.

III. System Behavior

First of all it should be shown how the selected real system reacts during the one day. Mentioned behavior is better seen in the data from the end of the heating season when outdoor temperature is able to significantly reduce heat requirements especially during the sunny afternoons. Following pictures show outside temperature course, corresponding heating water temperature, measured consumed heat and mass flow. Courses are show for two house stations (red and blue).

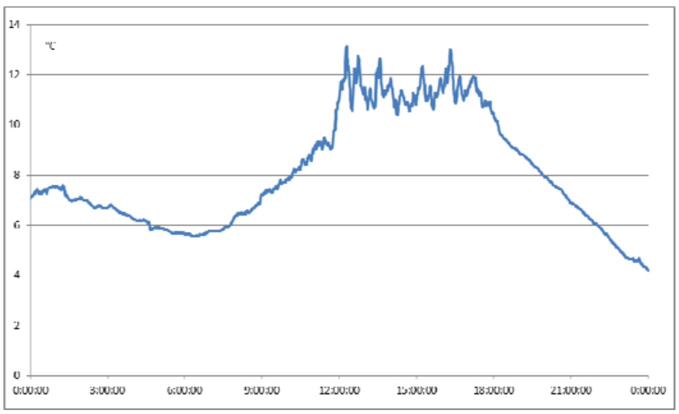

Fig. 2 Outside temperature

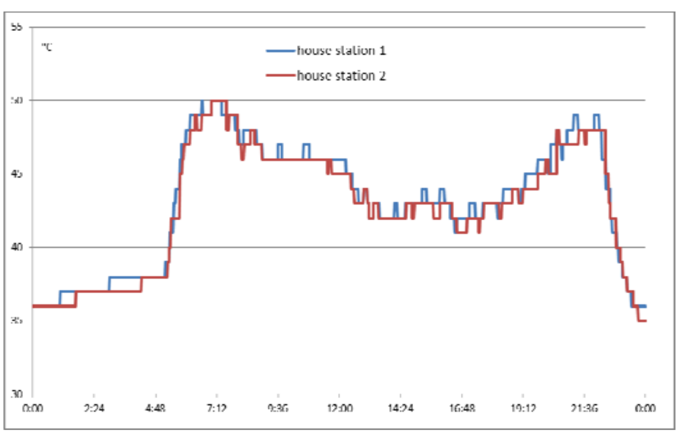

Fig. 3 Heating water temperature

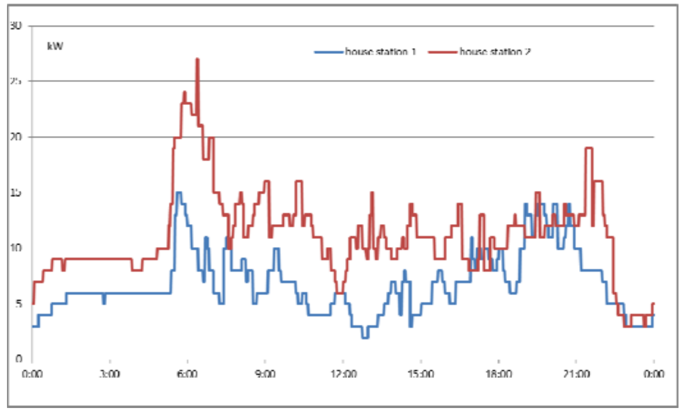

Fig. 4 Consumed heat

