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Experimental Research of Control Algorithm for Solar Assisted Hybrid Water Heating System

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Introduction

District heating (DH) and domestic hot water (DHW) systems of Lithuanian cities and towns currently undergo process of renovation and alteration of the traditionally used fuels. First of all consumption of the expensive and dirty boilers' oil was reduced from 44.1 % in 1998 up to 5.4 % in 2009. Distribution of the fuels by type used in the Lithuanian DH systems in 2009 is shown in Fig. 1.

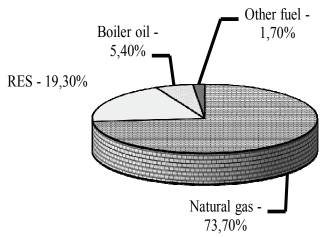

Fig. 1. Distribution of the fuel by types used in the Lithuanian district heating systems in 2009

Presently the main tasks of the Lithuanian heating economy renovation are implementation of the energy efficiency measures (first of all – relevant insulation of the heated buildings) and substitution of the expensive imported natural gas by the less polluting local renewable energy sources (RES). Share of renewable energy used for the DH and DHW production was progressively increasing during the last years step-by-step from 1.2 % in 1997 up to 19.3 % in 2009. According to the mentioned source of information, the main share of RES contribution to the heat energy production currently brings the wood fuel – 153450 toe or 90.15 % of total RES fuels amount.

Further development of CHP and DH systems in future years is also relied mostly on the wood and other types of biomass. We suggest taking into consideration other RES for including them into the space and DHW heating systems because of the following reasons:

1. Burning of wood and other types of biomass have some negative aspects (emissions of CO, NOx, VOCs, hard particles);
2. Utilisation of wood and wood residues from remote localities can be hard and expensive;
3. Some already existing heat energy technologies based on universally available solar irradiance can be used cost-effectively as independent heating systems or integrated into the hybrid heat energy installations;
4. Usage of wind energy for heating purposes can be also cost-effective in windy regions.

Solar and wind energy technologies for generation of heat energy have a huge and untapped potential, which could be realised with benefit to environment and economy. Innovative heating systems exploiting wind and solar energy are considered in references [1–4].

In this paper results of solar assisted hybrid water heating system experimental research are presented.

The object for experimental research

The purpose of the intended research is to check effectiveness of developed control algorithm and possibility of control optimization by gliding of the difference between the temperature of water in PWST and the temperature of heat carrier in SC. In our case the solar collectors can be backed up by electrical or gaseous heater, as it is shown in the diagram of building's experimental DHW system in Fig. 2.

According to the Fig. 2, the cold water in experimental hybrid DHW system is preheated by solar collectors SC in the first tank designed for the preheated water. After this the preheated water runs to the second tank for the final warming up by the existing water heating system running on natural gas and reserved by the electrical heater. The main purpose of solar collectors is to utilize maximum of solar irradiance, meanwhile one or another backing up heater has to raise the temperature of the preheated water up to the value set in advance.

Solar irradiance is measured by the transducer ET. Solar irradiation over the time of solar collectors' operation is calculated by the solar integrator SI. One heat energy meter Wh measures the heat energy contributed by solar collectors and another one – the heat energy contributed by the one or another backing up heater.

