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SCADA SYSTEMS IN DISTRICT HEATING – THE IMPACT ON INCREASING ENERGY EFFICIENCY AND THE REDUCTION OF CO_2 EMISSION

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Abstract. *Improving energy efficiency of district heating systems as a whole is closely related to the application of computer technologies for visualization and control of heat production and distribution. Control in district heating enables fast adjustability of all sub-systems to variations in heat demand. At the same time it enables solving optimal control problems in transition periods like system start and system stop. A district heating system supplies heat to different end-users which can differ in both the quantity of supplied heat and the character of their heat demand. Heat demand of end-users varies with change in outside conditions (outside dry bulb temperature, solar radiation, wind speed and direction etc.), so it is crucial to be able to adjust heat carrier parameters in order to meet the heat demand. This can be achieved only with proper control. In addition, the quality of heat supply can be improved and heat losses reduced, which leads to the reduction in primary energy consumption, the improvement of energy efficiency of the system and, finally, the reduction in green house gasses (GHG) emissions. It is considered that the largest potential of reducing GHG emissions lies in increasing energy efficiency, especially in the district heating sector. Special attention is paid to CO_2 emission, since this gas is substantially emitted through anthropogenic activities.*

Key words: *energy efficiency, district heating, SCADA, GHG emission*

1. INTRODUCTION

The contemporary civilization currently faces three main challenges in the energy sector [1]: current estimates show that CO_2 emission in Europe will increase for approximately 5% until 2030, with 55% of global emissions increase in the same period. At the same time, the dependence on the energy import in most of the EU countries will rise (up to 65% by 2030) which will influence an increase in energy prices. Investment in

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energy efficiency and renewable energy sources can lead to innovations and industry development which can positively affect the economies of these countries. To face these challenges, the EU with its member countries have adopted regulations in the energy sector and long-term plans in three different areas of energy policy [2]:

1) mandatory 20% GHG emissions reduction by 2020, compared to the reference year 1990, with a possibility to increase this target value to 30% (this is related to climate change agreements),
2) increasing renewable energy sources to 20% in final energy production by 2020,
3) increasing energy efficiency in order to save 20% of energy consumption compared to the reference year 1990, by 2020.

The accomplishment of these goals implies sustainable development.

District heating is an important component of sustainable development and sustainable energy supply. District heating systems are also being considered in the context of increasing energy safety, improving energy efficiency and slowing down climate changes. Many countries have adopted regulations where the district heating sector is considered as a vital factor towards sustainable energy systems [3-5]. Huge amounts of energy being used today for space heating in residential and public buildings require implementation of rational energy use. One of the many improvements in heating systems related to the increase in system efficiency, is the concentration of heat production for a large number of consumers. This has led to centralized heat production for several buildings, city blocks and whole cities. Heat produced centrally is distributed with hot water pipelines to heating substations where heat is transferred with a heat exchanger to secondary pipelines and end-users. Having in mind the principles of sustainable development, there is a need for optimized heat production and heat consumption. Optimization encompasses proper control and acquisition of all relevant parameters of the heating system in all phases: heat production, distribution, exchange and consumption [6,7]. Control assumes the possibility to manage and monitor main operation parameters. The supervisory control and data acquisition system (SCADA) [8] has vast application in district heating. Numerous authors have analyzed the efficiency of district heating with the goal of increasing it. Joelsson and Gustavsson [9] and Gustavsson and Joelsson [10] analyzed primary energy savings in a district heating system based on averaged final energy needs and averaged heat production. Annual savings in final energy and production of heat are dependent on primary energy savings and energy efficiency of the district heating system, on the one side, and buildings energy efficiency, on the other. The influence of end-users energy efficiency on district heating system efficiency can be very complex and mainly depends on the heat demand profile [11]. This affects the heating curve character and slope, in turn affecting primary energy consumption, costs of produced energy and GHG emissions reduction. It is considered that the largest potential to reduce GHG emissions in the Serbian energy sector by 2015 can be found in the increase in energy efficiency especially in the district heating sector [12, 13]. Special attention is given to CO_2 emission since it is related to anthropogenic activity. The data from 1998 show that CO_2 emission from the district heating sector was (fuel consumption was approximately 0.535Mtoe) around 88.83% of the value from the reference year 1990, while in 2008 the emission reached 94.28% (fuel consumption was approximately 0.590Mtoe) of the value from 1990 [12]. Having in mind that the installed capacity in the district heating sector of Serbia is 7000MW, and that the annual production is in the range of 8000GWh (approximately 25% of the building sector covered with district heating systems), increasing the efficiency of district heating system operation must be of particular importance.