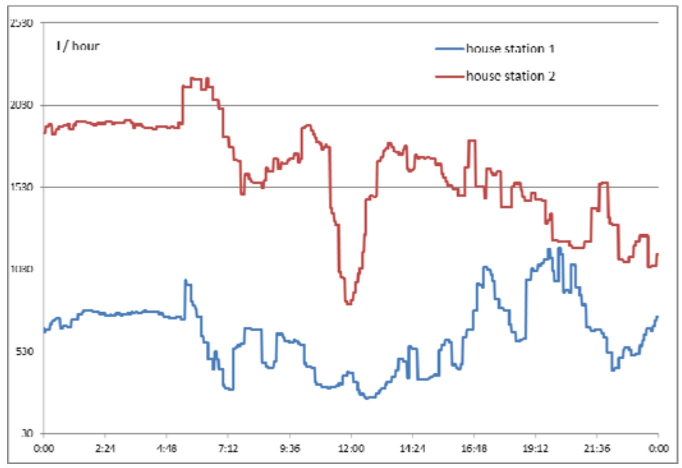

Fig. 5 Mass flow

A. Selected location

System behavior will be presented based on data measured in the secondary distribution network of Prerov town (CZ). Network contains one heat exchanger stance and fifteen house station. See fig. 6. Each house consumes heat energy for heating of dwelling and other space in house and for hot water preparation.

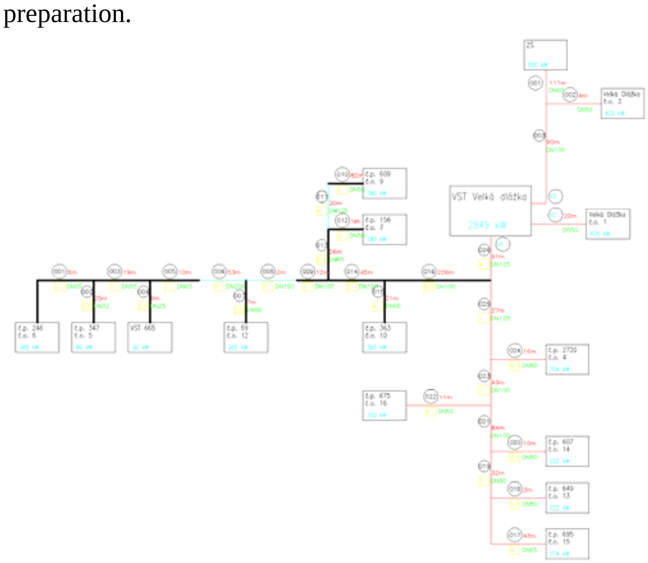

Fig. 6 Schematic consumers lay-out

The following figures show part of the city supplied by the selected heat exchanger and observed house. For an idea of the size, the photos of the house followed on the next figure.

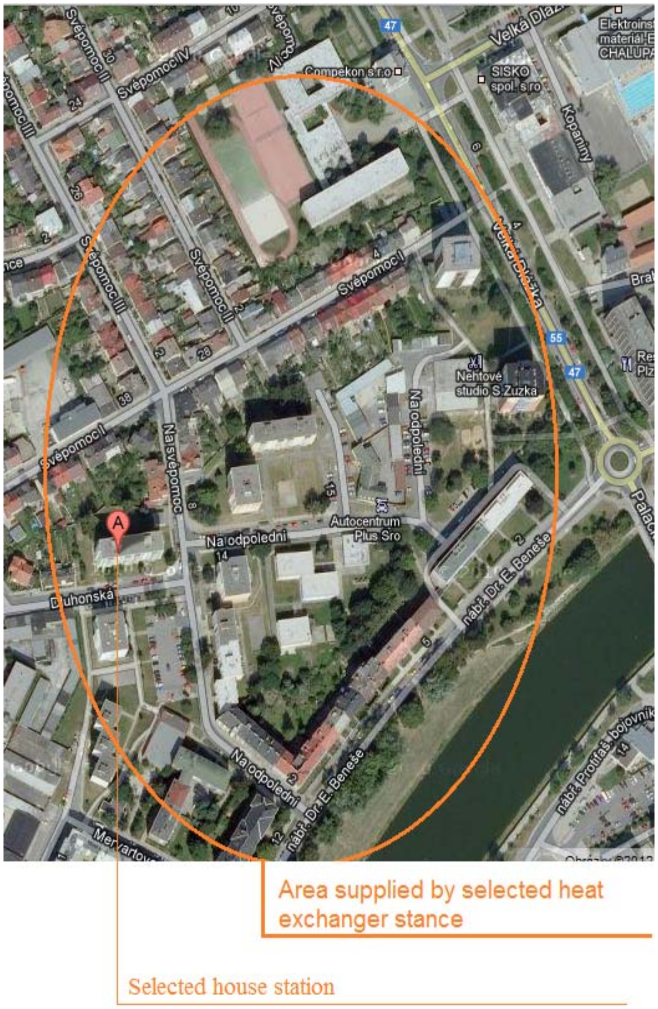

Fig. 7 Consumers area view

Fig. 8 Observed house.

