Simulation model of heat distribution and consumption in municipal heating network

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Abstract—This paper describes the designed and implemented computer model of the distribution system of heat consumption in the urban agglomeration (SHDC - System of Heat Distribution and Consumption). This model is designed as a simulation model. The simulation is one of the (few) methods, which can be effectively used for the analysis of large and complex dynamic systems properties, which the distribution system and heat consumption in the municipal heating networks is without doubt. The model was implemented in the form of computer applications and tested on real operational data.

Keywords—Consumption, discrete simulation, heat distribution, hot water, modelling, pipe.

I. INTRODUCTION

PROBLEM of distribution and consumption of heat energy in the urban agglomeration are very actual, especially in the context of finite worldwide energy resources and the constant increase in energy prices. There is also important ecological aspect, because obtaining and using of energy generally has mostly negative environment impact. Therefore, it is necessary to seek all paths leading to energy, including heat energy, savings.

One of the factors that can lead to savings of energy is the effective management of distribution of the heat energy. Heat energy must be transported to the place of consumption in time when it is required and in the expected quantity and quality. Quality of supplied heat energy is expressed in the temperature of heat transferring media. The correct delivery time, quantity and quality of heat energy must go hand in hand with minimal distribution costs [2]. It is obvious that the heat distribution is inextricably linked to its consumption and therefore we can talk about the management of the heat distribution and consumption.

Appropriate way of managing heat supply has also a substitution effect - the fact that for efficient use of resources, we can save part of the resources.

System of production, distribution and consumption of heat is very large and complex. Analysis of the features that need to be known for its efficient management is very difficult and there is not much practice, how such an analysis should be carried out with sufficient accuracy. Applicable procedures are almost exclusively based on modeling.

This paper describes the designed and implemented computer model of the distribution system of heat consumption in the urban agglomeration (SHDC - System of Heat Distribution and Consumption). This model is designed as a simulation model with a number of freely usable parameters.

II. SIMULATION MODEL

The simulation is one of the few methods, which can be effectively used for the analysis of large and complex systems. For the simulation is characterized to create a model of the system, usually an abstract model and today almost exclusively a computer model. With this model are performed experiments and their results are then applied to the original system.

The use of a simulation model in this case is fundamentally twofold:

1. It is possible *to analyze the properties and behavior of SHDC* as a wide dynamic system – offline model using.

2. Simulation model *can be integrated into the control system SHDC* as an instrument to prediction of the behavior of SHDC at a certain (limited) time in the future – online model using.

Proposed model is, in contrast to the commonly used continuous models, discretized in time - time is running in simulation discontinuous steps, with a sampling period. The size of the time period depends on the speed of change of monitored values. Therefore, if this model will be used for analysis by going to the SHDC run in normal mode and not going with great speed changes, such as surges in the piping, etc., it is possible to work with the time period of several minutes. For this kind of analysis is this concept of the simulation model justified.

This relatively long sampling period is also important for the second of described ways of using the simulation model, because in the time period of several minutes we can perform numerous calculations, which are usually needed for predicting the behavior of SHDC in the near future.

Detailed description of the simulation model usage for both mentioned purposes follows in chapter IV.

III. MODEL DESCRIPTION

The distribution network can be presented as a set of sources of heat energy (supply heating stations) and heat consumers, which are cross connected trough piping. The pipes are divided for model in sections, which are linked in nodes. Section starts and ends in the node and can be divided in several pipe lines. Pipe line is a part of piping, which has constant characteristic from the point of view flow and heat transfer. One simple example of simple part of distribution network is presented in the Fig. 1,
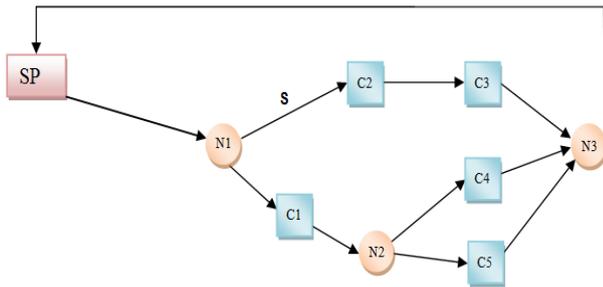
Fig.1 Example of schematic distribution network parts.

where:
- *C* consumer,
- *N* node,
- *S* section,
- *SP* supply (source).

Simulation time is running in discrete time intervals constant length signed as Δt. Time interval Δt is identical to the sampling time interval and Δt_j determine the simulation step *j*. As basic "moving" element ("transaction" in simulation terminology) consider "discrete flow quantum" DFQ of fluid (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.