2. Prinicple of District Heating System Operation

Heat produced in boilers is transferred with primary hot water pipelines towards a heating substation where it is supplied by heat exchangers to the secondary heating system. The heat is transferred to end-users by the secondary pipeline. In order to meet the required parameters of secondary fluid, the heating substation is equipped with the following: microprocessor controller with sensors, heat meter, stop valve, strainers, control valves, flow controllers and pressure keeping devices.

The supply fluid temperature on the primary side is controlled according to the heating curve in the boiler house, while the additional control of the fluid temperature on the secondary side is performed by the flow control on the primary side of the heating substation. The secondary side supply temperature is a function of the outside dry bulb temperature, time of day and day of week, and is embedded in the microprocessor controller. The microprocessor controller is equipped with an outside temperature sensor, supply and return water temperature sensors, primary and secondary side pressure sensors, indoor air temperature sensor and primary side water flow meter. Using a cable or a GPRS network, all controllers are connected to a remote PC in the operating room where remote control and data acquisition take place.

Heating substation microprocessor controllers operate in automatic mode with a predefined algorithm. Changes in controller operation, controlled variables and remote control can be achieved from the operator station. This is how remote control and data acquisition of a district heating system are achieved, while the heating substation operation is fully automated. The contemporary heating substation configuration and equipment selection should allow:

- remote acquisition of operation parameters
- remote control
- local control
- heat consumption measurement
- alarm states reporting.

3. District Heating System Control

Depending on the place where control is implemented, one can differentiate between central, group, local and individual control [14].

1. Central control takes place in a district heating plant (boiler house) according to changes in heat demand of most of the users, assuming this demand is more or less uniform.
2. Group control takes place in heating substations for users with similar heat demand, by providing adequate flow and supply temperature.
3. Local control takes place in a heating substation for additional correction of flow and supply temperature, but taking into account local outside conditions.
4. Individual control takes place directly on the heat exchanger and requires many local microprocessor controllers which results in higher initial investments.

When using water as heat carrier, the following methods of central control could be applied:

a) quality control, in which heat transfer is controlled by varying the supply temperature while maintains a constant water flow,
b) quantity control, in which heat transfer is controlled by varying the water flow while maintaining constant supply temperature,
c) quality-quantity control, in which heat transfer is controlled by varying both the supply temperature and water flow,
d) intermediate control, by switching the system on and off. The central intermediate control is applicable only in the district heating systems with similar heat demands among the users.

Heat demand of various users in modern district heating systems is not uniform, not by character nor by parameters of heat carrier. In order to provide high quality heat supply, combined control should be implemented. This combined control should include three levels of control: central control, local control and individual control.

Effective control can be realized only with the application of proper control systems unlike previously when manual control was used.

3.1. District heating system supervision

The best way to control heat transfer in district heating systems is to apply a combination of central quality control and local quantity control. The selection of the basic impulse for local control depends on the type and operation of a particular district heating system. This is a very complex task since indoor temperatures of heated spaces can differ significantly from one another, and because they are influenced not only by the delivered heat but also by the building type and operation, internal and external heat gains, building disposition, etc. In order to fully meet the heat demand, it is necessary to include local control on the room level as well.

An energy audit of the district heating systems can allow the determination of all parameters that influence the system efficiency, and it can be conducted by:

- close inspection of the system
- inspection and determination of system efficiency
- inspection of supplied heat.

