JSACE 2/11

Dimensioning of Solar Thermal Systems for Multi-Family Buildings in Lithuania: an Optimisation Study

Received 2015/01/07

Accepted after revision 2015/04/02

Dimensioning of Solar Thermal Systems for Multi-Family Buildings in Lithuania: an Optimisation Study

Rokas Valančius*, Andrius Jurelionis, Juozas Vaičiūnas

Kaunas University of Technology, Faculty of Civil Engineering and Architecture
Studentu st. 48, LT-51367 Kaunas, Lithuania

Eugenijus Perednis

Lithuanian Energy institute, Laboratory of Renewable Energy
Breslaujos str. 3, Kaunas LT-44403, Lithuania

*Corresponding author: **rokas.valancius@ktu.lt**

http://dx.doi.org/10.5755/j01.sace.11.2.12459

Small-scale solar thermal domestic hot water (DHW) systems in Lithuania can produce up to 523 kWh per year per one square meter of solar collector area. It is therefore one of the most common solar thermal applications in the country with the expected payback period of approximately 10 years. However, the number of solar water heating systems (SWH) installed in the renovated multi-family buildings is quite limited. On the other hand, the potential of integrating solar thermal systems in these buildings is much higher as DHW usage during the day is more uniform in multi-family buildings compared to the single-family houses. This aspect brings out a higher solar energy share without adding additional volume to the hot water storage tank. Simplified optimization tools for solar collector area selection, volume selection for the accumulation tank, installation costs and payback period estimation are required for promoting SWH systems for DHW production in multi-family buildings.

This paper deals with DHW consumption analysis in multi-family buildings in Lithuania as well as modelling of solar thermal systems to produce a tool for decision makers for preliminary analysis of SWH systems integration in renovated multi-family buildings. The main target group for the tool developed are multi-family buildings connected to district heating network. Simulation software "T*SOL 5.0 Pro" was used for SWH systems performance evaluation as well as financial analysis of SWH system alternatives.

KEYWORDS: solar thermal systems; water consumption; multi-family buildings; optimisation; dimensioning tool.

Journal of Sustainable Architecture and Civil Engineering
Vol. 2 / No. 11 / 2015
pp. 32-40
DOI 10.5755/j01.sace.11.2.12459

Introduction

Solar water heating (SWH) is one of the most common solar thermal applications. In 2012 the world added 55.4 GWth (more than 79 million m^2) of solar heat capacity (REN21, 2014) and the most popular types of solar collectors in EU and Switzerland are flat plate (89%) and evacuated tube (11%) collectors (ESTIF, 2013).

Only about 8200 m^2 (5740 kWth) of glazed solar collectors were installed till the end of 2013 in Lithuania and the applications were mostly limited to single-family buildings (ESTIF, 2013). Yet, average global solar irradiation in Lithuania is similar to the irradiation levels in such countries as Germany, Austria, Denmark, Poland, Latvia and Estonia with the annual potential of solar energy yield of approx. 1000 kWh/m^2. The daily potential in the country varies from 0.55 kWh in January to 5.8 kWh in June, therefore, almost the whole irradiated solar energy can be collected during the warm period of the year (from April till October). Due to this fact, solar water heating (SWH) systems are most efficient in domestic hot water (DHW) applications in Lithuania (Kytra, 2006). Nevertheless, technical-economic potential of solar heat energy production in the country reach up to 1.5 TWh/year (129 ktoe).

According to the meteorological data, the values of expected solar energy yield are increasing during the last decade as solar irradiation increased by 7% during the years of 2005 to 2014 compared to the long-term statistical data.

Some studies in Lithuania and in other similar countries of similar climate showed that small and medium scale solar DHW systems with flat plate or evacuated tube collectors can produce from 335 to 523 kWh/m^2 of thermal energy per year and the payback time of these systems is over 8 years without the subsidies. The potential of SWH for domestic hot water production is quite high, however, the support from government and EU funds is still necessary in most cases to achieve reasonable payback (Adomavičius, 2010; Ayompe and Duffy, 2013; Hugo and Zmeureanu, 2012; Jonynas and Valančius, 2010; Perednis et al., 2007; Valančius et al., 2015).