I. Flow modeling

Compressibility of water in the pipe is insignificant and does not need to be included in the model.

In each simulation step the flow quantum, denoted $^jDFQ_i$ in the network is monitored. Shown in the following picture,
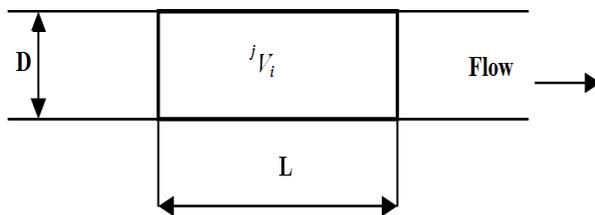

Fig.2 Discreet flow quantum

where:
- index *i* describe particular quantum,
- index *j* describe time period for $^jDFQ_i$ analysis, i.e. the simulation step,
- *D* is pipe diameter in current $^jDFQ_i$ location,
- *L* is current $^jDFQ_i$ length,
- ^jV_i is volume of $^jDFQ_i$

We can apply simple terms:

$$^jV_i = \pi * D^2 / 4 * L \tag{1}$$

and

$$^jV_0 = M_j * \Delta t_j \tag{2}$$

where:
- $^jV_0$ is volume of DFQ on input to distribution network
- M_j mass flow in simulation step j.

To monitor the flow quantum passing through the distribution network, it is of course necessary to respect the fundamental physical laws applicable to the fluid flow and heat energy transfer - conservation of mass and energy and the law of continuity.

In accordance with the law of continuity we have to follow several rules for flow quantum:

1. While passing through the section, the DFQ don't alter its volume, its length *L* in a pipe varies depending on the diameter *D* of the current pipe line.

2. Each section is divided into pipe lines, as noted above. While DFQ_i is passing two consecutive pipe lines *p* and *q* of the section, DFQ_i is split into the two new DFQ - DFQ_{ip} and DFQ_{iq}. DFQ_{ip} is the part of DFQ_i, which remains in the pipe line *p* - does not reach the border between pipe lines *p* and *q*, DFQ_{iq} is contrary of DFQ_{ip} - part of DFQ_i which passed transition of *p* and *q* in current simulation step and switched into *q* pipe line.

3. The above mentioned DFQ_i's splitting rules are valid also for each DFQ_i, which is entering node *k*. Each DFQ_i is split into two parts − DFQ_{ip} and DFQ_{iq}. DFQ_{iq} is the part of DFQ_i, which reached the node in particular simulation step and DFQ_{ip} is the part which does not reach it.

For each output section *j,* which is outgoing for node *k*, DFQ_j is created. From the law of continuity we can use equation:

$$\sum \text{Vol}(DFQ_{iq}) = \sum \text{Vol}(DFQ_j) \tag{3}$$

where:
- *Vol(DFQ)* describe function, which presents particular part of flow quantum,
- $\sum$ on the left is processed for all section, which allows flow to come into the node.
- $\sum$ on the right is processed for all sections, which allows flow to come out from the node.

II. Heat transfer modeling

For each flow quantum, which is at a given time in the distribution network, its heat balance is calculated in each simulation step. The heat balance is based on law of the preservation of the heat energy. The heat energy change in DFQ_i - decrease of heat - during the time interval Δt,

e.g. in single simulation step, is described by the equation:

$$\Delta^j Q_i = {}^{j+1}Q_i - {}^j Q_i \qquad (4)$$

where:

- ${}^j Q_i$ and ${}^{j+1}Q_i$ describe the amount of heat energy contained in the DFQ_i at the beginning of the simulation step j and simulation step $j+1$.

The next equation is still valid:

$$^j Q_i = V_i * \rho * c_v * {}^j T_i \qquad (5)$$

where:
- c_v is the heat capacity constant for the fluid (water),
- ρ is water density,
- V_i is volume of DFQ_i and $^J T_i$ its temperature.

Presented decrease of the heat $\Delta^j Q_i$ in DFQ_i during the time interval Δt arises from the fact that this heat is transferred to the surroundings, either in the form of losses (supply line) or in the form of consumption (consumers).

Note.: At this point the issue of efficient use of heat delivered to the consumer is not discussed - that is another broad topic to solve.

Pipeline losses can be determined by the relationship

$$^j Q_{i\,loss} = k_p * ({}^j T_i - {}^j T_{p\,ext}) * \Delta t \qquad (6)$$

where:
- k_p is the heat transfer coefficient in the current pipe line p,
- $^j T_i$ is water temperature for the DFQ_i
- $^j T_{p\,ext}$ is the outside temperature for the pipe line p, both in simulation step j.

