DE GRUYTER OPEN
DOI: 10.1515/agriceng-2016-0067

ISNN 2083-1587; e-ISNN 2449-5999
2016,Vol. 20,No.4, pp.85-99
Agricultural Engineering
www.wir.ptir.org

COMPARISON OF APPLICATIONS SUPPORTING SELECTION AND DESIGN OF HOUSEHOLD SOLAR COLLECTOR SYSTEMS

Przemysław Kobel*[a], Leszek Romański[a], Jerzy Bieniek[a], Przemysław Bukowski[a], Agnieszka Martynowicz[b]

[a] Institute of Agricultural Engineering, Wroclaw University of Environmental and Life Sciences
[b] V-projekt, Wrocław

* *Corresponding author: e-mail: przemyslaw.kobel@up.wroc.pl*

ARTICLE INFO

Article history:
Received: April 2016
Received in the revised form: June 2016
Accepted: August 2016

Key words:
solar energy,
solar collector systems,
collectors,
design

ABSTRACT

In order to support the designing process and selection of subassemblies of an installation, specialist application programs are created. Selected applications were compared in the paper through their use for designing hypothetical solar collector systems for a single family house with a varied number of household members. With the use of particular applications, calculations for the same input assumptions were made. Results obtained with the use of a traditional calculation method were a reference point. Applications were compared on account of the type and amount of input parameters which may be introduced, type and number of determined values and their value. Based on the obtained results usefulness and scope of use of an application were assessed.

Introduction

Solar energy on account of its availability is one of the most popular form of obtaining renewable energy and one of the purest energy kind obtained without detriment to natural environment. Its dominance over other forms consists in the fact that it may be practically used in each household and each facility. It may be changed into electric energy or into heat. Currently, conversion into heat has higher performance than conversion of solar radiation into electric energy. This performance is at the average of 40-50% (Romański, 2013), and according to Trząski and Wiszniewski (2009) it may be even up to 60%. The value of performance strictly depends on the angle of solar radiation incidence on a collector (Latała, 2006; Averowa and Avezow, 2009) and direction towards the sun. It should be also taken into consideration that performance decreases along with the increase of temperature difference between the working factor and the surroundings (Neupauer and Magiera, 2009; Jeleń, 2013). In our climate, heating hot utility water is the most effective utilization of solar energy (Dąbrowski et al., 2006). Main elements of a typical heating installation consist of collectors, pump, container collecting heated water and control equipment. In case of an installation equipped with flat-plate collectors it is assumed that its cost should be returned after 6-8 years with the use of aid. A manner of calculation of expenditures and costs related to construction of an installation may be found in the paper by Dąbrowski (2009).

In reality, the return period is longer since the authors do not take into account the fact of credit management (in Poland using a subsidy means the necessity of taking a loan) and the need of paying wealth tax i.e. subsidy amount tax. In the near future installations will be equipped with the so-called trackers, namely systems which allow tracking the sun location and placing collectors in the optimal position towards the radiation source (Dehmlow, 2011; Obstawski, 2013). Presently, such installations with regard to a driving system and control system practically are not yet widely used.

The main task of a designer of solar collector systems is an optimal selection of basic elements of the system based on the correctly accepted output data. On the market there are numerous computer applications, which considerably simplify design works, inter alia, through selection of the size of collectors, elements of an installation and determination of working parameters.

The objective of the paper was to analyse the results determined with the use of the selected widely available applications which may be obtained from producers of solar collector systems and to compare them to the authors' own calculations.

Object of research

General characteristic of the investigated applications

1) Selection modulus in ESOP program

Professional design program ESOP is designed for designers and installers (www. 1). *Selection assistant* is a part of this program. This tool allows initial selection of the size of a collector for the set conditions. A developed interface enables setting many input parameters. A comparative analysis of several variants of an installation is possible. One selected by a user constitutes a basis for simulation of the energy effect and further detailed design calculations. The program is developed and its usage requires professional knowledge and experience. Access to full functionality of the program is possible after obtaining a commercial license.