The number of medium-scale SHW systems in Lithuania is still relatively low at the time and represent the potential direction for development of these systems. There are several medium-scale SHW systems installed in the country varying from 60 to 204 m^2 of total solar panel area. Most of these systems are installed in the past few years in public buildings, hospitals and industrial facilities. The oldest still operational SHW system 77 m^2 was installed in 2002 in children sanatorium "Žibutė" (Kačerginė). However, it took 10 years for the first SWH system to be installed in multi-family building as the first such system was launched only in 2012 (Katinas et. al., 2013; Karbauskaitė and Perednis, 2011; Valančius et al., 2015).

Multi-family buildings represent one of the major potential for SWH installation as it is one of the best renewable energy alternatives for these buildings (Adomavičius, 2010; Diliunaite, 2013). More uniform DHW usage during the day is common for multi-family buildings compared to the single-family houses. It is related to variability of occupants and their hot water consumption habits and this aspect brings out a higher solar energy share without adding additional volume to the accumulation tank. Moreover, DHW consumption throughout the day presents the possibility to keep lower temperatures in the collectors even during periods of high solar radiation. Multi-family buildings provide a possibility to connect several users to the same combined SWH system, therefore the heat losses due to transformation and transportation of hot water will be incurred to a lesser extent during the system operation (Žandeckis et al., 2011).

The market growth of solar thermal systems and photovoltaics in Europe depends on the policy of the governments towards the use of solar energy systems. Considering the targets of EU for renewables in the 20-20-20 programme, solar energy systems can play a significant role in many countries (Caouris et al., 2012). When discussing multi-family buildings, government grants of up to 40% are currently offered in Lithuania for energy saving measures and usage of renewables in renovated buildings.

The major part of thermal energy used in multi-family buildings in Lithuania are supplied via the district heating network. 72.4% from all district heating produced energy was used for household purposes in 2012 (LŠTA, 2013) and the price in different cities varies in the range from 0,458 EUR/kWh to 0,901 EUR/kWh (LŠTA, 2015). The multi-family building stock in Lithuania can contribute to reduction of both greenhouse gas (GHG) emissions and energy consumption of the country significantly by integrating medium-scale SWH systems under the framework of renovation initiatives.

Relation between installation costs and area of the flat plate solar collectors (including heat storage tanks and auxiliary equipment) can vary in the range from 600 to 150 EUR/m^2 in SHW from 10 m^2 to 10000 m^2. The installation costs, annual maintenance and repairs costs vary in wide range depending on type of solar collectors and other equipment as well, but in general, larger SWH installations are relatively cheaper to maintain than small-scale SWH systems (Andrews et al., 2012; Leutgöb and Rammerstorfer, 2013). Additional costs for design of the systems in Lithuania add up to 8% from the installations costs. In some cases installing SWH systems in existing buildings can cost up to 20% more than in new buildings.

Several studies showed that despite the fact that evacuated tube and flat plate collectors are considered to be suitable for solar heating in Central European Climates, the evacuated tube collectors does not reach the additional expected energy yield (Trinkl et al., 2005). Flat plate collectors and evacuated tube collectors produce the same amount of energy from effective area during summer season in Lithuania, but it is much less expensive to use flat collectors in most cases (Ambrulevičius, 2005; Jonynas et. al., 2011). In recent years price of evacuated tube collectors is slowly decreasing and they are becoming increasingly popular. But there is still lack of efficiency and financial analysis for these collectors at the moment.

The guidelines performed in Germany showed that in general meeting 50% of the annual energy needs for DHW requires a collector area of 1-1.5 m^2 per apartment and about 50-60 l of solar heat storage per m^2 of collector surface (SOLARGE, 2007). The studies performed by Rodríguez-Hidalgo et al. (2012) and Kulkarni et al. (2007) showed that the optimal storage tank volume for medium-scale SWH systems are about 50 liters for 1 m^2 of collector field absorber area.

Considering the results of the above given studies and regional practice, decision making can be simplified by creating a user-friendly optimization tools for solar collector area selection, volume selection for the accumulation tank, installation costs and payback period estimation. Development of such a tool would promote medium-scale SWH systems in multi-family building sector.