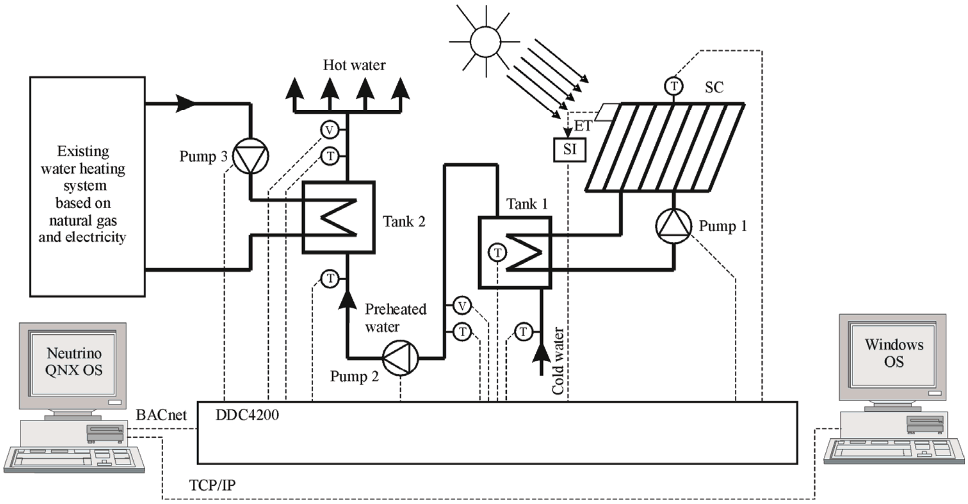

Fig. 2. Diagram of building's experimental DHW system

The equipment for experimental research and data collection

An automation and control system Neutrino BMS and direct digital control (DDC) equipment are installed in researched building (Fig. 2). Neutrino BMS provides function of measurement, regulation and process control technology for all building technical equipment. It interacts with the automation stations according to the principle of spatially distributed intelligence with front–end processing. The stand alone functions performed by the automation station DDC4200 continue to operate even if communication between DDC4200 and Neutrino BMS is interrupted [5, 6].

Neutrino BMS is based on QNX operating system. It is a real-time capable, network oriented multitask and multi-user system with embedded BMS network software and graphical user interface. The hardware architecture of an intelligent master has offered the necessary resources, so as to implement the real time application [8]. Neutrino BMS accomplish three main essential requirements to real time applications:

1. Ensuring a response from the computers system;
2. The promptitude of response, once this has been decided;
3. The security of application code.

Immersion type sensors were used to detect the collector's and preheated water storage tank (PWST) temperature. Specialized air temperature sensor is used for outside temperature detection. Both sensors are based on KP10 measurement element: 2.73 V at 0°C, temperature coefficient TK = 10 mV/K and were calibrated by automation station's DDC4200 functional modules.

Data exchanging between DDC4200 and Neutrino BMS is based on Building Automation and Control Networking Protocol (BACnet). For data of solar irradiation, temperature of water in PWST and the temperature of heat carrier in SC collection and outside air temperature an analog input BACnet objects are used. For exchanging of data in different formats an Extensible Markup Language (XML) was used [9].

For experimental data collection particular Neutrino BMS software modules were activated.

Post experimental analysis

As it was discussed before the experiment was running round the clock all year long. The recorded parameters were solar irradiation (SI), W/m^2; weather temperature outdoors (WT), °C; temperature of preheated water in the tank (STT), °C and temperature of domestic hot water (DHW), °C.

The total amount of data recorded was approximately 5 million records for each of the parameters. To make post experimental analysis more accurate, the following rules were applied:

1. Only days with sufficient solar irradiation (at least one solar collector's pump cycle occurred) were taken into account;
2. Only day-time was taken into account;
3. Only working hours were taken into account (DHW consumption).

These criteria gave us data of 76 days for further analysis.

As the data was constantly recorded (one record each 6 sec), we used a mean values of the parameters for further analysis: mean SI of the day, mean WT, mean STT and the mean temperature of DHW.

The first object was to find a correlation between mean values of solar radiation and the temperature of domestic hot water. The results are presented in Fig. 3.

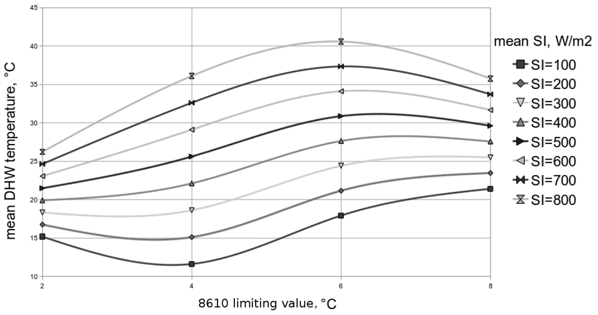

Fig. 3. Dependency of mean temperature of domestic hot water and mean solar irradiation