Coefficient k_p is based on pipe structure - pipe material, style and material of insulation, pipe seating, etc.

For the heat consumption at consumer r at time interval Δt_j the following equation can be used:

$$^j Q_{i\,cons} = s_r({}^j T_i,\, {}^j T_{r\,ext},\, \ldots) * \Delta t \qquad (7)$$

where:
- $s_r(\ldots)$ is the function describing heat consumption for the consumer r.

Determination of this function is obviously very difficult, but for the final solution of this task, especially in terms of its accuracy for those particular parts "consumers", it is very important. There may be applied many different important factors such as:

-type of the day - workday , weekend, holiday etc.,
-part of the day - morning, afternoon, evening, night,
-type of the consumers in the particular part of the network - flats, schools, industrial companies etc.,
-other weather conditions - sun intensity, wind, air humidity.

To determine the functional dependences of heat consumption on these factors it is also possible to successfully use the proposed simulation model. This usage of the model will be included in the identification of model parameters for given conditions.

IV. MODEL USE AND APPLICABILITY

It is expected that the proposed simulation model will be used in the control system SHDC for the following purposes:

1. Identification of model parameters for the selected time period

2. Prediction of appropriate timing of the supplied amount of heat energy for the next period.

I. Identification of model parameters for the selected time period

As mentioned, essential for the modeling approach to SHDC is to determine the function $s_r(\ldots)$ used in equations (7). This means that it is necessary to choose the appropriate form of parametric functions and find values of the parameters for the given conditions.

The procedure will be described in detail on simple example where the function $s_r(\ldots)$ shall only affect consumption fluctuations during the day. We will therefore assume that the function $s_r(\ldots)$ will have the form

$$s_r(\ldots) = \lambda_r * ({}^i T_j - T_{ext}) * k_h \qquad (8)$$

where:
- λ_r is the coefficient of heat transfer in segment r (here we suppose that the segments are pipe sections as well as consumer units, depending on the value of the coefficient λ),
- $^i T_j$ is the current temperature DFQ_i for the particular simulation step j,
- T_{ext} is the current outside temperature and
- k_h is coefficient which corrects heat consumption oscillations during a day.

The coefficient k_h is considered as a discrete function of time, which changes its value at one hour intervals. Assuming the daily frequency of consumption of heat, this is probably a reasonable assumption, so it is necessary to determine 24 coefficients k_h. When we use function $s_r(\ldots)$ in form of equation (8) then for each k_h it is possible, in the time between hours, to use the value from the previous hours or use interpolated values. It is possible to use linear or other more complex

interpolation. For our purpose of use k_h and needful accuracy, the linear interpolation is fully suitable.

To determine function k_h we can use the following procedure, which uses the simulation model in combination with genetic algorithm:

1. To select the appropriate length of time period, longer than one day. For the simplicity at the beginning of each simulation experiment we assume that the distribution network is empty. Therefore, for the beginning of the simulation, we must simulate the preceding interval, to let distribution network fills with hot water and let the state of the network become stabilized. This period is given at least as time delay for transportation, which means that all water from the source must have enough time to pass the system and come back to source again. Then we must follow at least one day period to obtain discrete values of k_h for each hour of the day.

2. For the chosen time interval to select and verify necessary historical data. For this task the following data are required (measured in time period Δt):

• Temperature of heating water T_v, measured on source output. This is also considered as an input for distribution network. For our purpose only one source is expected, but model is generally capable to use various combinations of sources and consumers.

• Temperature of returned water T_{vv} – output of distribution network ergo reentry into source. It should be noted that this value is implicitly influenced by the size of the time delay for distribution network but this is already covered in the structure of simulation model.

• Total mass flow M in distributive network, again measured on the network input (output of the source)

• Air temperature measured for particular points of distributive network. Quantities of these values will depend on the density of the network, its measuring points for the outside temperature at that location. If measuring points are located at different places than the landmarks of the distribution network, it is also possible to use interpolated values, in this case, interpolation in the area, i.e. two-dimensional. Also, if there are meteorological data measured in a different time period than Δt, the value interpolated in the timeline has to be used.

Following data, if available, can help refine the whole calculation, e.g.:

• Temperature T_v a T_{vv} in different parts of distributing network.

• Pressure ratios in the major individual network points. These are particularly important in cases where the topology of distribution networks is complicated. According to these, , the value of the mass flow in different sections of the distribution network may be determined - without the knowledge of pressure ratios can be mass flow in each section only estimated.

