Method of heating curve modification for rush hours in practical experiment

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***Abstract*—** This article deals with method of modifying the heating curve with regard to the consideration of heat consumption in rush hour and shows possible benefits of improvements in such heating system control. For the large heat distributors in Czech Republic is common to use simple weather compensation heating curve to set temperature of heating water in their systems. In such system the heating water temperature value is directly proportional to outside temperature. Usually two curves are used, one for daytime and second for night. This many years used and proven method is easy to implement and use, however the transitions between these two curves are the possible weakness and gave rise to this research. Heating control carried out with night setback (common scheme), switch to day mode causes shocks in heat consumption. These are the rush hours in heating systems. To compensate resulting shocks by appropriate settings of input parameters is the task for smart control. With respect to analysis of the measured data, the simple modification in the existing system control were prepared and verified by simulation and practical tests. Obtained results show improved behavior, which is evident from the reduction of shock and peaks in the system.

***Keywords*—** Equithermal curve, heating curve, heat consumption, rush hour, simulation.

I. Introduction

CENTRAL heating systems are usually controlled by the heating curve. This is natural way of control, if we use the fact, that heat requirement to supply buildings is primarily dependent on the outside temperature. Heating curve is typically exponential, with natural limitations based on the possible outdoor temperatures and with high limit to temperature which is the requirement for the heating suspension or end of the heating season. Such a condition is usually the value of the average daily outdoor temperature. In the Czech Republic it is determined that the central heating should be discontinued at achieving of the 13 or above degrees of Celsius for a period of at least three days.

The general aim of any heating control is to determine the temperature of heating water to provide enough heat for the consumer but also to eliminate unnecessary losses in the pipeline and at the same time use the minimum energy to transport the heat medium from source to consumer [1, 2, 3].

These natural requirements are however supplemented by a number of other, depending on the used technology. Modern power sources are not just producers of usable heat, but are capable of cogeneration or even trigeneration. That means that source could simultaneously generate electricity and useful heat. High quality cogeneration system shall be able to change the ratio of its production output by demand.

The ability to change the ratio of production should be achieved quickly, but of course without decreasing the quality of the suppressed output.

Having regards to the mentioned requirements, it is essential that such systems must be well controlled and operates in deterministic and steady action. One of the important objectives of heat management which must not be forgotten is the overall supply balance. Provided amount of heat must be properly distributed between mass flow volume and temperature. This qualitatively quantitative strategy is also fully respected in here presented methods.

Nevertheless, let's return to the basic ideas of heat supply. Higher temperature increases the loss of heat during the transfer medium, vice versa low temperature does not transfer as much energy and it is therefore necessary to increase the quantity of transferred heating water. 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 basic parameters – temperature of heating water and its quantity, i.e. mass flow.

The above description is of course a considerable simplification, because the values of both parameters are also dependent on time and especially at 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 time 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. The control, which used this type of heat curve, is usually called an equithermal, or weather-compensated control.

Here described heating curve modification depends 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 behavior of consumers, e.g. house residents. Also outside weather adds stochastic behavior as well.

In the first part of the article, the data from real heating system, which is supplying part of the selected town will be shown and described. On these data will be presented weaknesses of the used control system and derived a theoretical basis for the subsequent modification and simulation experiments. Ideas verified by simulations were later applied in real heat distribution 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.

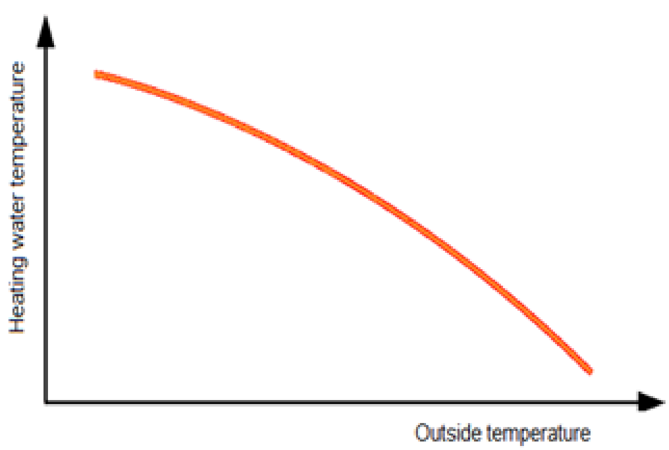

Fig. 1 Heating curve

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. Data Analysis

The proposed method is based on the measured data from real heat distribution system. Data come from the exchange station. This station supplies fifteen consumer objects. The objects are mostly residential houses. Schematic is shown on figure 2.