2) On-line Viessmann calculator

This calculator is made available on the webpages of the company and designed for potential clients (www. 2). It allows estimation of the collector size, selection of collectors from Viessmann's offer and calculation of energy and ecological effects resulting from the use of collectors. The calculator enables setting many input data with the use of a simple interface operation in which subsequent parameters are set "step by step". Results are presented in the form of schematic diagrams, plots and lists. Visible comments explain further stages of selection.

3) Viessmann calculation sheets

These are two Excel calculation sheets - one for flat collectors Vitosol F, the second one for Vitosoll T vacuum collectors (www. 3). They enable selection of the collector size and determination of basic parameters of the collector elements. Calculations have an approximate nature and are based on two input data (number of household members and costs of installation). The course of calculations is invisible and unavailable for a user.

4) On-line Viessmann calculator

This calculator is made available on the webpages of the company and designed for potential clients (www. 4). It allows approximate determination of the surface of collectors (only of flat-plate ones). The calculator enables setting basic input data. Remaining parameters are accepted as constant. The enclosed description explains the manner of using a calculator and provides the accepted assumptions.

5) On-line Fakro calculator

This calculator is available on the web pages of the company and designed for potential clients. It allows estimation of the size of a collector, selection of collectors from Fakro offer (only flat-plate ones but compatible with roof windows of this company) and calculation of energy effects, resulting from the use of collectors. The calculator enables setting many input data with the use of a simple operation interface in which all parameters are seen in one panel. Results are presented in the form of plots and lists. This application carries out a detailed list of the elements of an installation (including fittings).

Methodology

A comparative analysis was divided into three stages:

– The objective of the first one was determination of functionality of each application and quality and quantity determination of the possible scope of input and output data. Results of these analyses were reflected in table 1 and 2.
– The second stage aimed at detailed comparisons of the results of selection of collectors and HUW (Hot Utility Water) dispenser through specific applications (see table 3 and 4). Calculations with the use of each of them were carried out for the same input data. They were accepted as to reflect real conditions, in which installation can operate. Values were selected so as to set them in each analysed applications which will ensure comparable conditions of assessment. These data include:
  - location: Wrocław (51,1°N, 17,0°E),
  - facility type: a single-family house,
  - roof orientation: southern,
  - roof inclination angle: 45º,
  - designation of a solar installation: heating HUW,
  - collector type: flat or vacuum,
  - number of household members: 5 persons,
  - daily consumption of water per one person: 50 dm^3,
  - required HUW temperature: 45ºC,
  - average temperature of supplying water: 10ºC,
  - HUW circulation: no,
  - degree of covering energy demand with HUW in a year: 60% (0.6),
  - second source of heat: furnace supplied with natural gas E group (GZ-50).

A reference, to which results obtained due to selection application programs, were compared, constituted authors' own research, the course of which was presented below.

For these calculations annual solar radiation on the surface of a collector was determined with the use of PVGIS (www. 6) system and it was 1280 $kWh \cdot m^{-2}$.

General efficiency of a thermal solar collector system was at the average level for real installations as 30% (0.3) for flat-plate collectors and 45% (0.45) for vacuum collectors.

The basis for selection of collectors was determination of the required active surface at the use of the relation:

$$F = \frac{Q_{wr} \cdot W_p}{E_r \cdot \eta_i} \tag{1}$$

whereas:

$$Q_{wr} = 365 \cdot n \cdot V_{wj} \cdot c_w \cdot (T_{wc} - T_{wz}) \tag{2}$$

where:

- F – active surface of collectors, (m^2)
- Q_{wr} – annual demand for heat for HUW heating, (kWh)
- W_p – degree of demand coverage,
- E_r – annual solar radiation, ($kWh \cdot m^{-2}$)
- η_i – efficiency of collector installation,
- n – number of people using water, (os)
- V_{wj} – unit HUW consumption, ($dm^3 \cdot os^{-1} \cdot d^{-1}$)
- T_{wc} – hot water temperature, (°C)
- T_{wz} – cold water temperature, (°C)
- c_w – volumetric appropriate thermal volume of water: $c_w = 1.16 \cdot (Wh \cdot dm^{-3} \cdot {}^{o}C^{-1})$.