3. To determine searched values k_h for 24 points of timeline is possible to use several methods based on principles allowing us to find a function(s) which should have the best course approximating analyzed variables. One option is for example to use genetic algorithms. In the presented solution was the method PSO (Particle Swarm Optimization) used - see [7] [8]. This method has been lately compared with other methods, such as SOMA, neural networks [11], and Levenberg-Marquard algorithms for nonlinear methods of least squares. It was found that the results achieved in terms of accuracy and speed of convergence is similar. PSO is therefore comparable for the determination of the correction factors and we use it.

4. The main idea of calculation is that the approximated function is the timing of the T_{vv} for the output of the distribution network to source.

5. For calculating the approximating function the simulation model will be used. For each simulation experiment, we set sought coefficient k_h for selected points in the timeline to values generated by the PSO algorithm. With this sets of parameters one simulation experiment is processed for the selected time slot according to point 1. Rate of the quality of approximation is calculated according to equation (9), i.e.

$$F = \sum ({}^jT_{vv\;meas} - {}^jT_{vv\;calc})^2 \qquad (9)$$

where:
- F is value of approximation accuracy (fitness),
- ${}^jT_{vv\;meas}$ is measured value of returned water temperature for the time interval Δt_j and
- ${}^jT_{vv\;calc}$ is calculated value of returned water temperature for the simulation step j.

The sum is performed for the entire simulated period in each simulation step. It is thus the sum of squares of deviations between the measured values T_{vv} (the values measured on the real system) and the calculated values T_{vv} (the values calculated using the simulation model) in terms of the search parameters - the values of k_h in 24 points of the timeline.
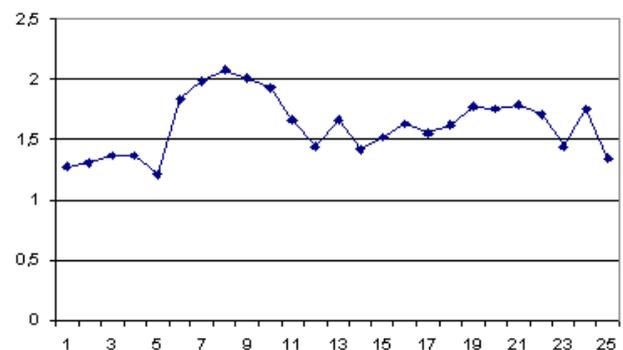

Fig. 3 Calculated k_h coefficient

The calculated F value is transmitted into PSO algorithm, which will use it to generate the next set of values of the coefficients of k_h, with which the process

repeats. After a certain number of iterations (from practical results, there is a few thousand iterations necessary), the calculated values T_{vv} are close to measured values T_{vv} with sufficient accuracy. So designated coefficient k_h can then be used in the simulation model as the parameters for its further use - see section II in chapter IV.

An example result of the calculation of the coefficient k_h was shown in Fig. 3.

An example for comparison of measured and predicted values of T_{vv} in identified model, based on calculated ceoeficients, is shown in Fig. 4.
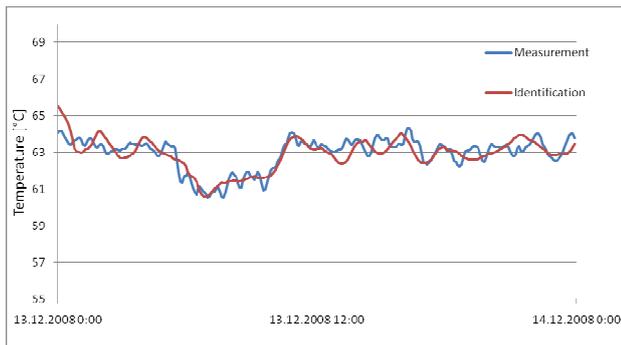

Fig. 4 Identification of SHDC - calculated and measured temperature of T_{vv}.

It is obvious that the described procedure can be reused if the typical pattern of consumption of heat will vary in different types of days - a working day, weekend day, holiday, etc. In this case, repeat the procedure for each typical day, with the use of appropriate choice of time period in accordance with point 1. Then, for each type of day we obtain own set of values k_h that the model "switch" according to the type of the day which is being modeled.

These procedures are thus used to identify the model, i.e. to find such values of model parameters that provide the most accurate approximation of the function characterizing the system behavior - in this case of SHDC it is the timing of T_{vv}.

It is also apparent that this procedure can be similarly used to seek the values of correction coefficients for other variables that affect the consumption of heat, like any other variable weather - sunshine, wind direction and magnitude, relative humidity, etc. [4]. Also, the procedure may be easily modified, if we assume a different shape and form of the function $s_r(...)$.