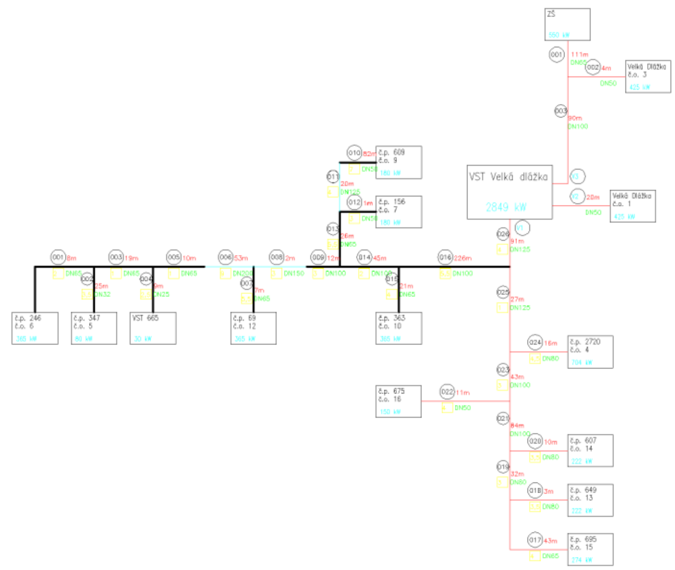

Fig. 2 Schematic consumers lay-out

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. 3 Observed house.

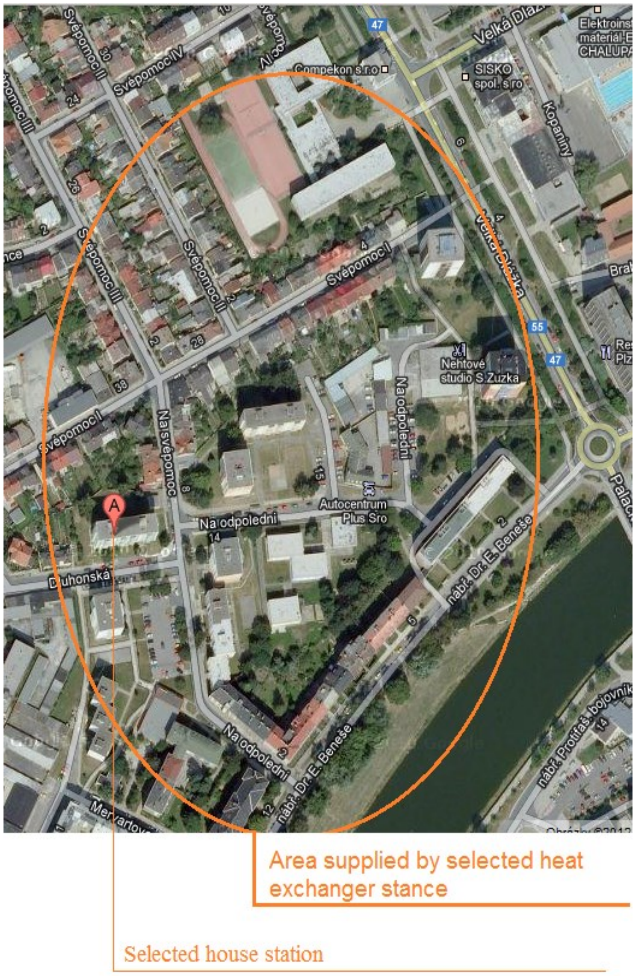

Fig. 4 Consumers area view

Observed building showed on fig. 3 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. 8 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.