The next step consisted in selection of typical collector annual heat yield Q_{kr}, (kWh) was calculated and the energy demand degree of HUW with the use of the following relation:

$$Q_{kr} = F \cdot E_r \cdot \eta_i \tag{3}$$

$$W_p = \frac{Q_{kr}}{Q_{wr}} \tag{4}$$

Thus, a possibility of realization of the assumed degree of coverage with the use of available collectors was verified.

The required volume of a HUW container was calculated with the use of the following relation:

$$V_{zas} = 1{,}5 \cdot n \cdot V_{wj} \tag{5}$$

Based on the result, the size of the container was selected from among the typical ones.

The third stage aimed at comparing results of a system at a variable number of household members.

An independent variable was the number of persons n accepted within 2 and 8. The remaining input data and the method of calculations were the same as in the second stage. The following dependent variables were selected: the surface area of collectors F, m^2, surface area of collectors per one person f, $m^2 \cdot os^{-1}$. Degree of demand coverage $W_{p,}$ and the volume of the HUW container V_{zas}.

Research results

Comparing applications on account of functionality were presented in tables 1 and 2. Analysed applications differed considerably with regard to possibility of introduction of input data. Differences were noticeable in the number and type of parameters, manner of introduction (e.g. entering, selection from the list, "adjuster"), scope and resolution of particular parameters (table 1).

Table 1.
Type and manner of input data introduction to application

Specification	ESOP program	Viessmann online calculator	Viessmann calculation sheets	Vaillant on-line calculator	Fakro on-line calculator
Location:	selection from the world list	selection from Poland	—	permanent annual solar radiation 1000 kWh·m^{-2}	selection from the list for Europe
Roof orientation	circumferentially every 45º	selection (0, ±25º, ±45º)	—	east÷west every 15º	numerically scope–90÷90º
Roof inclination	numerically scope–0÷90º	selection every 15 scope– 0÷90º	—	selection (30º, 50º,70º)	numerically scope–90÷90º
Collector type	flat and vacuum	flat and vacuum	flat or vacuum	only flat	only flat
Collector type	selection from among the company's offer	3 types to choose from	Vitosol type F or T	—	selection from among the company's offer
Number of people	number of people or total consumption	number of people or total consumption	numerically scope 2÷15	selection scope 2÷8	numerically scope 0÷20
Daily HUW consumption			—	selection 30/50/70 dm^3/os	scope in numbers 0÷100 dm^3/os
HUW temperature	in numbers 40÷70ºC	in numbers	—	45ºC	scope in numbers 0÷90ºC
Temperature of supplying water	summer and winter in numbers scope 5÷35ºC	—	—	10	—
HUW circulation	yes/no	yes/no		yes/no	—
Coverage of demand	in numbers scope 10÷80%	—	—	50% or 60%	—
Fuel of supporting furnace	selection various fuels	selection oil/gas/el.	—	—	selection various fuels
Static height	in numbers	—	in numbers	—	in numbers
Additional options	CO heating	—	—	—	CO and pool heating

— a given value cannot be introduced

Also the number, type and method of presentation of results of collector's selection were considerably different than for particular applications. A part of applications carried out additionally selection of other elements of installation. A comparative list was presented in table 2.