Observed building showed on fig. 8 has insulated walls, roof and new windows.

Two following pictures show diagrams of house station and heat exchanger stance from the selected location. Tv on fig. 9 means heating water input - pipe from and to the heat exchanger stance. This input temperature equals to the output from the heat exchanger temperature minus loss in the pipelines. The pipes are split into two circuits.

First marked TUV is in charge of heating hot water for building. Because the hot water is expected in stabilized temperature (about 55 °C) and consumption course can contains many peaks and amount has large variability. Consumption, of course, corresponds to the behavior of the residents. Late morning on weekday or deep night means minimum consumption, but in the morning or evening values reach maximum. Mentioned fluctuations are compensated in the system by hot water tank. In the following experiment, however heat consumed for hot water production were not monitored.

Left side of the diagram, marked UT is in charge of heating, supply hot water for room radiators. Main parts of the UT circuit are regulation valve, mixing valve and circulation pump. Temperature in UT circuit is controlled by heating curve in its basic form, see chapter II.

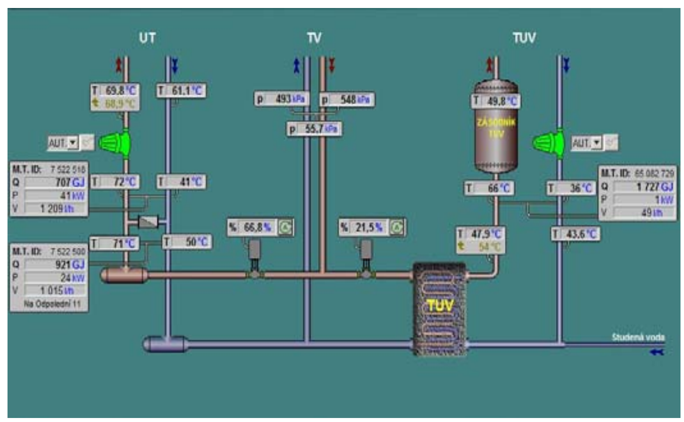

Fig. 9 House station diagram

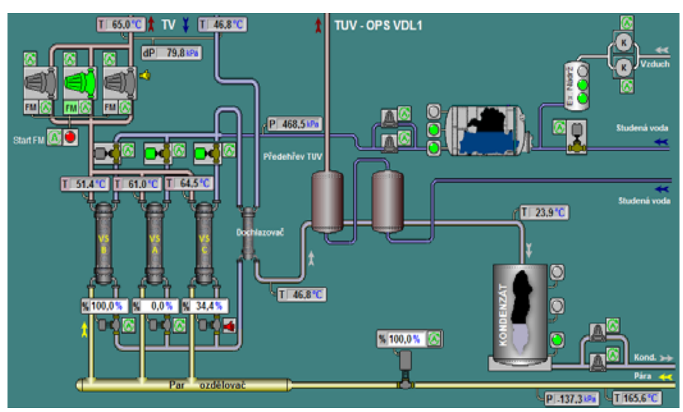

Fig. 10 Heat exchanger stance diagram

IV. The Experiment

A. *Flow smoothing*

The required heat can be supplied in two ways. Quality - the heating medium temperature and quantity - amount of the heat media transfer in pipes. In real systems it is necessary to find a good balance between these ways. The usual objective is to minimize costs while complying with the required quality.

One of the components affecting the cost is the price of pumping work. Price in case of pumping work is related to the use of optimal pump level. The pump should operate at the optimum load and it is also not appropriate that there are shocks when the desired performance is changed.