The aim of this study was to simulate the performance of SWH systems for DHW production for Lithuanian climatic conditions and to produce a user-friendly tool to be used in decision making and quick estimation of performance of solar thermal applications. The main target group for the tool developed are multi-family buildings connected to district heating network. Simulation software "T*SOL 5.0 Pro" was used for SWH systems performance evaluation and the chart for estimation of SWH projects was developed. Solar energy yield and district heating energy price of Kaunas city was selected for the study.

Methods

Several assumptions and boundary conditions were utilized to develop the tool for user-friendly estimation of SWH system performance. Typical schemes of SWH systems selected for the study are presented in **Fig. 1** and can be characterized as hybrid solar thermal DHW systems. Both system "A" and system "B" are connected to district heating network as well as solar collectors. Antifreeze is used in the solar collector loop for heat transfer into the hot water storage tank. System "A" represents the simpler solution as cold water (CW) is stored in hot water tank while in case of the system "B" hot water tank works as heat accumulation device. The function of heat

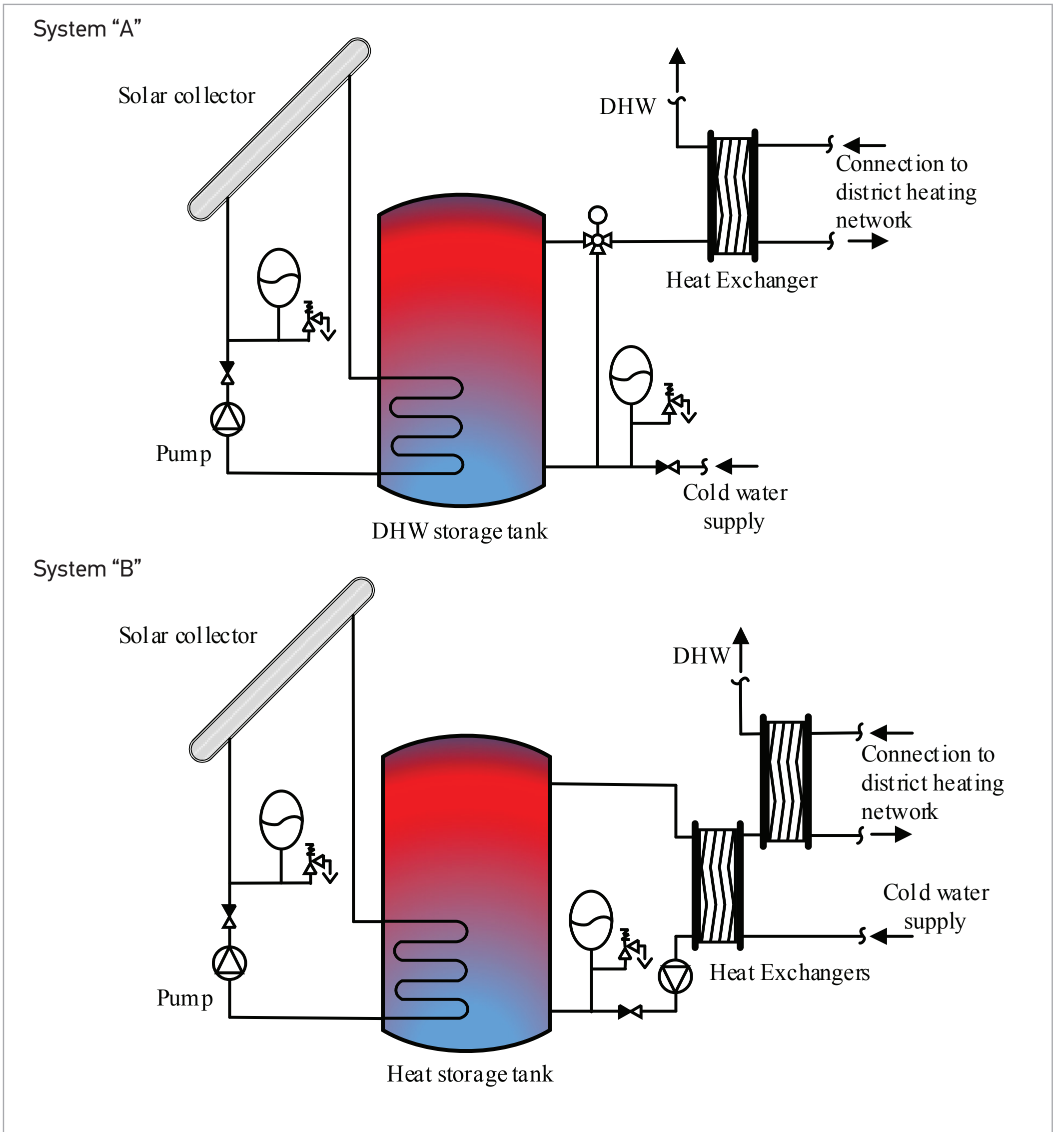

Fig. 1

Typical schemes of hybrid SWH system connection to domestic hot water distribution system and district heating network.

exchanger in the system "A" is to heat up the water in case of too low DHW temperature. This unit is also present in the system "B". However, the system "B" is equipped with the secondary heat exchanger which separates hot water tank loop from DHW loop. Therefore, no potable water is stored in the hot water tank. This ensures higher hygienic parameters of the DHW and lowers the risk of bacterial growth in the tank itself.

Both system "A" and "B" can be efficiently used in multi-family buildings. However, in this study the system "B" was selected as a better alternative due to lower risks of malfunction in case of insufficient maintenance.

Groundwater of average temperature equal to +8°C is used in Lithuania in water supply systems of buildings. Heating it up to +52°C is required for DHW supply. The energy demand for 1 m^3 of DHW preparation was assumed to be 51 kWh in the simulations.