Table 2.
Calculation of values and method of their presentation

Specification	ESOP program	Viessmann on-line calculator	Viessmann calculation sheets	Vaillant on-line calculator	Fakro on-line calculator
Result of selection of collectors	number of items actual area	calculated area number of items actual area	number (flat) area (vacuum)	only calculated area	number of items actual area
Energy and ecological effects					
Amount of heat from installation of collectors	total distribution in a year	—	—	—	Total
Satisfaction of demands	average distribution in a year	average distribution in a year	—	—	average distribution in a year
Efficiency of an installation	average distribution in a year	—	—	—	—
Savings of fuel	total distribution in a year	—	—	—	—
Reduction of pollutants emission	CO_2 total and distribution	CO_2 CO NO_X SO_2 sums	—	—	—
Selection of installation elements — result is not provided ☼ result is provided					
HUW container	☼		☼	—	☼
Expansion vessel	—	—	☼	—	☼
Pump	—	—	—	—	☼
fittings	—	—	—	—	☼
Amount of agent	—	—	☼	—	☼
Pressure in installation	—	—	☼	—	—
Possibility of saving results in a file	yes	yes	no	no	Yes

Results of the second stage, where the values which characterize compared installations obtained from selection applications were set in table 3 for flat-plate collectors and in table 4 for vacuum collectors.

Table 3.
List of results of selection for flat collectors

Specification	own calculations			ESOP program		Fakro on-line calcula-tor	Viess-mann calcula-tion sheet	Vaillant on-line calcula-tor	Fakro on-line calcula-tor
	referen-ce	variant 1	variant 2	variant 1	variant 2				
Collectors type	—	Vitosol 100-F	Vitosol 100-F	Vitosol 100-F	Vitosol 100-F	Vitosol 100-F	Vitosol F	—	SKW 114x20 6
Number of col-lectors	—	*2*	*3*	2	3	2	2	—	4
Active surface of collectors, (m^2)	5.81	4.66	6.99	4.66	6.99	4.6 calcula-ted 5.1	4.66	7.00	8.28
Annual yield of heat, (MWh)	2.23	1.79	2.68	1.96	2.39	—	—	—	3.08
Degree of satis-faction of de-mand CWU, (%)	*60*	48.1	72.2	50.1	60.1	59.5	—	*60*	74
General efficien-cy of collector installation, (%)	*30*	*30*	*30*	35.1	28.5	—	—	***30***	—
CWU container volume, (dm^3)	375	375	375	500	500	200	400	—	400

XX – values assumed, ***XX – value imposed by application***

Table 4.
List of results of selection for vacuum collectors

Specification	Own calculations			ESOP program		viessmann on-line calculator	Viessmann calculation sheet
	reference	variant 1	variant 2	variant 1	variant 2		
Collectors type	—	Vitosol 200-T 3 m^2	Vitosol 200-T 2 m^2	Vitosol 200-T 3 m^2	Vitosol 200-T 2 m^2	Vitosol 200-T	Vitosol T
Number of collectors	—	1	2	1	2	2	—
Active surface of collectors, (m^2)	3.87	3.23	4.30	3.23	4.30	4.0 calculated 3.7	4.00
Annual yield of heat, (MWh)	2.23	1.86	2.48	1.92	2.32	—	—
Degree of demand coverage of HUW, (%)	*60*	50.1	66.6	49.1	58.6	60.1	
General efficiency of collector installation, (%)	*45*	*45*	*45*	49.5	44.9	—	—
Cubic capacity HUW container, (dm^3)	400	400	400	500	500	300	400

XX – values assumed, ***XX – value imposed by application***

The main objective of the compared application programs for selection of solar installations is to determine the required surface area of collectors. It is proportional to the heat demand and thus – to the the number of people using heated utility water (Fig. 1). The required area per one person is permanent (Fig. 2). Finding the size of collectors which precisely meets the assumed degree of coverage of the HUW demand is not always possible. Selected collectors may be undermeasured or overmeasured (it is the most noticeable in case of systems designed for 2 persons) in comparison to demands (Fig. 3). At the assumed degree of coverage 60% use of too big collectors will result in excessive heat production in the summer time, thus, selection of smaller collectors is recommended.