The following states are of particular interest:

- outside dry bulb temperature
- primary side supply temperature
- primary side return temperature
- pressure of primary side supply
- pressure on primary side return
- secondary side supply temperature
- secondary side return temperature
- pressure on the secondary side
- current water flow
- supplied heat energy.

States of interest are:

- percentage of control valve openness
- pump operation indication
- expansion tank pressure indication
- service intervention indication.

SCADA solution for a heating substation takes into account:

- measurement and display of all parameters in the heating substation
- adjustable control parameters
- trend diagram of measured values
- possibility to choose between manual and automatic substation operation
- during manual operation - possibility to control valve and pump operation
- alarm states display
- system display should be compact
- improved information for users
- list of alarms, diagrams - both current and archive
- reports adjusted for easier display
- simple control - turning pumps on/off, control valve opening/closing
- archiving of all commands and operators who imposed them during remote control
- optical internet
- possibility to expand the system in the future.

By applying these modern solutions the following goals can be met:

- savings in heat production/supply (outdoor compensated secondary side temperature control in combination with maximum flow limitation of every heating substation)
- quality in heat supply (remote control from the operator station enables better balancing of the system)
- reducing operating costs of the district heating system (easier fault detection and diagnosis, longer operating life of equipment, lower maintenance costs)
- increasing availability of the district heating system
- more rational energy use and stable financial incomes (by introducing payment only for the heat consumed by particular end-users)
- investment optimization and preservation (applying know-how and knowledge transfer to end-users).

3.2. SCADA system

SCADA (Supervisory Control And Data Acquisition) is a system used for gathering sensor readings located in heating substations, remote transfer to/from the operator station. In reality, SCADA systems can monitor and control up to several thousand input/output values. The main purpose of SCADA systems in thermal engineering, and HVAC systems, is to provide a simple yet effective way to display all relevant parameters of HVAC system operation on one monitor, to provide possibility for remote control of systems and preventive maintenance, and also to provide archiving of these parameters for future analysis.

The operator station is connected to in-field microprocessor controllers who serve for local control thus providing data transfer in two directions: from the systems towards the station and vice-versa. The connection is established by a special communication interface which can be produced either as an internal PC card or as an external device.

The operator monitors online all sensor readings in the system, reads-out setpoint values, monitors the status of every actuator in the system, etc. Furthermore, the operator has the possibility to give the commands to every actuator and device in the system. A graphical display of the system leads to easier understanding of the system operation and displayed values. Using software for remote access allows the user to access the operator station from any PC connected to the local network.

3.3. Microprocessor controllers

Microprocessor controllers are fundamental devices for the control of HVAC and other technical systems operation. In case they are connected to a network, according to the built-in communication protocol, controllers send all the data towards the operator station and conduct all the commands sent back to them. All microprocessor controllers connected to SCADA have their unique communication address which allows remote control. When controllers are on network, the device itself can display only setpoint and measured values, unlike when they are off network when the possibility to change parameters is enabled. Remotely altered parameters are written in the controller memory so they remain active even if the network "crashes".

Using a functional keyboard and graphic LCD screen overview of current values, changing setpoint values and manual tests of actuators is possible. Information displayed is organized in two groups of screens. The first group are INFO screens. These screens display all relevant information on system operation (measured values, setpoint values, digital inputs/outputs state, alarm states etc.). The contents and appearance of INFO screens depend on the selected application, and users can define their INFO screens while creating their own programs.

The second group are the so-called MENU screens which are always the same and which can display/change setpoints, digital inputs/outputs, date and time, communication parameters, interface language, etc.

Using one of the communication interfaces (RS232 or RS485) enables the connection of the microprocessor controller to SCADA system.