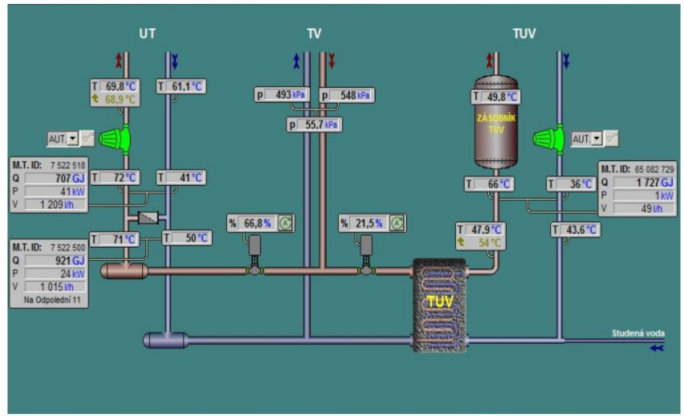

Fig. 5 House station diagram

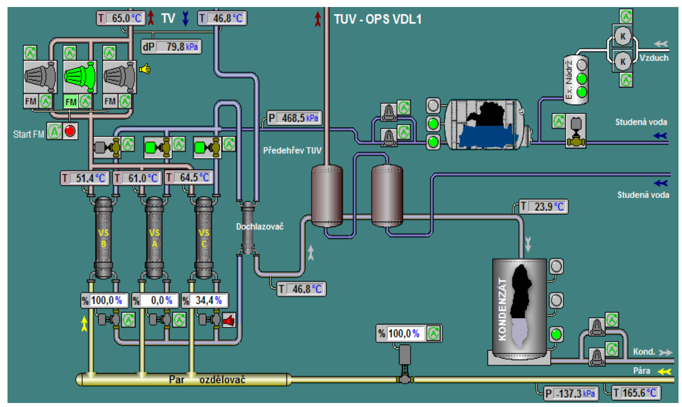

Fig. 6 Heat exchanger stance diagram

The following pictures shows sample behavior of one day. Heating water temperature control uses two heating curves, which can be also recognized from figure 7 and 8. These figures show outside temperature and temperature of heating water, which is currently based on the outdoor temperature. The first heating curve is valid from 9 PM to 4 AM, the second curve is then valid in the rest of a day. As can be seen from previously mentioned figures, transitions between curves are smooth.

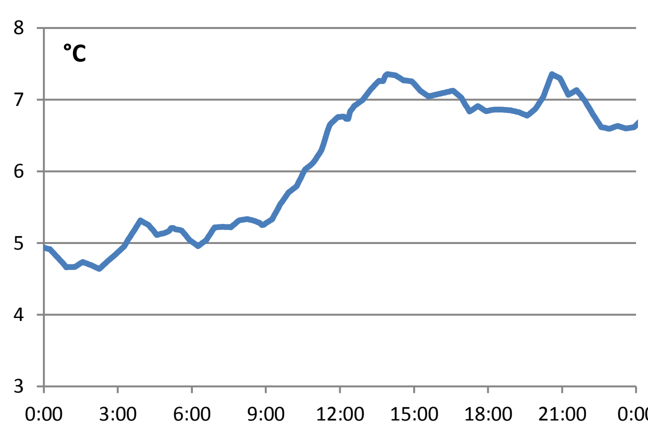

Fig. 7 Outside temperature

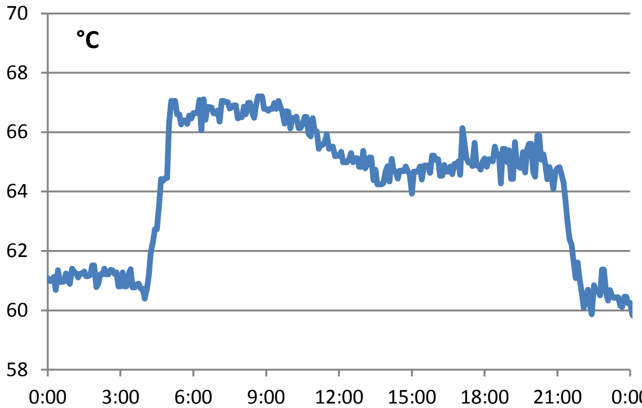

Fig. 8 Heating water temperature (Tv)

To have complete view of system behavior, figures 9 shows mass flow and figure 10 water temperature in returning pipe.