II. Prediction of appropriate timing of the supplied amount of heat energy for the next period

One of the practically applicable results tied to the use of the simulation model SHDC is to design a predictor of heat supply, useful for its production, as well as for its distribution.

Such a predictor is a very convenient tool that enables efficient management of SHDC and meets the objectives stated at the beginning of this article. It makes it possible

to perform dynamic calculations, which take into account both the characteristics of the SHDC and its temporal changes in response to external conditions (especially climate), which at the particular moment SHDC influence. Without such tools, the whole procedure is based only on experience and intuition of management and controllers, which can lead, especially when there are rapid changes in the state and not fully achieving the normal state system, to not fully effective control of production and distribution of heat.

Based on the results of this work with the simulation model, a procedure for the design, processing and use of predictors in the heat of urban agglomeration consumption was proposed. The procedure is described in the next sections.

It should be noted that the idea of building a predictor in the project gradually evolved and changed. At the beginning of the project, the opinion prevailed that it will be enough to identify a model for a longer period and once identified, the model could be used for this period without any modifications. But it turned out that this approach does not lead to sufficiently accurate results, the characteristics of the system are not sufficiently "stable". It is probably due to both the details of the processed model and major stochastic nature of the whole system. Therefore, the idea was abandoned, and the work moved in the direction of the procedure described below. Given the fact, that the work on the project is not yet finished, described process reflects the present state of the solution and may not be definitive.

The proposed procedure is based on several fundamental ideas:

- SHDC will behave similarly under similar conditions.
- Predicted period is suitable to choose short and necessary calculations (including simulation) to perform for the shorter period repeatedly. This is depending, as already mentioned, on speed changes inside the SHDC and size sampling period Δt. If this period is few minutes, it is easy to perform calculations repeatedly.
- To control the production and distribution of heat, there are two control variables - temperature T_v and mass flow M. It will be necessary to find and use an appropriate cost function, which allows the required amount of heat supplied to optimally divide to the parts obtained mass flow M and the temperature T_v. Search for this objective function is the task for other parts of the project and is not in this article further discussed.

The individual steps of the proposed procedure are as follows:

1. Prediction of conditions for a selected future time interval of the SHDC control. It is usually used the time interval at about a few hours, at the most to one day. Conditions mean generally everything that affects the distribution and consumption of the heat - primarily weather variables such as outdoor air temperature, sunshine, wind strength and direction, etc., as well as type of heat consumption in different parts of the distribution network, amount change in consumption

during the day, etc. These conditions and factors can be integrate one by one and the model can be gradually refined – see section I in chapter IV. The predicted data for the conditions can be collected from weather forecast servers and from historical operative data. It's clear that accuracy of the weather forecast is important, because of very high influence of T_{ext} and other weather variables on the SHDC. So, if the weather variables are more accurate, the results are more credible.

2. Seeking the time interval with similar conditions. In the historical data it is necessary to find appropriate time interval - corresponding to the length and location on the calendar, i.e. the location of it on the same type (working day, weekend day, etc.). The time interval is perceived as the historical operating data in the corresponding time intervals evaluated by degree of similarity according to the SR relationship (10), a similar to relationship (9)

$$SR = k_d * \sum ({}^jV_{pp} - {}^jV_{sp})^2 \qquad (10)$$

where:
- *SR* is the value of accuracy (similarity ratio) of both time intervals,
- k_d is the weigh reflecting the fact that comparison interval less time away from the predicted has greater similarity than distant time interval (longer-term impact of changes in properties of SHDC),
- ${}^jV_{pp}$ is the variable value chosen for comparison, such as, for example, outdoor temperature T_{ext} in predicted time period in interval Δt_j,
- ${}^jV_{sp}$ is the value of the same variable but in a similar timeframe, in intervals Δt_j.

If more variables for comparison are used, than it there should be for each of them established the weight of w_i and the total value of similarity SR determined as a weighted sum

$$SR = \sum SR_i * w_i \qquad (11)$$

For subsequent uses the interval with the lowest SR is selected.

3. Identification of model parameters for time period with similar conditions. This is carried out by analyzing historical operating data recorded during periods with similar conditions. The length of time period is determined as described in point 2. The identification procedure is described in section I of chapter IV of this article. Simulation model and artificial intelligence methods are used to seek for model parameters and to minimize the differences of calculated and measured values of appropriate functions - timing of back-water temperature.