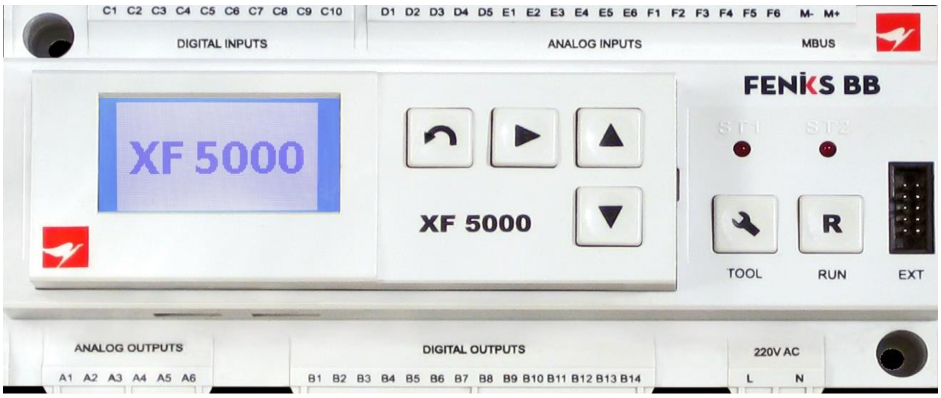

Fig. 1 Microprocessor controller XF 5000, manufactured by "Feniks BB d.o.o"

3.4. Functions of the customized SCADA system CENUS

CENUS-3000 [15] is a SCADA solution from company "Feniks BB d.o.o" Niš, Serbia. It is a MS Windows application (software). It provides a detailed systems display with all relevant parameters on the operator station monitor(s). It provides an overview of all system operation parameters and a possibility to perform remote change and control (the operator can remotely change the status of actuators: pump on and off, opening and closing of control valve, etc.). Selected system operation parameters are stored on a hard drive which allows their overview in the table or graph form as well as continuous printing in real time (or from archives).

Software modules

CENUS should have the following modules:
Supervisory module
Tabulated analysis module
Graphical analysis module
Alarm states overview module
Switching between modules is realized by toolbar buttons. Only one module can be actively displayed.

Supervisory module

Supervisory module (Figure 2) is activated by selecting the "NADZOR" button on the toolbar.

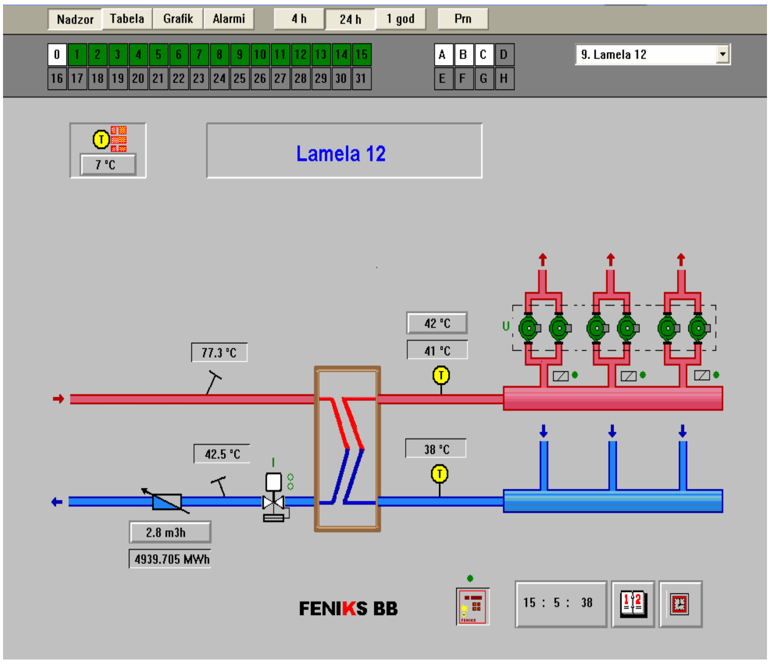

Fig. 2 Supervisory module with a display of measured and setpoint values for a heating substation connected to the district heating system of the Faculty of Mechanical Engineering in Niš

This module allows the following:

- numerical display of all measured values,
- display of measured values in bar-graph form,
- information on the status of digital outputs,
- read-out and change of setpoint values,
- status of electric actuators,
- giving commands remotely to electric actuators,
- saving all system operation parameters on the hard drive.