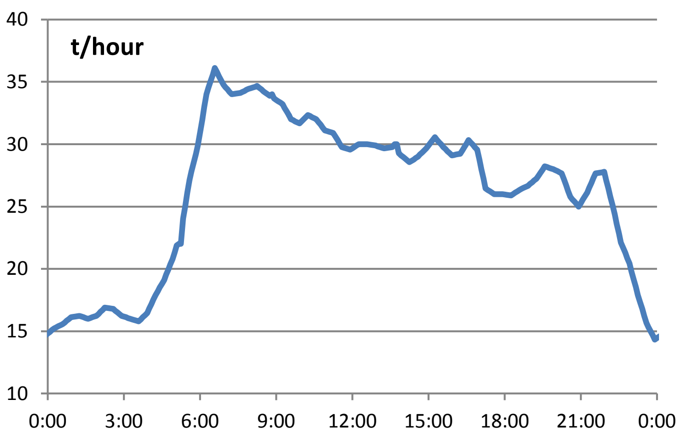

Fig. 9 Mass flow

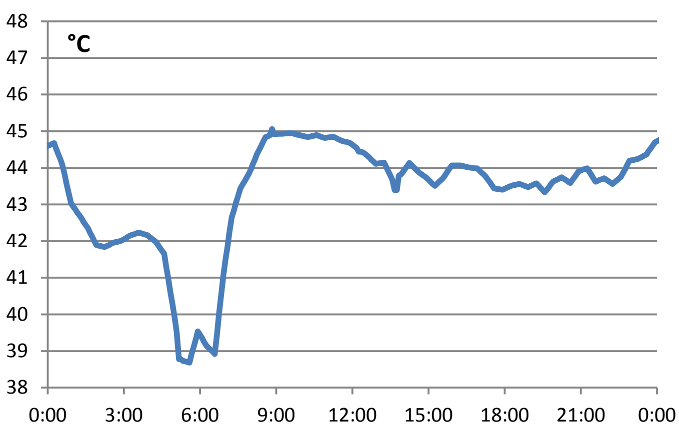

Fig. 10 Water temperature in returning pipe (Tvv)

The mass flow and Tvv courses shown on figure 9 and 10 are typical for mentioned heating control. These figures clearly show time segments with improper behaviour. Generally can be said that mass flow should be balanced, and thus pumps should operate at a constant and optimal speed, without unnecessary impacts. Aside from the different levels during the night, which is due to the natural behaviour of the system that works in saving mode, but look for changes induced in the morning.

The amount of heat obtained from the heat transfer medium is given by the following equation.

$$Q = m * c * \Delta T \qquad (1)$$

where:

m is mass flow,

c specific heat and

ΔT change in temperature (for our example $\Delta T = Tv - Tvv$)

It is obvious that to keep required amount of the heat energy Q and still affect the mass flow - the only solution is to change the temperature difference. Value *Tvv* is hard to modify in real systems, because it is determined by the technology and any modifications would have to be applied to the consumer. However, heating water temperature *Tv* is just the value which is already controlled and provides greater flexibility for changes.

IV. Proposed Modification

As introduced earlier, the aim of this work was to improve existing system of control and thereby achieve a steadier course of mass flow.

Presented measured courses showed time intervals that should be addressed. To examine system behaviors with modified inputs, several heating curve modifications were prepared. Simple corrections (in time-limited intervals) were made also because of the possibility of subsequent validation in real time control, where operator can only enter curve modification manually.

The figure 11 shows proposed correction. They are derived from the period of the greatest growth in mass flow, see fig. 9. These corrections therefore cover morning rush hours.

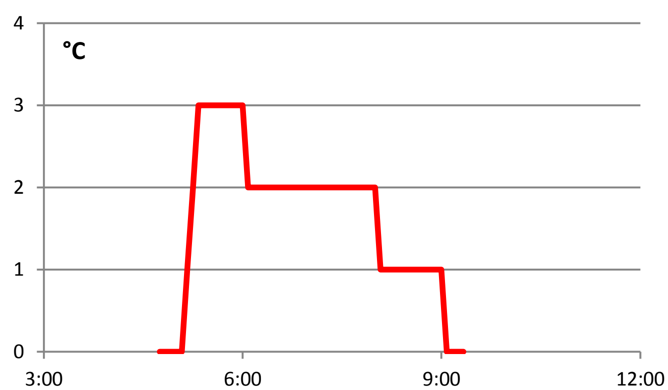

Fig. 11 Proposed temperature corrections

The corrections will be applied by addition of the defined values to the temperature value calculated from the heating curve. See example on figure 12.