The effort to reduce the cost of pumping work is one of the current tasks. The first step of the experiment was to calculate and see the temperature requirements in a situation where the mass flow is constant. For this experiment was not considered time delay of the consumer. With this simplification could be applied equation (1). Set course of mass flow is shown in fig. 11. Fig. 12 shows the calculated temperature, while holding the amount of consumed heat. The mass flow was set to constant from 6AM to 8 PM. Values are shown for second house station (blue curves on fig. 2, 3 and 4),

$$Q = (T_v - T_{vv}) * m * c \qquad (1)$$

where:

T_v heating water temperature (input)
T_{vv} returning water (output)
m weight
c thermal capacity

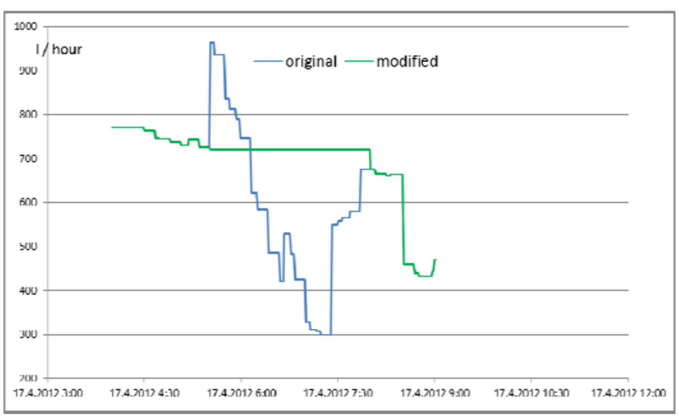

Fig. 11 Modified – smoothing flow

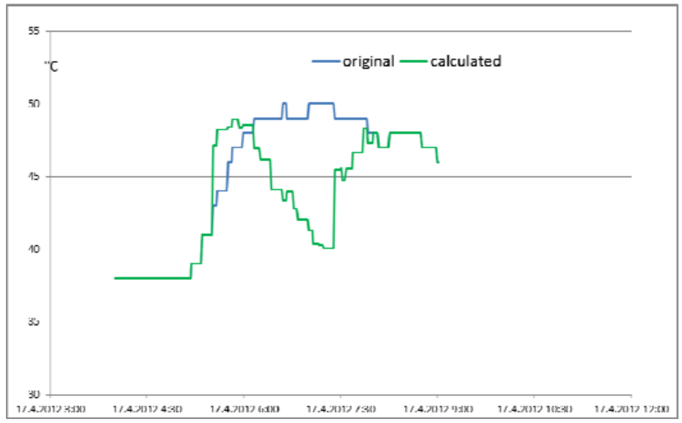

Fig. 12 Heating water temperature

B. *Real system experiment*

Previous example illustrates only basic ideas. The methods are preferable to verify in real operation, where they are exposed to many influences. The experiment was carried out on 19th and 20th of April and the differences in behavior will be shown in comparison with the data from 18th of April. These two days had a similar course of outdoor temperature. See fig. 13 and 18.

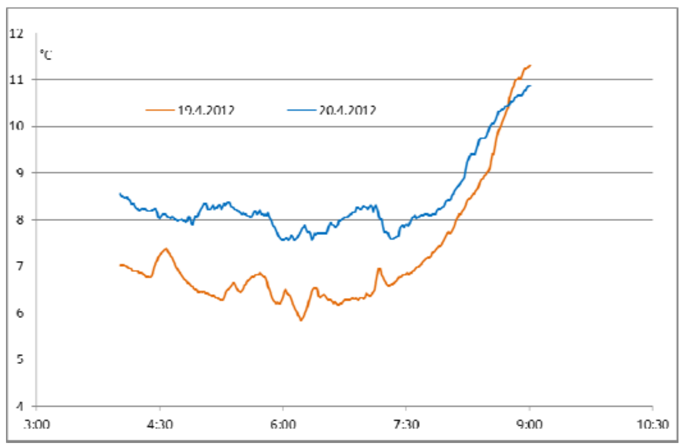

Fig. 13 Outside air temperature

The real technology at selected location only allowed manual intervention to variable T_V. For the initial experiment, the value of heating water in the morning rush hours has been increased by 2 °C above the values calculated from equithermal curve. The proposed modifications are shown in fig. 14 and 15. Later applied and obtained values are shown in fig. 16 and 17. Figure 16 shows comparison between calculated heating water temperatures by current system from heating curve and proposed level. Experiment consists of two modifications – evening and morning rush hour. Experiment started on evening afternoon 18th.