Fig. 3 Dialog menu with current selection and possible options for pump operation control valve actuator

Giving commands to electrical actuators in the system is performed by clicking on the actuator symbol. In this case a dialog menu appears with the current selection and possible options as displayed in figure 3.

After selecting an option by pressing the OK button, the command is forwarded to a microprocessor controller. The "Lokal"option is used for putting a microprocessor controller in the local control mode according to the predefined control algorithm. The status of the circulation pump or control valve is displayed with letter symbols next to the element on the monitor.

4. CO_2 EMISSIONS

CO_2 emitted during fossil fuel combustion can be determined from the eq. [16, 17]:

$$EM^i_{CO_2} = \frac{AC^i \cdot EF_c}{1000} \cdot OC^i \cdot \frac{44}{12} \tag{1}$$

where: AC^i is the energy potential of the particular fuel used

$$AC^i = \sum_i m^i \cdot H^i_d \tag{2}$$

m^i (m^3) – the fuel consumption (natural gas), and H^i_d – (TJ/kt) – the lower heating value of the fuel used [16], (for natural gas this value is around 34 MJ/m^3). The lower heating value of natural gas in TJ/kt can be determined with natural gas density of 0.752kg/m^3, which gives

$$H^i_d = \frac{34 \quad (MJ/m^3)}{0.752 \quad (kg/m^3)} = 45.22 \quad (\frac{TJ}{kt}) \tag{3}$$

EF_c = 15.3 (t/TJ) – the carbon emission factor [16], and OC^i – the percentage of oxidized carbon during combustion (according to Tier 1 approach [16] this value is 99.5% for natural gas)

5. APPLICATION OF CENUS-3000

The ultimate goal of a district heating system is to provide adequate indoor air temperature in heated premises, which is defined by design conditions (usually this temperature is 20^{o}C). This is realized through the control of supply water temperature on the secondary side of the heating substation according to the defined heating curve. While defining the heating curve one must take into account the thermal mass of the heated buildings. Due to this, and having SCADA available, the classic heating curve slope (90/40^{o}C supply water temperature for outside temperatures -15/12^{o}C) could be changed more frequently with lowering the supply temperatures for the same outside temperatures.

5.1. Building description

Benchmark values for comparing the effects of SCADA implementation on primary energy savings and lowering CO_2 emissions are obtained with the building energy performance simulation tool EnergyPlus 8.2.0 [18]. The net heat demand was simulated by imposing the measured indoor temperatures as heating set-points, while the outside temperature was varied according to the measurements on the location (given in table 1). The other climatic conditions, necessary for performing the simulation run, were taken from the weather database of the Republic Hydrometeorological Service of Serbia, Observatory in Niš.

Table 1 Measured outside and inside air temperatures for 17/12/2013 used in simulation

Time	Outside air dry bulb temperature, ^{o}C	Inside air temperature ^{o}C
00:00	3	21.00
01:00	3	20.60
02:00	3	20.20
03:00	3	20.20
04:00	3	20.10
05:00	3	20.00
06:00	3	20.40
07:00	3	20.60
08:00	3	20.90
09:00	4	21.20
10:00	4	21.50
11:00	4	21.60
12:00	5	21.60
13:00	5	21.60
14:00	5	21.70
15:00	5	21.20
16:00	5	21.50
17:00	4	21.60
18:00	4	21.60
19:00	4	21.80
20:00	3	21.80
21:00	3	21.80
22:00	3	21.80
23:00	3	21.50

The investigated residential building, abbreviated L11-13, shown in Figs. 4 and 5, is part of a larger residential settlement "Nikola Tesla" located in Niš, Serbia (shown in Fig. 6). The whole settlement is supplied with energy for space heating from the district heating system operated by the Faculty of Mechanical Engineering in Niš, through 4 heating substations. One of the heating substations is used for providing space heating for the investigated building L11-13.