For tests of this step some historical data were used. The period "to predict" was chosen, period with similar conditions was found, and the model for found periods was identified. With this model the "predicted" period was calculated. An example of the result in form of comparison of identified and measured values is in Fig. 5.
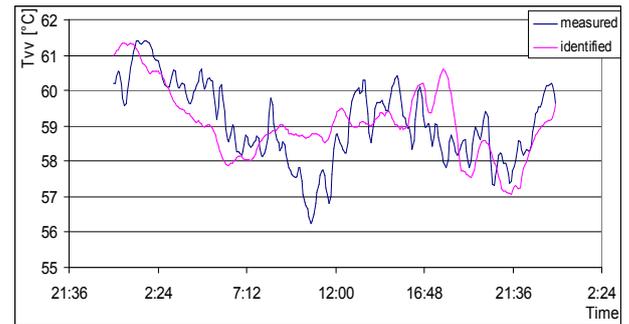

Fig. 5 Identified and measured values for time period with similar condition

4. Identification of model parameters for previous time period. For correct calculation of the required heat in the predicted period it is necessary to continuously follow up on the deliveries of heating in the period immediately preceding predicted period. To do this, it is necessary to have a simulation model, which is identified for the previous period. The model is identified in the same way as described in section I of chapter IV and with data recorded in a database of historical data for this, just passed, period. For further action - see point 5 - it is needed to find a good way to switch from the previous model settings to model for a similar period. It is about finding a suitable time to switch from one simulation model to another, so that continuity is without any jumps.

5. Calculation of control actions for the selected time interval. When calculating the control actions in accordance of quality-quantitative control [1], i.e. determining the time course of temperature and flow of heating water, again with the benefit of the proposed model of SHDC. This model can simulate the behavior of SHDC on various versions of control actions, and find the option that best matches the selected purpose (evaluation) function. A detailed analysis using a simulation model for prediction of control actions will be subjected to the further research work.
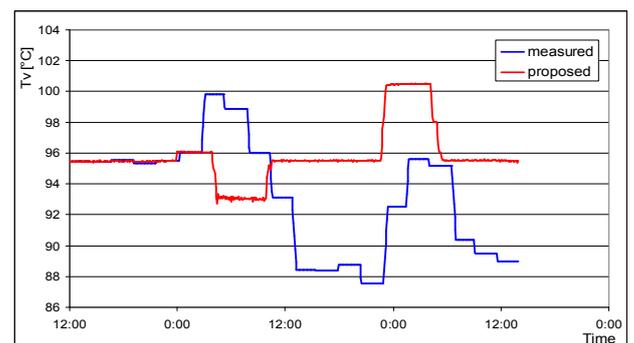

Fig. 6 Proposed values of T_v

There are currently only available results of the first alternative of solution, where control actions are limited to one controlled variable - temperature T_v. The second controlled variable, mass flow has just chosen course. The submitted mass flow course is just a modified course of the period with similar conditions found under point 2. The following pictures show the results of T_v calculations

for control actions compared with the values used in period with similar conditions - Fig. 6 and results for the subsequent control action using proposed *Tv* values in following picture.
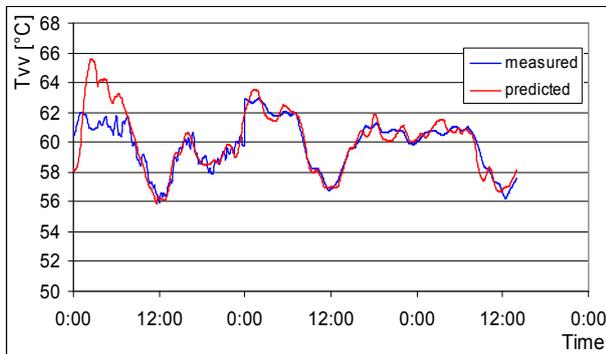

Fig. 7 Predicted and measured values of T_{vv}

V. MODEL REALIZATION AND RESULTS

Introduced model was implemented in the form of a software application. The program modules are written in Java, data – historical operational data, configuration and description data for distribution network, simulation results – are stored in database. Connection to database is realized through JDBC interface and all queries to database are defined by SQL statements. These chosen software tools and solution allow easy portability to different SW environments.

The basic class is class SIMULATOR, which realize separately one complete simulation experiment, i.e. one simulation run for whole simulated time period. This gives the possibility to write application as multithreaded, so that there are running in parallel several instances of the class SIMULATOR, every one in their own thread. It gives higher performance for calculation, especially in case, when many simulation experiments must be provided.

Block diagram for the whole application can be seen in Fig. 8. Block diagram for class SIMULATOR is in Fig. 9.