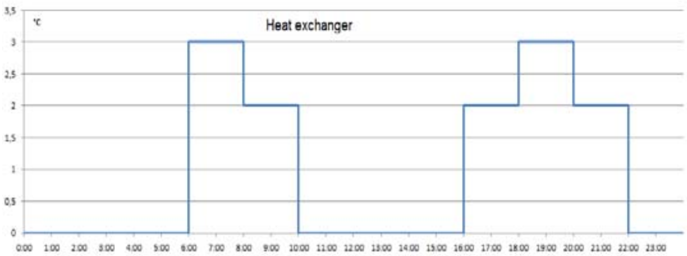

Fig. 14 Proposed changes in the temperature of heating water (heat exchanger stance)

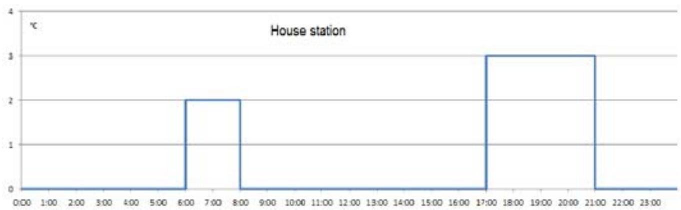

Fig. 15 Proposed changes in the temperature of heating water (house station)

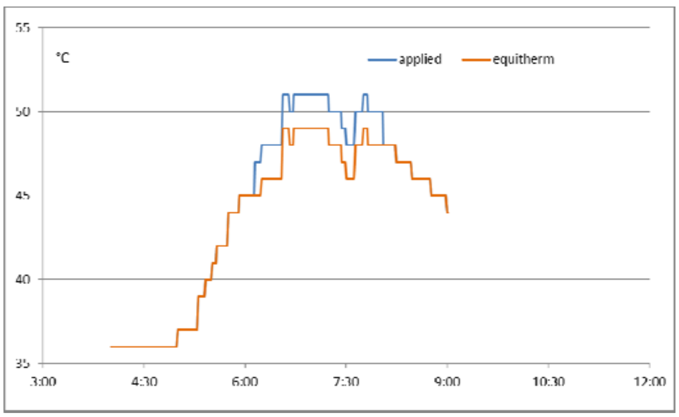

Fig. 16 Applied heating water temperature

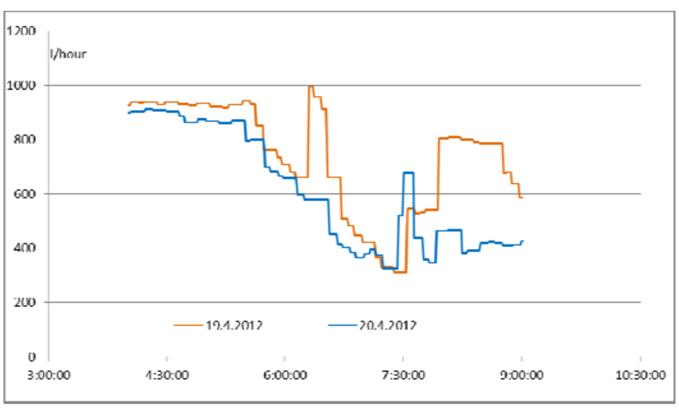

Fig. 17 Obtained mass flow

Figure 17 shows obtained heating system behavior in morning rush hour. To show difference in behavior, measured course is compared with course obtained previous day. It is really hard to judge results from one experiment, because there is no exact, a typical behavior. The 19th of December were selected for several reasons for comparison.

- Days are close to each other and can therefore be expected, to have similar behavior in the consumption.
- Both days are weekday. It is not suitable to mix weekend day weekday, because consumption has slightly different course in these cases.
- Days have similar outdoor temperature as mentioned earlier, see fig. 13.

Thus, as can be seen in figure 17, the increase on input water temperature influenced mass flow requirements. Mass flow decreased and jumps in values were also eliminated.
It seems that proposed modification had a positive effect, however let's have a look evening rush.