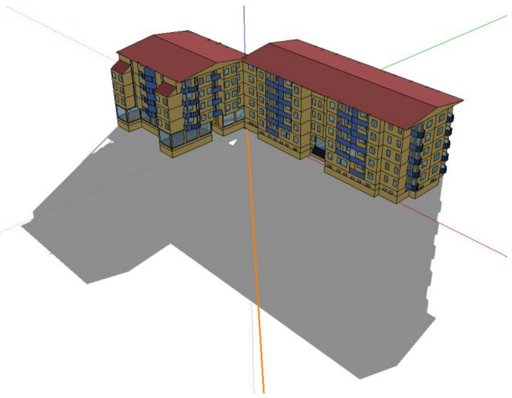

Fig. 4 Building L11-13, North view

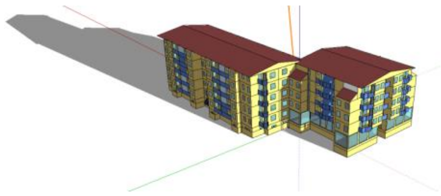

Fig. 5 Building L11-13, South view

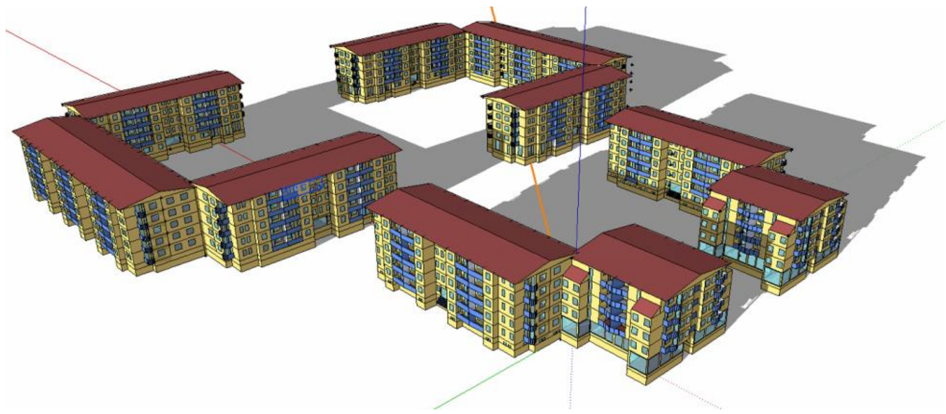

Fig. 6 Settlement Nikola Tesla

The building L11-13 comprises three buildings, two of which (L12 and L13) share the common wall, while the third (L11) is spatially offset. All three buildings are 4-storey high with basement and ground floor. Each storey has 4 apartments. While L12 and L13 have 4 apartments each on the ground floor, L11 has a supermarket on its ground floor. This accounts for a total of 57 heated zones, where one zone represents one apartment (supermarket). Corridors on every building storey as well as basements are modeled as separate unheated zones.

The total floor area of the building L11-13 is 8689m^2, and the heated floor area is 5300m^2. The gross wall area is 4479m^2, and the window area is 1149m^2. The external wall consists of 15mm thick mortar, 80mm thick polystyrene insulation, 250mm thick hollow brick and additional 15mm layer of mortar on the inside. The U-value of this wall is 0.394W/m^{2}K. The windows are double glazed filled with air (4-12-4 construction type) with U=2.73W/m^{2}K and SHGC=0.768. The infiltration rate of 0.6 air changes per hour was maintained constant during the simulation.

The simulation of net heat demand was performed for the period 12-17/12/2013, while the results were requested only for 17/12/2013, the same day for which the real measurements were performed (in the case after SCADA was implemented).

Figures 7 and 8 show the variation of supply temperatures (measured and calculated values), outside and inside temperatures with SCADA implemented (for the date 17.12.2013.) and before SCADA implementation (day with similar outside temperature profile, measured inside temperature within the same apartment, calculated and measured supply water temperatures in the same heating substation).