V. Simulation Model

This model was prepared in the previous stage of development [5, 6, 7] and even it is still in progress, it is capable to identify heat consumption in particular heating system based on measured data [3].

The distribution network is presented as a set of sources of heat energy and set of heat consumers connected through piping. Model works in discrete intervals constant length signed as Δt. The basic, moving element is considered "discrete flow quantum" DFQ of fluid, usually water. The DFQ flows in the network and gradually loses its energy, depending on the current position. The volume of the quanta is determined by the quantity of water entering into the distribution network for the time interval Δt in given step of simulation. Amount of heat energy in DFQ is based on its quantity and its temperature [3].

This model has two modeling levels:

- *Flow modeling*

To monitor the flow quantum passing through the distribution network

- *Heat transfer modeling level*

Each flow quantum in the distribution network has recalculated heat balance in each simulation step. The heat balance is based on law of the preservation of the heat energy.

VI. Simulation Experiment

To demonstrate the ideas described in chapter 3, the experiment on the simulation model was prepared. The experiment required to modify the temperature calculated from heating curve by the proposed values, see fig. 12. These modifications were applied on historical sample data; see fig. 13 and by simulation model introduced in chapter 4, the calculation of system behavior performed.

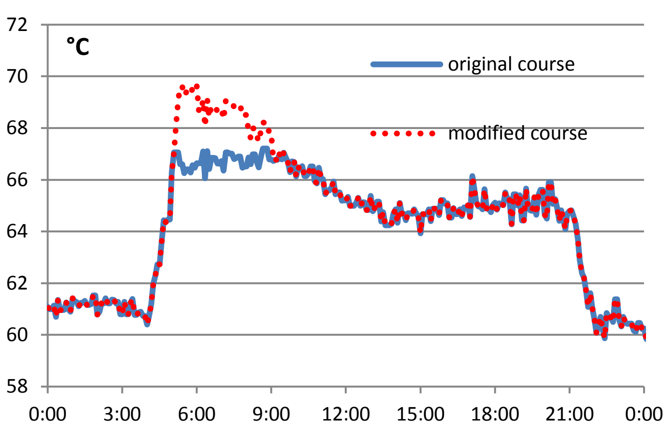

Fig. 12 Measured and modified temperature

Following figures show results obtained from the model.

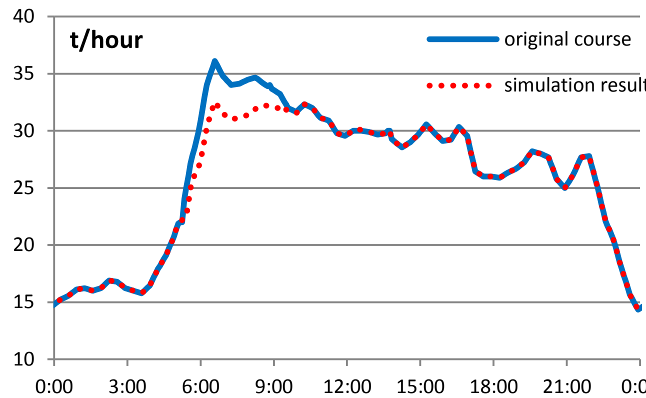

Fig. 13 Mass flow

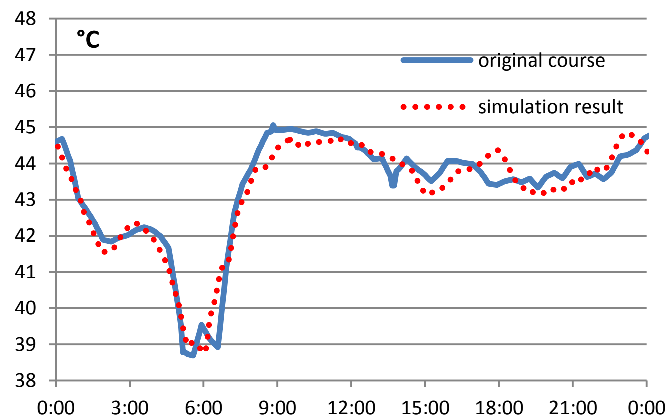

Fig. 14 Water temperature in returning pipe

VII. 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 morning. These two days had a similar course of outdoor temperature. See fig. 15.