It seems that proposed modification had a positive effect, however let's also have a look at evening rush courses. Following pictures will show complete results. X-axis shows time from the start of the experiment, at 12 PM, April 18th, so first peak is evening rush, second peak is morning that has already been presented on fig. 16 and 17.

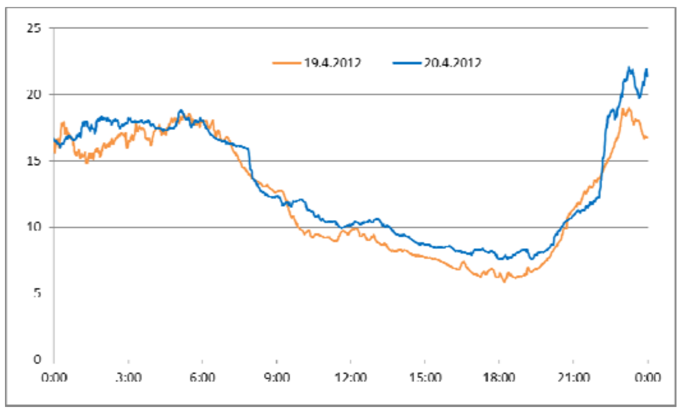

Fig. 18 Outside temperature course from 18th of April 12 PM.

Figure 18 shows measured outside temperature from two consecutive days. There is a great match between the temperatures on both days and could be therefore expected a very similar pattern of consumption of heat. Figure 19 shows heating water temperature applied on both days. Even the outside temperature in location were almost the same, the temperature of heating water has number of differences. Of course, the blue course was influenced by application of proposed modification, see fig. 15, but there is still more differences. The temperature in the two days is driven by the same heating curve, but the controller for the station house has it's own temperature sensor and the measured values don't have to coincide with the temperature from main sensor, fig. 18.

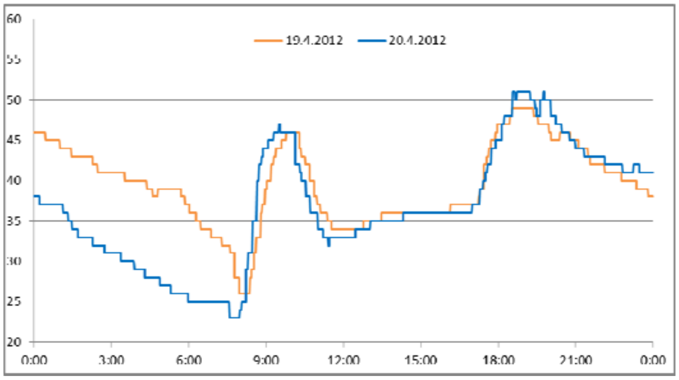

Fig. 19 Heating water temperature

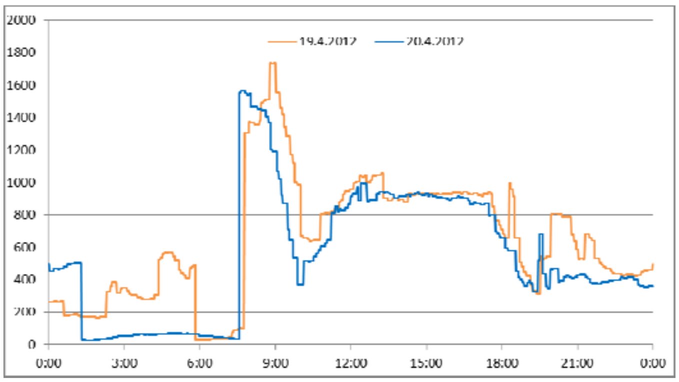

Fig. 20 Mass flow

Decline in the first period - in the afternoon, see fig 20, is caused by turning off the heating circuit. The experiment took place in the second half of April and the outdoor temperature during the afternoon were already so high that the system will automatically cut off. It follows that the planned modifications could be applied only for a few hours. The result of the afternoon part of the experiment can not be competently assessed.