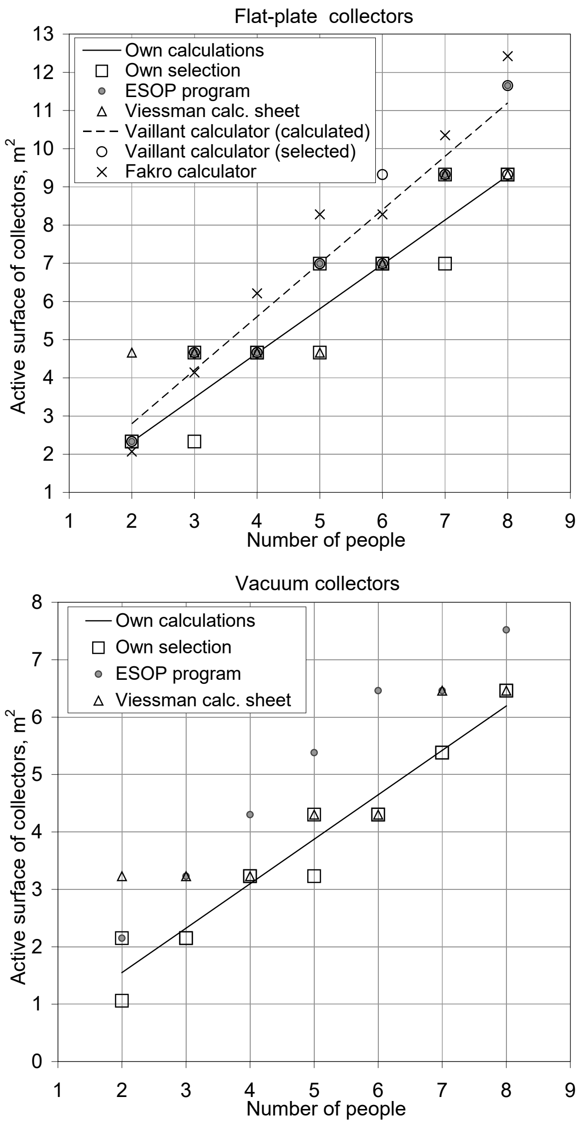

Figure 1. Selected surface area of collectors in relation to the number of household members

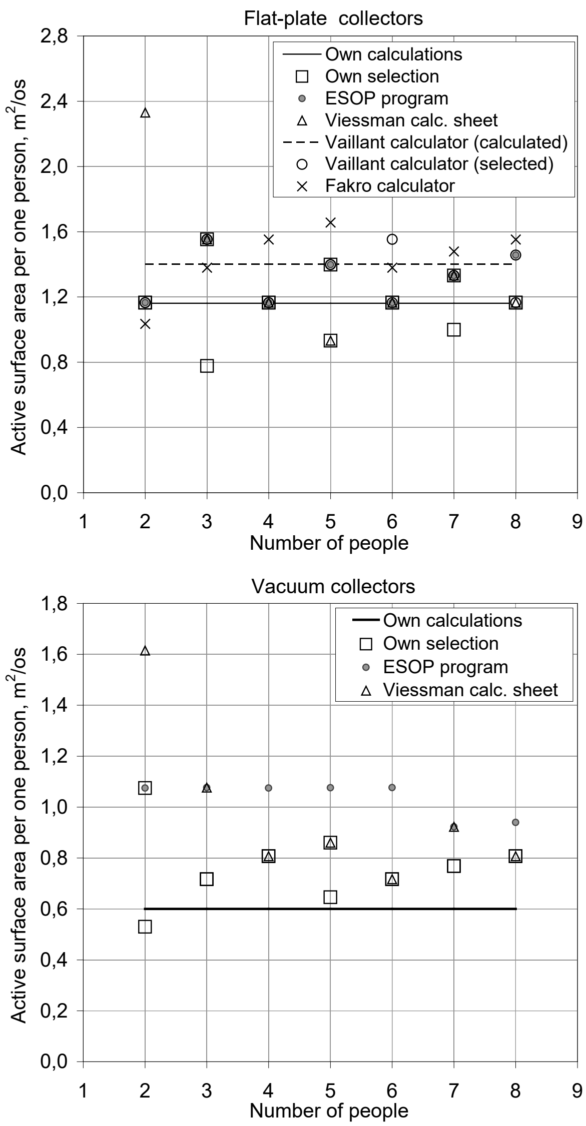

Figure 2. Surface area of collectors per one person in relation to the number of household members