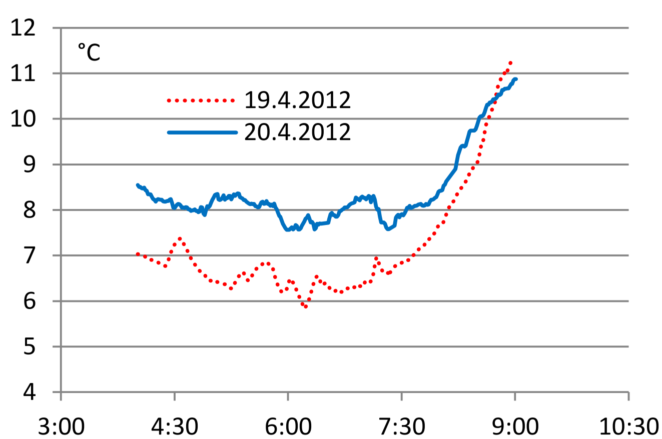

Fig. 15 Outside air temperature

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. 16 and 17. Later applied and obtained values are shown in fig. 18 and 19. Figure 18 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 18[th].

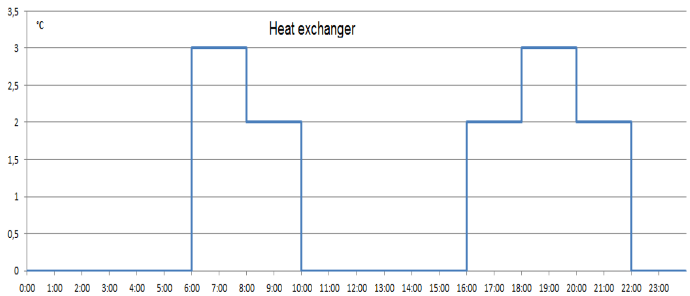

Fig. 16 Proposed changes in the temperature of heating water (heat exchanger stance)

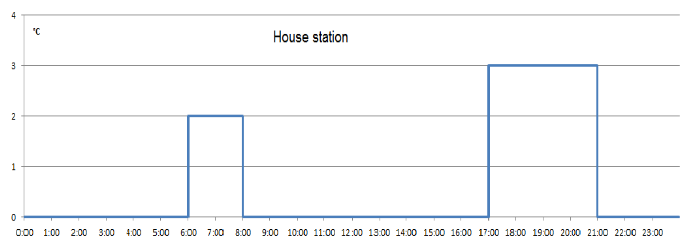

Fig. 17 Proposed changes in the temperature of heating water (house station)

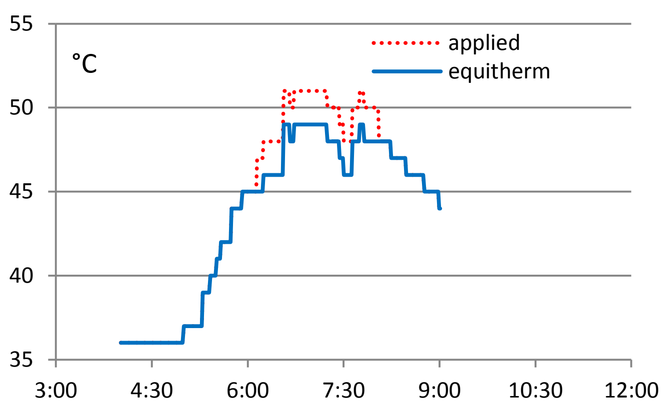

Fig. 18 Applied heating water temperature (house station)

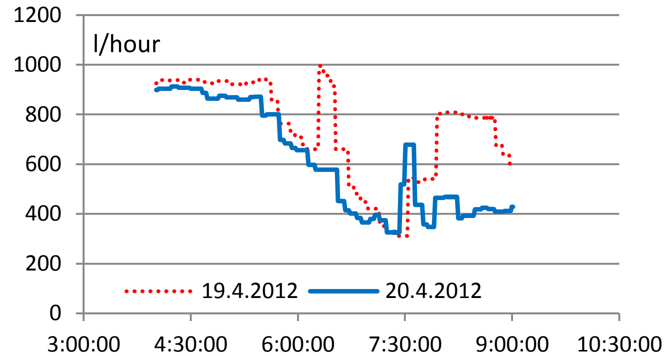

Fig. 19 Obtained mass flow (house station)

Figure 19 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 19[th] 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. 15.