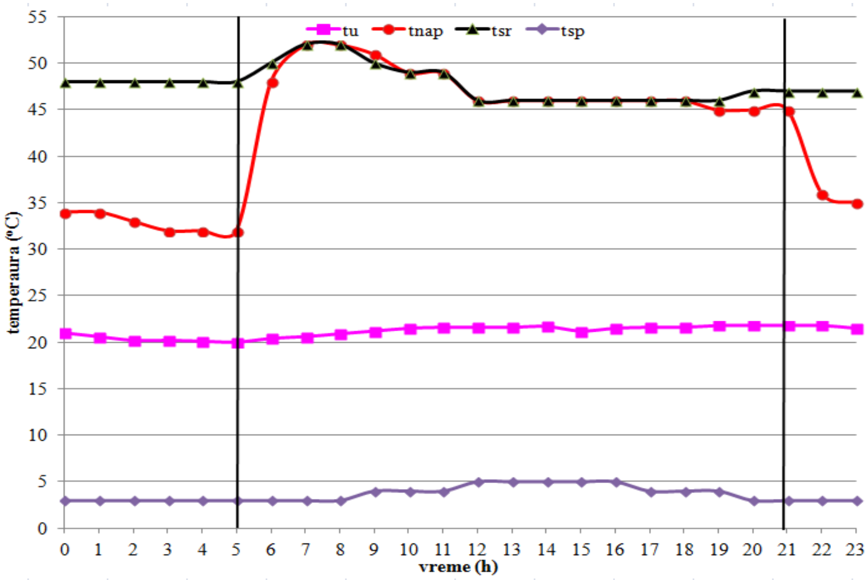

Fig. 7 Measured supply water temperature, calculated supply water temperature, outside and inside temperatures with SCADA system for 17/12/2013.

From Table 1 and Figure 7 it is clear that the inside temperature was higher than the designed one, but it was well controlled throughout the day by changing the supply water temperature on the secondary side of the heating substation. The secondary side supply water temperature was close to its calculated values with SCADA implemented due to the fact that the heating curve was changed several times during the day with significantly lower operating conditions compared to the classic heating curve (90/40oC). In the situation before SCADA was implemented, the measured supply water temperature was higher for 10oC on average, compared to its calculated value (it was locally controlled in the heating substation and the heating curve was constant during the day). The indoor temperature was significantly higher compared to the design value.

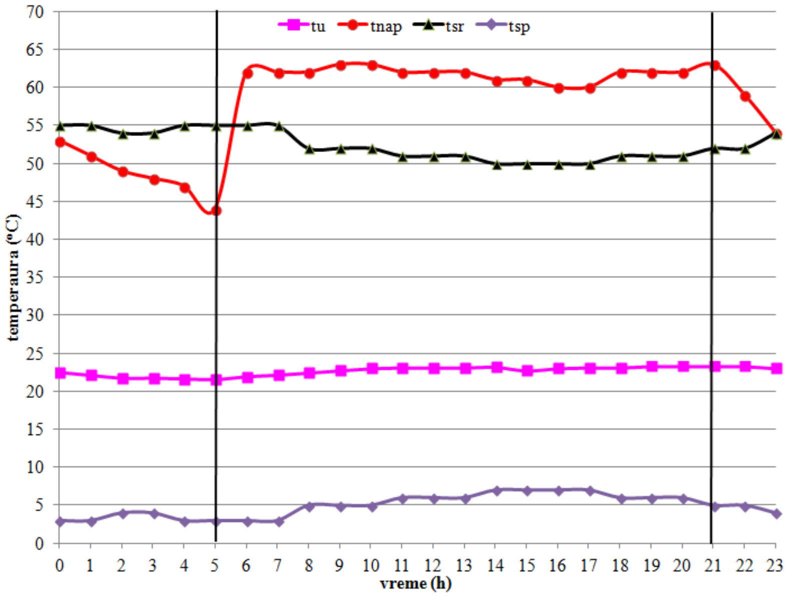

Fig. 8 Measured supply water temperature, calculated supply water temperature, outside and inside temperatures without SCADA system