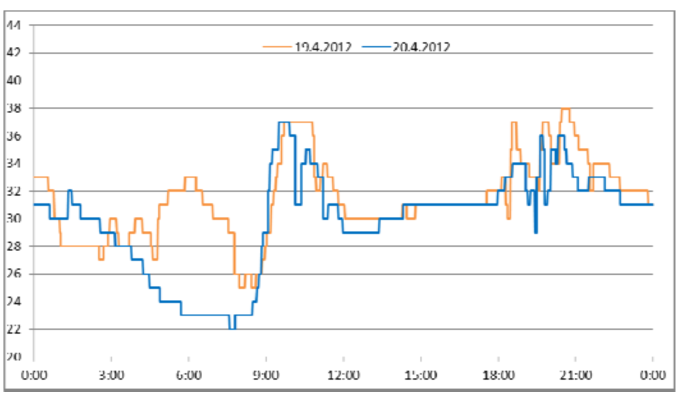

Fig. 21 Water temperature on return

To see all relevat variables, the fig. 21 show water temperature on return. The figure shows that the modification of the flow temperature, not substantially affected the temperature in the return line.

The following three images show the behavior of variables on heat exchanger. On fig. 22 is clearly visible applications designed modifications. Figure. 23 shows the flow behavior. There is an apparent decline that was expected and desired. The last figure shows the water temperature in return line. The similarity to the previous day is very good and it can be stated, that modification of the water temperature has a positive effect on the flow and does not bring undesirable behavior of water in the return line.