The inclination angle of the solar collector should be 30°-60° and orientation to the South with the error of ± 20° to achieve maximum efficiency of the solar collectors should be ensured (Genutis, 2008). Orientation of the solar collector to the South with the inclination angle of 45°was used for

Table 1

Parameters used for the simulations of SWH systems.

Life span, years	20
Specific fuel costs, EUR/kWh	0.07
Specific electricity costs, EUR/kWh	0.14
Index for energy prices, % per year	3.0
Interest capital, %	2.5
Running costs, %	1.5

simulations of SWH systems in this study.

Total annual global irradiation in Kaunas city (55°32'0"N / 25°6'0"E) is equal to 984.9 kWh/m² which was the value used for performance simulations of SWH systems.

High efficiency flat plate collectors (optical efficiency of collector η_0 - 80 %) were selected for the simulations. The other parameters used for modeling SWH systems are presented in Table 1.

Simulations were carried out by using the software "T*SOL 5.0 Pro". This simulation tool with weather data and extensive product databases allows dynamic calculation of DHW fractions, energy balance and system efficiency as well as to design SHW systems to achieve economic efficiency, fuel savings, avoided CO_2 emissions.

The potential of SWH was estimated by using the DHW usage data from 15 multi-family buildings in Kaunas, Lithuania constructed between the years of 1946 to 1990. Number of flats and floors of the buildings varied in the range of 40-120 and 5-12 respectively. Vast majority of the analyzed flats were 30 to 90 m² area 2 bedroom apartments. The average number of occupants in one apartment was approx. 3.

Results

The potential of SWH was estimated by using the DHW usage data from 15 multi-family buildings in Kaunas expressed in monthly energy demand in kWh. The average consumption of DHW of temperature approx. equal to +53.5°C in the analyzed buildings was 2.47 m³ (±9.1%) per month and was lower compared to cold water consumption 3.86 m³ (±8.1%) per month. Average monthly consumption of both cold and hot water was more or less stable during the year with the exception of summer season when the water usage has decreased.

Monthly average energy demand for DHW heating, solar irradiation in Kaunas as well as the potential of solar energy yield considering the conversion factor of SWH system are presented in Fig. 2. It can be observed from Figure 2 that the typical solar collector area for one apartment should be around 1.7 m² to reach approx. 100% solar fraction in summer time.