Thus, as can be seen in figure 19, 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 group of pictures will show complete results. X-axis shows time from the start of the experiment, at 12 PM, April 18[th], so first peak is evening rush, second peak is morning that has already been presented on fig. 18 and 19. As mentioned above the timelines of following pictures show relative time from start of the experiment. For example, midnight from 18[th] to 19[th] of April has timestamp 12:00.

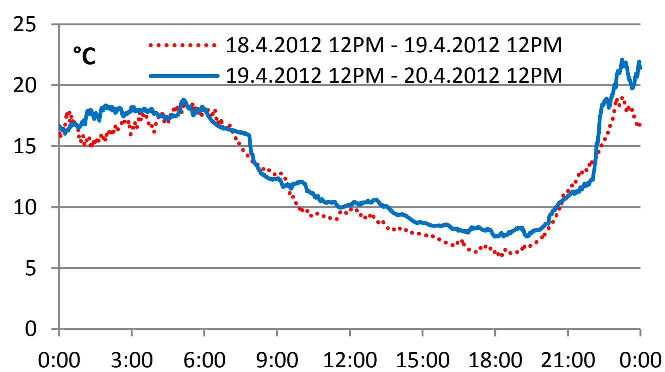

Fig. 20 Outside temperature course

Figure 20 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 21 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. 17, 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. 20.

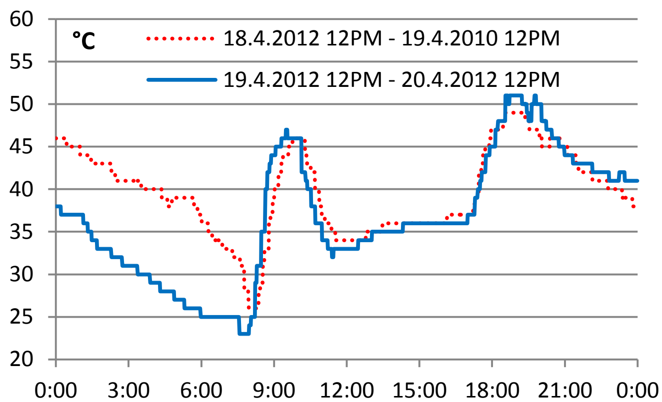

Fig. 21 Heating water temperature (house station)

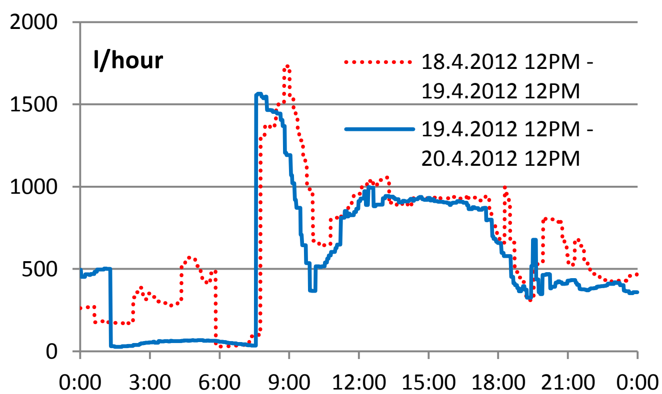

Fig. 22 Mass flow (house station)

Decline in the first period - in the afternoon, see fig 22, 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.