The results show that best results are achieved when combination *“8610 limiting value”=8* and *“8612 Xsd”=6* (when mean SI is below 400 W/m^2) is used. Combination *“8610 limiting value”=6* and *“8612 Xsd”=3* is more effective when mean SI is higher than 400 W/m^2. Other two combinations: *“8610 limiting value”=4*, *“8612 Xsd”=2* and *“8610 limiting value”=2*, *“8612 Xsd”=1* showed poor results at the same testing conditions and are not efficient. The dependency of mean DHW temperature from different “*limiting values*” at individual mean SI values is presented in Fig. 4. Here we see that combination of *“8610 limiting value”=8* and *“8612 Xsd”=6* is most efficient when mean SI is below 400 W/m^2 and combination of *“8610 limiting value”=6* and *“8612 Xsd”=3* is most effective when mean SI is above 400 W/m^2.

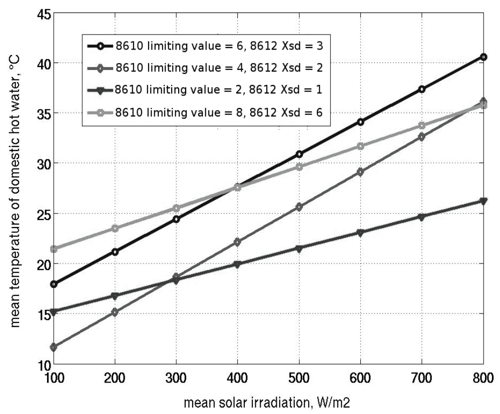

Fig. 4. Dependency of mean DHW temperature from different *limit* values at individual mean SI values

The further analysis of dependency of mean DHW temperature from mean SI and weather temperature outdoors gave us following result (1)

$$DHW = K_C + K_S \cdot SI + K_W \cdot WT, \quad (1)$$

where K_C=8.9052 °C; K_S=0.0122 °C/(W/m^2); K_W=0.6352.

The adequacy of (1) was checked using Fisher adequacy criteria (2) [7]. The result showed that expression (1) is adequate

$$F = \frac{S_d \cdot \varphi_2}{S_e \cdot \varphi_1}, \quad (2)$$

where φ_1 is degree of freedom of sum S_{d1} and φ_2 is degree of freedom of sum S_{d2}.

The experimental results of mean DHW vs mean SI and mean WT are presented in Fig. 5. Fig. 6 shows the approximated results using (1).