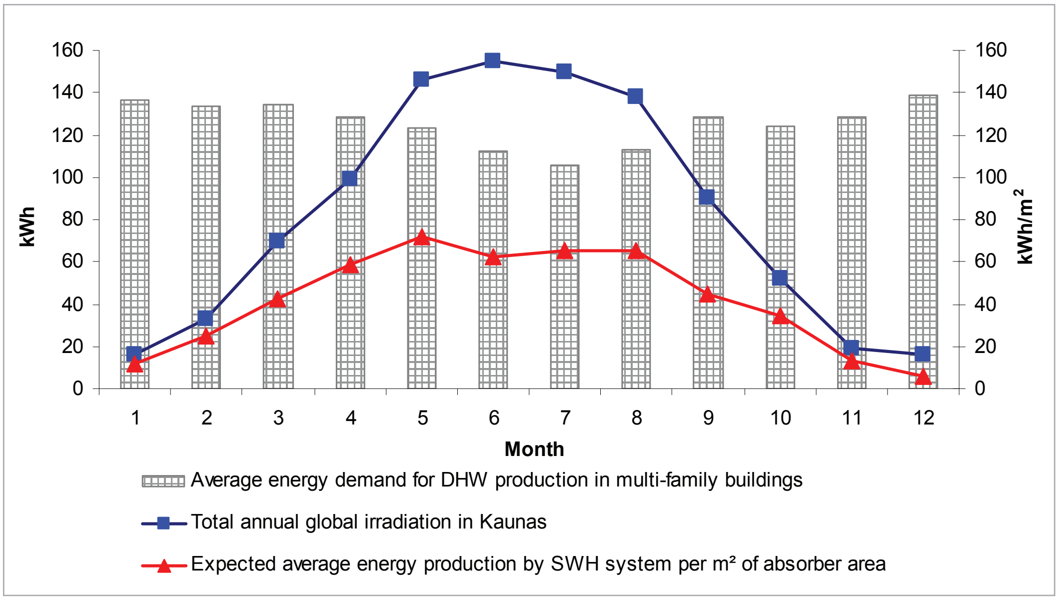

Fig. 2

Monthly average demand for DHW heating in 15 multi-family buildings in Kaunas (55°32'0"N / 25°6'0"E), solar irradiation (Kytra, 2006) and expected solar energy yield of SWH system

20 simulations were performed by using the “T*SOL 5.0 Pro” software to obtain relations between major parameters required to optimize SWH systems for DHW applications in multi-family buildings in Lithuania. The results of the simulations were expressed in the form of a chart utilizing several steps of SWH system estimation and are presented in Fig. 3.