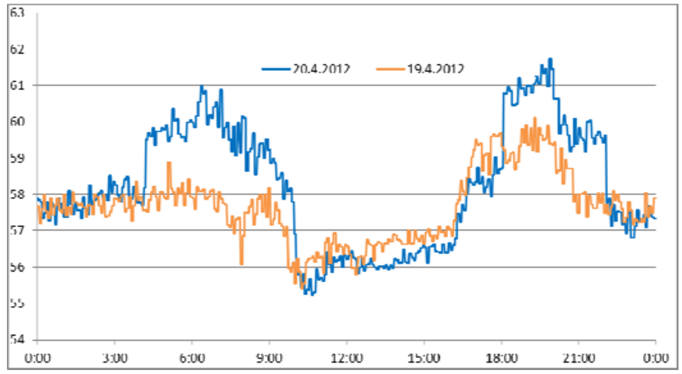

Fig. 22 Heating water temperature on exchanger stance

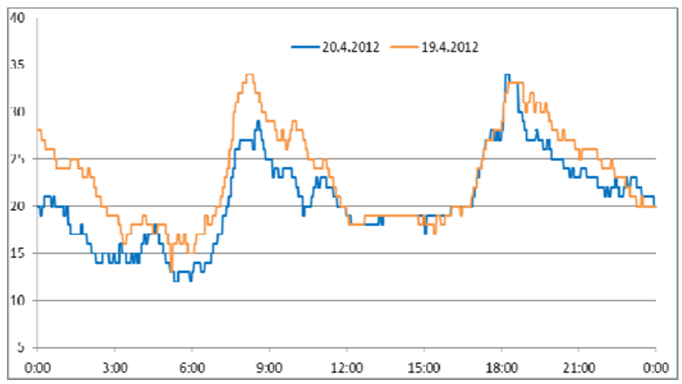

Fig. 23 Mass flow on exchanger stance

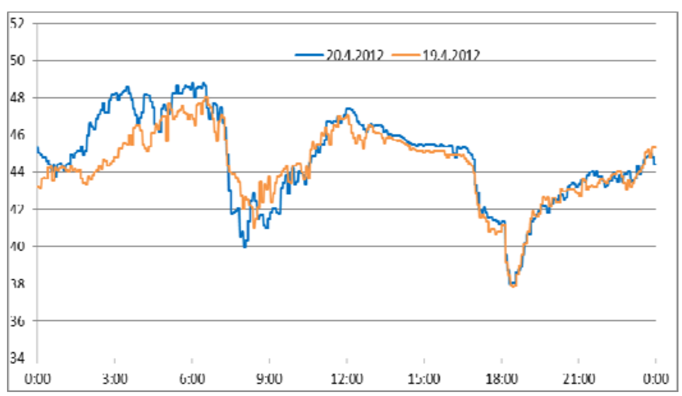

Fig. 24 Water temperature on return on exchanger stance

V. Conclusion

This article presents the idea of weather compensation control corrections. If the heating control procedure depends only on simple curve, system is usually unevenly loaded. The critical points are usually morning and evening rush hour. In these points, it appears appropriate to modify the weather compensation curve. Because the real system did not allow more complex interventions, a simple correction was applied for the morning rush hour from 6 am to 8 pm. Temperature increase was set to 2 °C plus level obtained from the commonly used heating curve. The system behavior was then monitored. The result was then compared with the measured course from the previous day, when common control was used.

From the results it appears that the increase in temperature has a positive effect on the flow behavior. Temperature increase caused only a slight decrease in flow, but the peaks that arise during the morning rush hour were partly eliminated. The experiment showed that it makes sense to modify the heating curve, but it is certainly necessary to introduce more sophisticated methods for designing corrections. And this should be the future task – to continue on simulation experiments to prepare more sophisticated algorithms for modification of the heating water temperature with a view to achieve predictable and smooth mass flow. Goal for the next heating season is also preparing algorithms that implement the experiences from simulation so that they can be verified and applied on a real heating system.

Acknowledgment

The work was performed with financial support of research project NPVII-2C06007, by the Ministry of Education of the Czech Republic and is also supported by the European Regional Development Fund under the Project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

References

[1] Balate, J. “Automatic Control”, 2nd edition, BEN - technical literature, ISBN 80-7300-148-9, Prague, 2004.

[2] Balate J., Chramcov B., Navratil P. ”Strategy evolution of control of extensive district heating systems”, Powereng 2007: International Conference on power engineering – energy and electrical drives proceedings, vols 1 & 2 Pages: 678-683 Published: 2007.

[3] Incropera, F. P.; DeWitt, D. P. & Bergman, T. L. “Introduction to Heat Transfer”, Wiley, ISBN: 978-0471457275, London, 2006.

[4] Chramcov B.” Identification of time series model of heat demand using Mathematica environment”. In Recent Researches in Automatic Control: Proceedings of 13th WSEAS Int. Conference on Automatic Control, Modelling& Simulation. Lanzarote: WSEAS Press, 2011. pp. 346-351. ISBN 978-1-61804-004-6.

[5] Saarinen, Linn. “Modelling and control of a district heating system”. Uppsala, 2008. 67 s. Uppsala University. ISSN 1650-8300.

[6] Vasek L., Dolinay V. “Simulation Model of Heat Distribution and Consumption in Practical Use”. Proceedings of the 13th WSEAS International Conference on Automatic Control, Modeling and Simulation, Lanzarote, WSEAS Press 2011, pp. 321-324, ISBN 978-1-61804-004-6.

[7] Vasek L., Dolinay V. “Simulation Model of Heat Distribution and Consumption in Municipal Heating Network”. International journal of mathematical models in applied sciences, <http://www.naun.org/journals/m3as/>. ISSN 1998-0140, 2010.

[8] Vasek L., Dolinay V., Kral E. “Methods for Prediction of Heat Distribution Parameters”. Mathematical Methods and Techniques in Engineering and Environmental Science, Catania, Sicily, Italy, WSEAS Press 2011, pp. 335-340, ISBN 978-1-61804-046-6.

[9] Varacha P., Jasek R. ANN Synthesis for an Agglomeration Heating Power Consumption Approximation. In Recent Researches in Automatic Control. Montreux : WSEAS Press, 2011, s. 239-244. ISBN 978-1-61804-004-6.

[10] Control and measurement [Online]. Available: http://hestia.energetika.cz/encyklopedie/9.htm#9_2_3

[11] Matz V. (2010). Weather-compensated control - principles and applications in heating control systems [Online]. Available: http://vytapeni.tzb-info.cz/mereni-a-regulace/6294-ekvitermni-regulace-princip-a-vyuziti-v-systemech-regulace-vytapeni