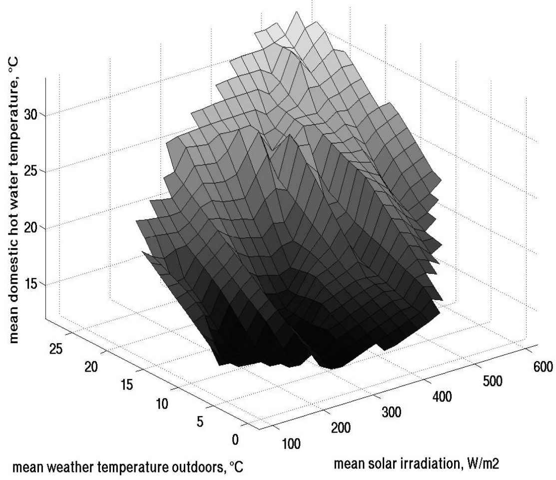

Fig. 5. Experimental results of mean DHW vs means SI and WT

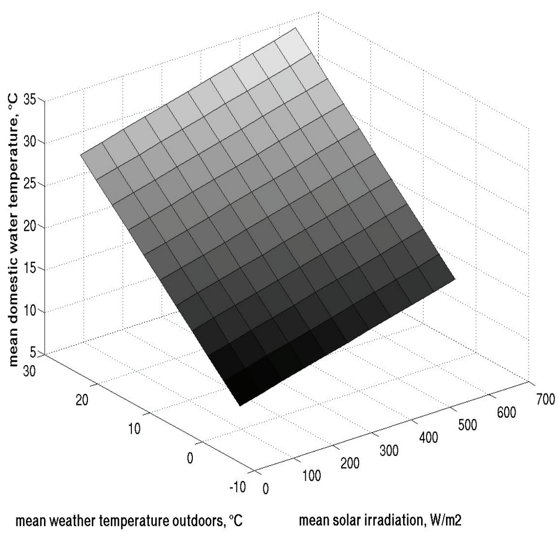

Fig. 6. Approximated dependency of mean DHW vs means SI and WT

Conclusions

1. Presently process of the fossil fuel substitution in district heating systems of Lithuania is mostly oriented on the biomass, however solar and wind energy is not taken into consideration.
2. Solar and wind energy technologies for generation of heat energy in Lithuania and other countries have a huge and untapped potential, which could be realised

with considerable benefit to environment and economy.
3. Presented installation of experimental research intended for optimization of water heating system control is based on SCADA Neutrino BMS, BACnet, XML and provided completely automated experimental research and data collection.
4. The appliance of control system Neutrino BMS collected the total amount 5 million of measurements for each of the parameters during one year. Only records of 76 days fit previously presented criteria for post-experimental analysis.
5. Analysis of experimental data shows that it is possible to predict mean domestic hot water temperature from mean solar irradiation and mean weather temperature outdoors. This may help optimize domestic heating system combining independent solar water heating system and other heat sources (e.g. central heating system, etc.).
6. Researches show that optimal domestic hot water heating results are achieved when pump cycle parameters "8610 limiting value" and "8612 Xsd" are equal *6* and *3* respectively when mean SI>400 W/m^2 and equal *8* and *6* respectively when mean SI<400 W/m^2.
7. Theoretical presumption of possibility to maximize solar energy harvesting by the developed control algorithm was confirmed experimentally.

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In this paper presents results of solar assisted hybrid water heating system's control algorithm experimental research. Main purpose of research - prove the ability of energy harvesting by modifying control algorithm. The main problem of experiments with renewable sources of energy is absence of ability to control the main parameter – solar irradiance. The automated data collection based on control station Neutrino BMD was engaged for experimental research of control algorithm. During 365 days of data collection about 5 million data points was recorded. According to presented criteria only records of 76 days were selected for post experimental research. The post experimental analysis shows that optimization of control algorithm allows energy harvesting in hybrid water heating systems by sliding control parameters according to solar irradiance. Ill. 6, bibl. 9 (in English; abstracts in English and Lithuanian).

G. Petrauskas, V. Adomavičius, A. Knyš. Hibridinės vandens šildymo sistemos su saulės kolektoriais valdymo algoritmo eksperimentinis tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 8(114). – P. 97–100.

Pateikti hibridinės vandens šildymo sistemos, naudojančios saulės energiją, valdymo modifikuoto algoritmo eksperimentinio tyrimo rezultatai. Esminė eksperimentų su saulės energija problema ta, kad negalima valdyti pagrindinio parametro – saulės apšvitos. Šiai problemai spręsti atliekama ilgalaikė eksperimento duomenų stebėsena. Visiškai automatizuotam eksperimentiniam tyrimui ir ilgalaikiam duomenų surinkimui buvo pritaikyta pastato valdymo sistema „Neutrino BMS". 365 dienas trukusio eksperimentinio tyrimo metu buvo automatiškai, pagal laiko programą, keičiami valdymo algoritmo parametrai ir įrašomi pagrindiniai duomenys. Per vienus metus trukusį eksperimentą valdymo sistema įrašė apie 5 milijonus įrašų. Apdorojant duomenis pagal saulės apšvitą, tik 76 dienų rezultatai pripažinti tinkamais toliau vertinti. Eksperimentinių duomenų analizė parodė, kad yra galimybė optimizuoti hibridinės vandens šildymo sistemos efektyvumą keičiant valdymo parametrus priklausomai nuo saulės apšvitos. Il. 6, bibl. 9 (anglų kalba; santraukos anglų ir lietuvių k.).