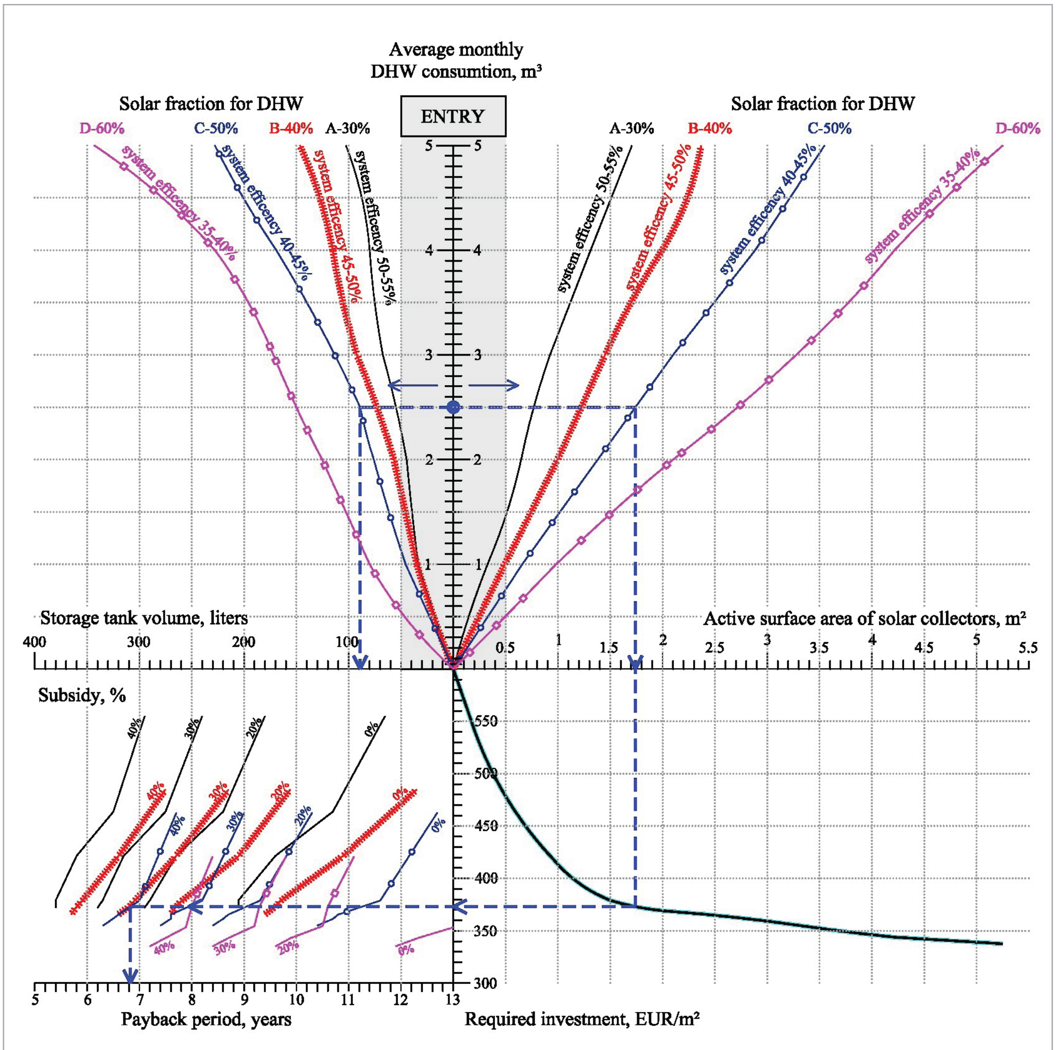

Fig. 3

SWH performance estimation chart comprising DHW usage per average apartment, optimal area of solar collectors and storage tank, required investment (without design costs) and payback period of the solar thermal system for multi-family buildings in Lithuania

The entry point of the chart is based on average monthly DHW consumption which is followed by selection of solar fraction for DHW. This is the parameter which can be selected by the decision maker as an additional input, namely the percentage of annual energy demand for DHW which will be covered by the SWH system (values from 30% to 60% were analyzed). Active surface area of solar collector, storage tank volume, expected system efficiency as well as required investment are obtained as a result. The payback period of the selected system can be obtained by knowing the percentage of subsidies for SHW system installation (values from 0% to 40% were used in the chart).

An example for such selection is provided in Figure 3 and the input and output data for this case is provided in Table 2.

Simulations showed that SHW systems in Lithuania can reduce GHG emissions from 92 to 147 kg $CO_2/m^2_{absorber}$ per year, when SHW systems efficiency varies from 35 to 55%.

Table 2

Input / output parameters and the steps of the procedure for the example case

Step No	Input		Output	
	Parameter	Value	Parameter	Value
Entry				
1	Average monthly DHW consumption	2.47 m^3	↓	
2	Solar fraction for DHW	50%		
3	↓		Efficiency of SWH system	40-45%
4			Storage tank volume per apartment	90 l
5			Surface area of solar collectors per apartment	1.7 m^2
6			Required investment	370 Eur/m^2
7	Subsidy	40%	↓	
8	↓		Payback period	6.8 years
End				

Conclusions and discussion

Analysis of domestic hot water consumption data showed that the average DHW demand for multi-family buildings in Lithuania is equal to 2.47 m^3 per month. According to the meteorological data for solar irradiation, active collector area of 1.7 m^2 and 90 l of heat storage tank volume per apartment are required to meet 50% of the annual energy needs for DHW production.

20 cases were simulated by using the "T*SOL 5.0 Pro" software to obtain relations between major parameters required to optimize SWH systems for DHW applications in multi-family buildings in Lithuania. SWH performance estimation chart comprising DHW usage per average apartment, optimal area of solar collectors and storage tank, required investment and payback period of the solar thermal system was developed as a result. The chart can be used by decision makers as a quick estimation tool for SHW installations in multi-family buildings. It may contribute to promoting SWH applications in multi-family building sector. Simulations showed that SHW systems in Lithuania can reduce GHG emissions from 92 to 147 kg $CO_2/m^2_{absorber}$ per year, when SHW systems efficiency varies from 35 to 55%.