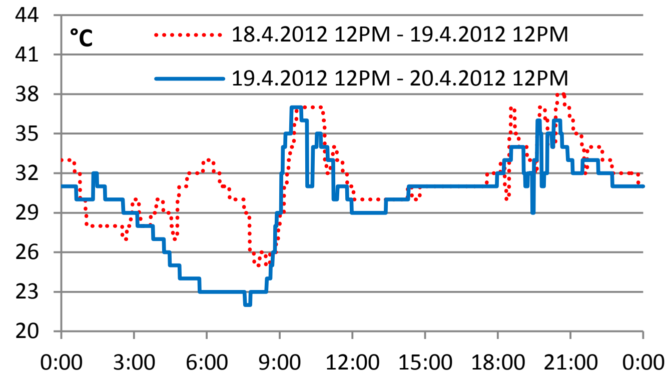

Fig. 23 Water temperature on return (house station)

To see all relevat variables, the fig. 23 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. 24 is clearly visible applications designed modifications. Figure. 25 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.

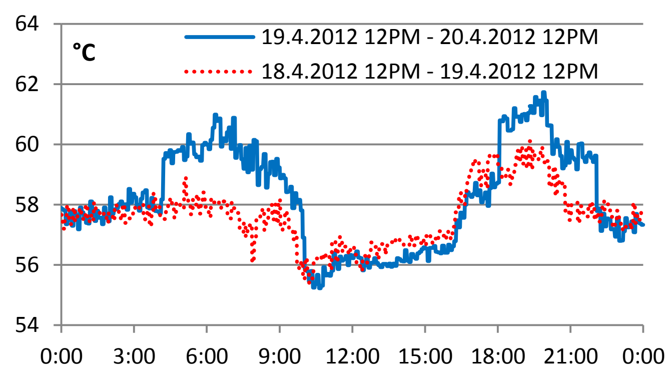

Fig. 24 Heating water temperature (exchanger stance)

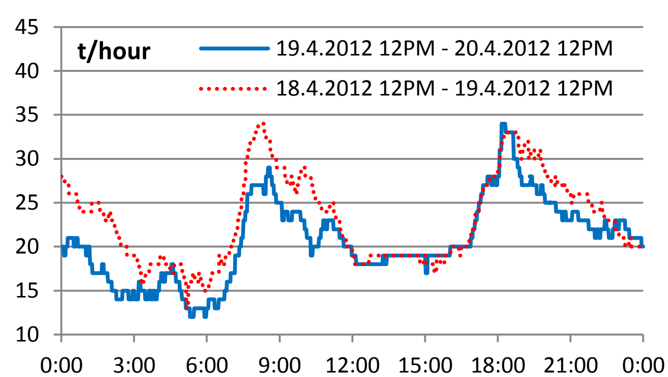

Fig. 25 Mass flow (exchanger stance)

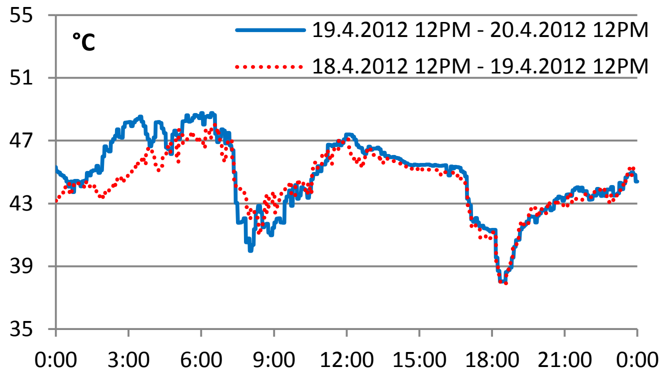

Fig. 26 Water temperature on return (exchanger stance)

VIII. Conclusion

This article presents the idea of weather compensation control modifications for heating curve in particular day periods. According to disadvantages of classic control used in many heat producers and distributors companies, sequences of simple corrections were prepared.

Verification of the accuracy of these modifications was performed through a simulation model described in earlier articles. Obtained results showed that the applied modification on heating water temperature had a positive effect on the more steady of mass flow. Effecting of the water temperature in the return pipes was minimal. A positive finding from the simulation provides conditions for the success in the real operation.

Selected real system did not allowed 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 monitored and results were compared with the measured course from the previous day, when common control was used. It was not so straightforward result as in the simulation, but the improvement is observable. 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

Presented solutions that contribute to improving the quality of the control mechanism, which should be beneficial especially in cogeneration systems. There it is important that the heating production works in steadier mode, because it increases the calculability of power useful for ancillary services in electricity production.

Acknowledgment

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