The implementation of SCADA system enabled the changing (lowering) of the heating curve during the day, and keeping indoor temperature close to the design value (it was slightly higher), which led to reduced heat supply. The supplied heating energy was 2.93MWh for the case with SCADA and 3.31MWh before SCADA was implemented. Final energy savings were app 380 kWh. For calculating CO_2 emissions (equation 1) final energy should be converted to primary energy (natural gas consumption) by taking into account the distribution system efficiency (97%), heat losses in the boiler plant (5%) and boiler efficiency (92%). Results are given in table 2. Similar values can be derived by using CO_2 emission coefficients (1.9kg CO_2/m^3) for natural gas according to the Ordinance of Building Energy Efficiency of the Republic of Serbia [19]. Simulation results are lower than the measured values but this was expected since these values represent the theoretical minimum (assumed perfect control and heat supply perfectly matching heat demand) for the buildings observed.

Table 2 Comparisons of savings with and without SCADA to simulation results

		Without SCADA	With SCADA	Simulation
Supplied heating energy	kWh	3310	2930	2575
Savings in supplied heating energy	kWh	-	380	745
Natural gas consumption	m^3	413.398	365.938	321.601
Saving in natural gas consumption	m^3	-	47.460	91.797
CO_2 emissions	kg	807.65	714.93	628.31
CO_2 emission reduction	kg	-	92.72	179.34

6. CONCLUSIONS

This paper shows the impact of SCADA implementation in a district heating system on reducing heating energy supply while preserving the thermal comfort of the occupants. Based on results the following can be concluded:

- The secondary side supply water temperature should closely match the calculated values, which is achieved by changing the heating curve slope.
- The heating curve of the secondary system should be adjusted to particular buildings (its thermal mass).
- This allows the application of low-temperature secondary side operating regime.
- Changes in the heating curve are possible only with remote control, which leads to significant energy savings.
- Reduced heating energy supply implies saving in primary fuel consumption and the reduction of CO2 emissions.

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SCADA SYSTEM U DALJINSKOM GREJANJU – UTICAJ NA POVEĆANJE ENERGETSKE EFIKASNOSTI I SMANJENJE EMISIJE CO_2

Unapređenja energetske efikasnosti postrojenja daljinskog grejanja tesno su povezani sa primenom računarske tehnologije za vizuelizaciju i automatizaciju procesa proizvodnje i distribucije toplotne energije. Automatizacijom procesa u sistemima daljinskog grejanja obezbeđuje se brzo prilagođavanje rada svih sistema na promene u potražnji za toplotnom energijom. Istovremeno se rešava i problem optimalnog upravljanja u prelaznim stanjima kao što su uključenja i isključenja. Sistem daljinskog grejanja snabdeva toplotnom energijom različite potrošače, kako u pogledu veličine tako i u pogledu karaktera toplotnog opterećenja. Režimi korišćenja toplotne energije kod potrošača su različiti a pri tome ono se menja u zavisnosti od meteoroloških uslova (temperature spoljnjeg vazduha, vetra, insolacije). Zbog toga je neophodno menjati parametre nosioca toplote u skladu sa potrebama potrošača. Ovo se postiže odgovarajućom regulacijom, čime se poboljšava kvalitet snabdevanja toplotnom energijom, smanjuju gubici toplotne energije a samim tim se smanjuje potrošnja primarne energije. Time se povećava energetska efikasnost sistema daljinskog grejanja, odnosno smanjuje se emisija gasova sa efektom staklene bašte. Smatra se da se najveći potencijal za smanjenje emisije gasova sa efektom staklene bašte nalazi u povećanju energetske efikasnosti korišćenja energije naročito u sektoru daljinskog snabdevanja toplotnom energijom. Posebna pažnja se poklanja emisiji CO_2*, iz razloga što je to gas koji se u značajnoj meri emituje usled antropogene aktivnosti.*

Ključne reči: *energetska efikasnost, daljinsko grejanje, SCADA, GHG emisija*