It is important to note that the chart and data provided in this study is based on DHW consumption in the existing buildings in Lithuania, however the optimization procedure is solely based on simulation results. Numerical calculations show high potential of SWH application for DHW production in multi-family buildings and the data from existing buildings should be included in future studies to evaluate the difference between the results of the simulations and actual data from case studies. At the moment there is still lack of operational installations of this type equipped with monitoring systems to perform such an analysis.

Acknowledgment

The authors express sincere gratitude for JSC "Kauno vandenys" for guidance and help while working with the DHW consumption data from different multi-family buildings.

References

Adomavičius V. Atsinaujinančiųjų energijos išteklių naudojimo galimybės daugiabučiuose namuose [Possibilities for renewable energy usage in apartment buildings]. Lietuvos taikomųjų mokslų akademijos mokslo darbai: tarptautinis inovacinis taikomųjų mokslo darbų žurnalas = Official Journal of Lithuanian Applied Sciences Academy, 2010; 6: 107–122.

Ambrulevičius R. Saulės kolektorių sistemų eksploatavimo ypatumai [Exploitation peculiarities of sun collectors systems]. LŽŪU ŽŪI Instituto ir LŽŪ Universiteto mokslo darbai, 2005; 37(4): 54–69.

Ayompe L.M., Duffy A. Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate. Applied Thermal Engineering, 2013; 58: 447-454. http://dx.doi.org/10.1016/j.applthermaleng.2013.04.062

Andrews D. et al. Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion. EC Joint Research Centre. Luxembourg: Publications Office of the European Union, 2012. [accessed 5 May 2015]. Available from Internet: https://setis.ec.europa.eu/system/files/JRCDistrictheatingandcooling.pdf

Caouris Y. G., Rocco P., Zucchetti M. Situation and perspectives for solar energy in Europe and a comparison with nuclear energy, after Fukushima. Fresenius environmental bulletin, 2012; 21(11A): 3301–3311.

Diliūnaite A. Atsinaujinančių energijos šaltinių panaudojimo daugiabučiuose gyvenamuosiuose namuose tyrimas [Analysis of use renewable energy sources in living premises], in Proc. of the 16th Conference for Junior Researchers „Science – Future of Lithuania“, Statyba/ Civil Engineering, Vilnius, Lithuania, 2013.

ESTIF 2013. European Solar Thermal Industry Federation. Solar thermal markets in Europe - trends and market statistics 2013. June 2014 [accessed 5 May 2015]. Available from Internet: http://www.estif.org/statistics

Genutis A., et al. Atsinaujinantys energijos šaltiniai. Akademija, Kaunas, 2008.

Hugo A., Zmeureanu R. Residential solar-based seasonal thermal storage systems in cold climates: building envelope and thermal storage. Energies, 2012; 5(10): 3972-3985. http://dx.doi.org/10.3390/en5103972

Jonynas R., Valančius R. The comparison of two different solar collectors systems, in Proc. of EuroSun 2010 the International Conference on Solar Heating, Cooling and Buildings, Graz, Austria, 2010, 1–8.

Jonynas R., Valančius R., Šuksteris V., Perednis E., Mekas G. Study of medium scale solar water heating plants in Lithuania, in Proc. SES Solar World Congress, Kassel, Germany, 2011, 921–927.

Karbauskaitė J., Perednis E. Kačerginės vaikų sanatorijos šilumos energijos vartojimo mažinimo galimybės [Trends of energy consumption efficiency at the Kačerginė children's sanatorium]. Energetika, 2011; 57(1): 20–25. http://dx.doi.org/10.6001/energetika.v57i1.2040

Katinas V., Karbauskaitė J., Perednis E., Valančius R. Efficiency analysis of combined biomass and solar energy in Lithuania. Clean Technologies and Environmental Policy, 2013; 15(4): 667-676. http://dx.doi.org/10.1007/s10098-012-0534-x

Kytra S. Atsinaujinantys energijos šaltiniai. Kaunas: Technologija, 2006.