Short description of some selected block content:

Block "INITIALIZATION":
-Read necessary data from database.
-Create and initialize internal data structures for program modules.
-Create and reset data structures for results.

Block "PARAMETERS":
-Get set of model parameters. The set of parameters is generated by PSO algorithm. It is realized in the procedure, which has as output set of model parameters and input is value of fitness for given set of parameters. This procedure is a part of the block "PARAMETERS".

Block "START SIMULATOR":
-Create a new instance of SIMULATOR class to which given parameters are assigned.
-Define and start a new thread in which the new instance of SIMULATOR is running.

Block "WAIT FOT RESULTS":
-Wait the end of simulation for each SIMULATOR instance in individual thread.
-If the end is reached, the result (the value of fitness) is put in procedure with PSO algorithm.

Block "CALCULATION END":
-This block is reached if the conditions for end of calculation are filled.
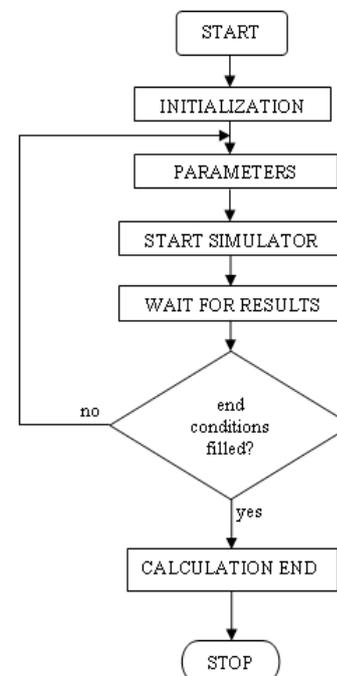-The results are saved in database.
-Program ends.

Fig.8 Block diagram for application run

Notations for class SIMULATOR
NODE　　　　 - a mark for node object in model;
first NODE　 - the node on the beginning of distribution network, usually the output point from heating station;
last NODE　 - the node on the end of distribution network, usually the input point on heating station;
input NODE　 - the node in which the section begins, is defined for each SECT;
output NODE　 - the node in which the section ends, is defined for each SECT;
SECT　　　　　　　 - a mark for section object in model;
first SECT　 - first section in distribution network, usually starts in first NODE
last SECT　 - last section in distribution network, usually ends in last NODE

next SECT   - the next section in list of SECT, it not have to be necessarily a topologic consequential SECT
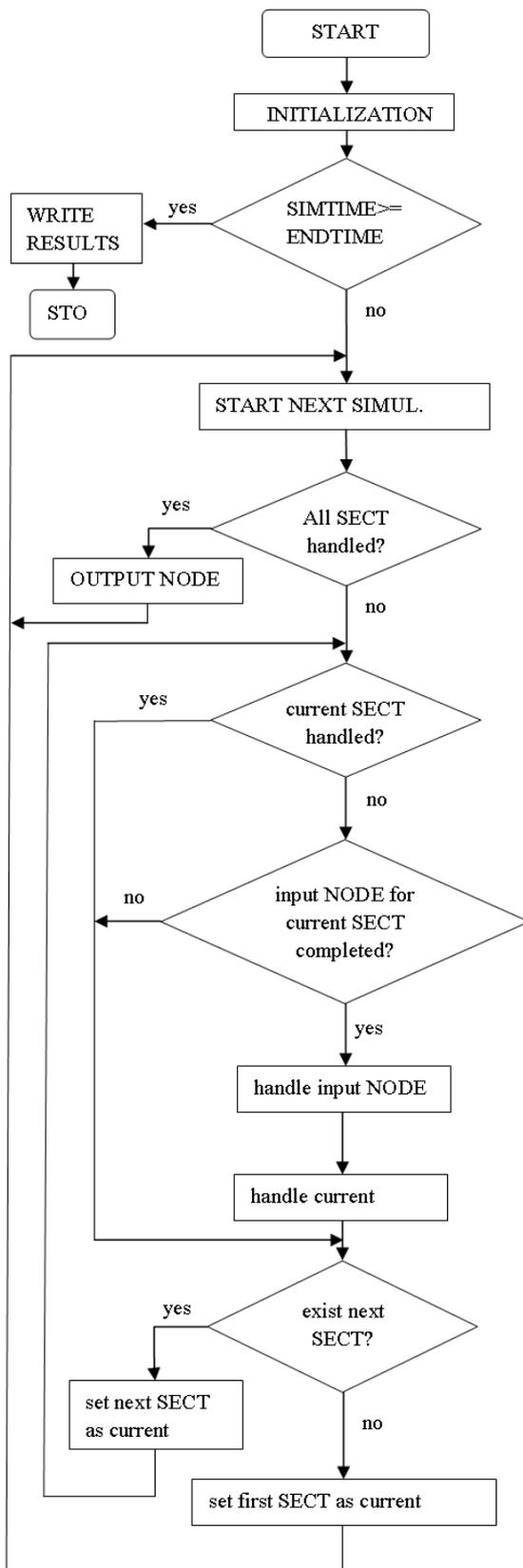   SIMULTIME - simulation time