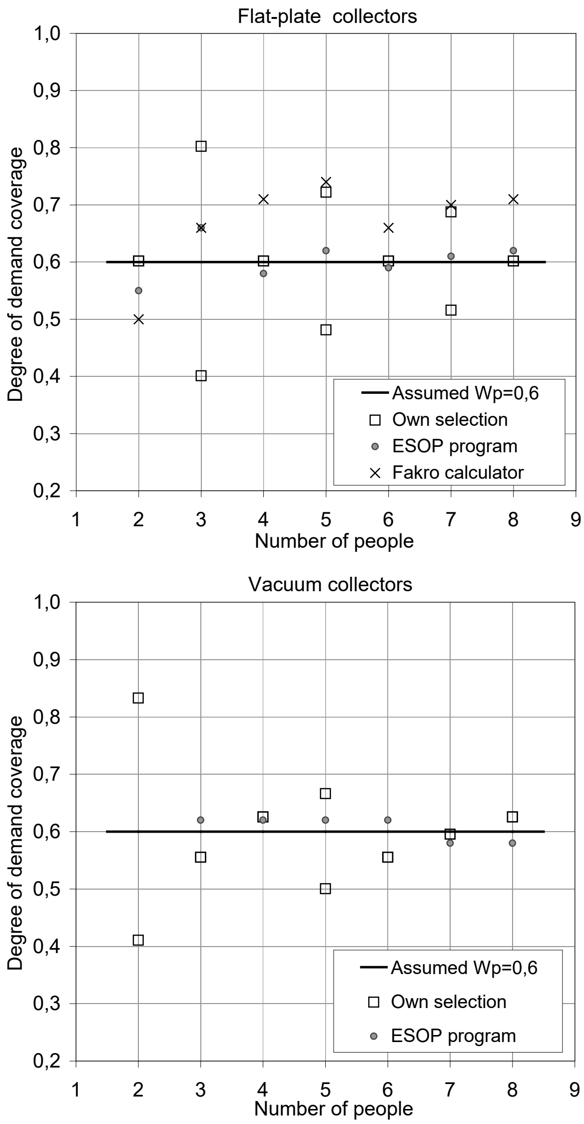

Figure 3. Degree of satisfaction of demands by collectors in relation to the number of household members

Installations with vacuum collectors have a higher average annual efficiency than those with flat ones. As a result the required surface area of vacuum collectors is lower (fig. 4).

Theoretical required cubic capacity of HUW container is also proportional to the number of people who use the installation (fig. 5). Containers with typical cubic capacities are available for selection (e.g. in Viessmann it is 300, 400 and 500 dm^3) They result in the reduction of effectiveness of the collector installation operation.

Summary and conclusions

Selection application programs, which aid designing of solar installations, differ considerably with functionality. Some of the comparable applications allowed selection of both collectors and the remaining elements of an installation (in a varied scope). Others were limited only to collectors.

The most simplified and the poorest on account of the calculated data is Vaillant on-line calculator. Fakro on-line calculator has the biggest number of input parameters and calculated results.

Viessmann sheets of selection of solar installation elements contain a lot of information on the elements of an installation; however, on account of a small number of input parameters their determination has an approximative character. Results obtained from particular programs are similar and similar to the authors' own calculations on account of the determined required surface area of collectors and thermal parameters of an installation (e.g. degree of coverage, efficiency). On the other hand, results obtained from the application program of solar installation elements have an approximate nature and serve for initial selection of parameters of an installation.