Kulkarni G. N., Kedare S. B., Bandyopadhyay S. Determination of design space and optimization of solar water heating systems. Solar Energy, 2007; 81: 958–968

Leutgöb K., Rammerstorfer J. Implementing the cost-optimal methodology in EU countries. Case study Austria. BPIE. 2013

LŠTA 2012. Lietuvos Šilumos tiekėjo asociacija. Šilumos tiekimo bendrovių 2012 metų ūkinės veiklos apžvalga. Vilnius. [accessed 11 May 2015]. Available from Internet: 2013. http://www.lsta.lt/files/statistika/19493_LSTA_Ukines%20veiklos%20apzvalga_2012_WEB.pdf

LŠTA 2015. Lietuvos Šilumos tiekėjo asociacija. Vidutinė šilumos kaina gyventojams (po perskaičiavimų) 2015.05.11 [accessed 12 May 2015]. Available from Internet: http://lsta.lt/lt/pages/apie-silumos-uki/silumos-kainos

Perednis E., Kavaliauskas A., Plikšienė V. Karšto vandens ruošimo naudojant saulės kolektorius efektyvumo tyrimai [Investigation of hot water utilization in solar collectors]. Energetika, 2007; 1: 34–38.

REN21. Renewables 2014. Global status report [accessed 5 May 2015]. Available from Internet: http://www.ren21.net/gsr

Rodríguez-Hidalgo M.C., Rodríguez-Aumente P.A., Lecuona A., Legrand M., Ventas R. Domestic hot water consumption vs. solar thermal energy storage: The optimum size of the storage tank. Applied Energy, 2012; 97: 897-906 http://dx.doi.org/10.1016/j.apenergy.2011.12.088

SOLARGE 2007. Solar heat for large buildings. Guidelines and practical examples for apartment buildings, hotels and business 2007 [accessed 8 May 2015]. Available from Internet: http://www.solarge.org/uploads/media/SOLARGE_Best_Practice_Catalogue_en.pdf

Trinkl C., Zörner W., Alt, C., Stadler C. Performance of vacuum tube and flat plate collectors concerning domestic hot water preparation and room heating, in Proc 2nd European Solar Thermal Energy Conference, Freiburg, Germany, 2005.

Valančius R., Jurelionis A., Jonynas R., Katinas V., Perednis E. Analysis of Medium-Scale Solar Thermal Systems and Their Potential in Lithuania. Energies, 2015; 8(6): 5725-5737. http://dx.doi.org/10.3390/en8065725

Žandeckis A., Timma L., Blumberga D., Rochas C. Possibilities for utilization of solar thermal energy in multi-family buildings in Latvia. Environmental and Climate Technologies, 2011; 6: 138-146 http://dx.doi.org/10.2478/v10145-011-0020-4

About the authors

ROKAS VALANČIUS

Lecturer

Kaunas University of Technology, Department of Building Energy Systems

Main research area

Renewable energy, indoor climate, energy performance in buildings

Address

Studentų st. 48, LT-51367 Kaunas, Lithuania
Tel. +37068010000
E-mail: rokas.valancius@ktu.lt

ANDRIUS JURELIONIS

Assoc. Professor

Kaunas University of Technology, Department of Building Energy Systems

Main research area

Indoor climate, HVAC technologies, energy performance in buildings, renewable energy

Address

Studentų st. 48, LT-51367 Kaunas, Lithuania
Tel. +37068391004
E-mail: andrius.jurelionis@ktu.lt

JUOZAS VAIČIŪNAS

Lecturer

Kaunas University of Technology, Department of Building Energy Systems

Main research area

Water supply and disposal systems, hydronic performance of HVAC systems, structural stability of buildings

Address

Studentu st. 48, LT-51367 Kaunas, Lithuania
Tel. +37061556760
E-mail: juozas.vaiciunas@ktu.lt

EUGENIJUS PEREDNIS

Senior Research Associate

Lithuanian Energy Institute, Laboratory for Renewable Energy and Energy Efficiency

Main research area

Energy efficiency of buildings, renewable energy

Address

Breslaujos st. 3, 44403 Kaunas, Lithuania
Tel. +37037401813
E-mail: saule@mail.lei.lt