Fig. 9 Block diagram for class SIMULATOR

Short description of some selected block content:

Block "INITIALIZATION":
- Set simulation time to start value.
- Create and initialize internal data structures for program modules.
- Create and reset data structures for results.

Block "start NEXT SIMUL STEP":
- Add time interval Δt to the SIMULTIME
- Clear all marks "NODE handled" and "SECT handled"
- Create new DFQ. Its volume is calculated from current mass flow from heating station, its temperature is given by current temperature of water on output from heating station.
- Put this new DFQ into first NODE.

Block "NODE HANDLE":
- Sum volume V_i of all DFQ's (more exactly the parts of DFQ's which reached the node) - volume V.
- Calculate temperature T of volume V
- Divide volume V to sections which are outputs from the node – volumes V_j
- Mark node as handled.
- Create new DFQ's with volumes V_j, temperature T and put they into output sections for this node.

Block "LAST NODE":
There are some similar functions as in other nodes. Differences are:
- Write the output from this node into results
- Destroy input DFQ's
- Don't create new DFQ's on the output from this node.
-
Block "input NODE complete ?":
- The NODE is complete if all SECT, for which the NODE is output node, are handled

Block "SECTION HANDLE":
- Calculate length of input DFQ from its volume and diameter of first pipe in section.
- Move all DFQ's in section through all pipelines in section, i.e. calculate for each DFQ its new position. On calculation must be respect pass of DFQ's over boundary lines between two consequential pipe lines and between last pipe line in section and output node – as described in chapter III.
- Calculate amount of heat and temperature change (decrease) for each DFQ in section based on heat transfer from DFQ to environment of pipe line corresponding to its current position (heating of space or energy losses).
- Mark section as handled.

Block "write results":
- The results for each simulation step are written into internal data structures on the end of simulation step. The results contents:

o Simulation time,
o input mass flow,
o temperature of input water,
o temperature of output water and
o other characteristics needed for the analysis.

The characteristics is possible to define by user
- Write results for whole simulation experiment from internal data structures into database.

Application was tested on data from the real process in the selected heating plant. Examples of achieved results are presented in Fig. 10.
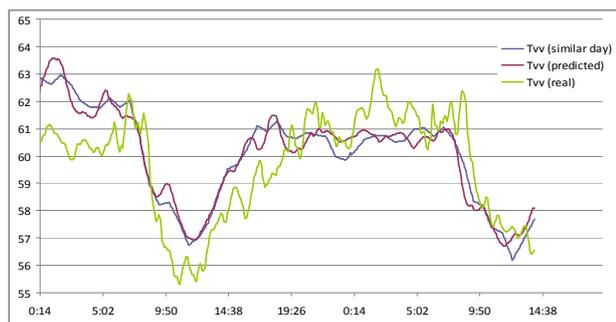

Fig. 10 Results of real process testing

The picture above shows differences in the time course of T_{vv} (predicted), i.e. calculated using the simulation model and T_{vv} (real), i.e. measured in real system. It should be noted that these two curves represent the results of two different ways to control the production and distribution of heat. One is based on analysis of the behavior of SHDC using the simulation model, the other on the basis of experience-based process controller, which uses empirically determined equithermal curve. To make it possible to reliably compare these methods and evaluate their quality, it will be necessary to carry out further and deeper analysis of the behavior of SHDC. The analysis will be conducted in the next phase of the project and will be tied to finding a suitable evaluation function, using the described simulation model and subsequently finding the optimal variant of control for the entire system of production, distribution and consumption of the heat.

VI. CONCLUSION

The results obtained during the model verification, tested on real measured data show that the proposed simulation model is a well suited tool for analyzing the properties and behavior of SHDC.

Introduced simulation model can be used also in different mode, which is practically very interesting and useful. It can be incorporated into the control system to predict the behavior of SHDC at a certain (limited) time in the future, to streamline the management of SHDC. This relates to the length of the sampling period in the simulation model, since that period (order of minutes) allows real-time software to carry out quite complicated and extensive calculations and apply the results in real-time control system.

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