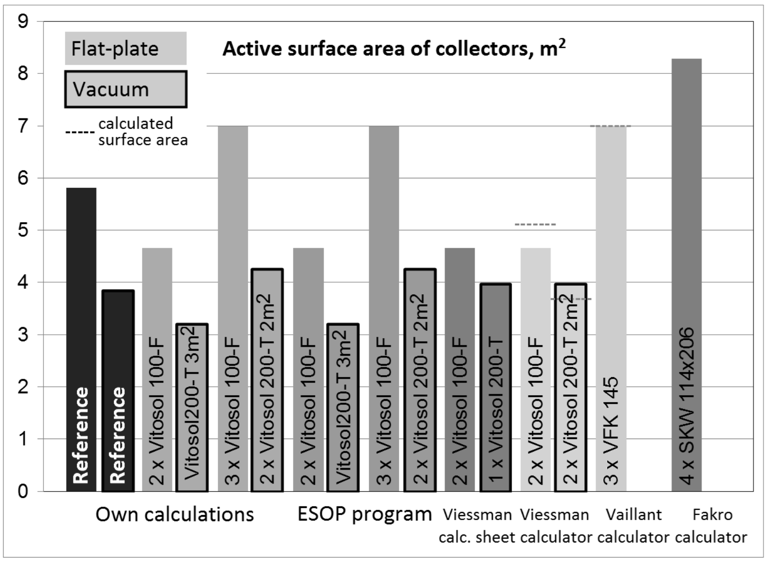

Figure 4. Comparison of the selected active surface

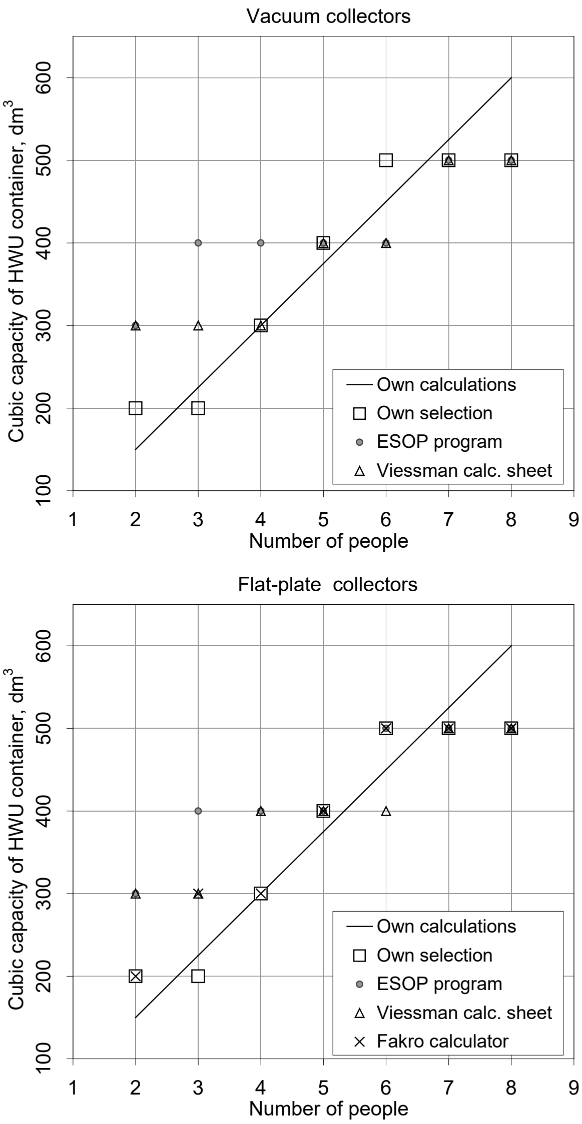

Figure 5. Selected cubic capacity of HUW container in relation to the number of household members

Professional calculation programs, such as ESOP allow precise verification of author's own calculations or results of automatic selection including the impact of many factors, due to simulation which may be applied.

All selection calculations and simulations have a model nature - they include simplifying assumptions and are based on the approximated or averaged data (e.g. concerning meteorological conditions). Therefore, effects obtained from real, made systems may differ from assumptions and results of calculations.

References

Avezova, N., Avezov, R. (2009). Impact of solar radiation attenuation coefficient of translucent cover material on heat efficiency of translucent cover-radiation absorbing heat-exchange panel system of flat solar collectors. *Applied Solar Energy*, 4, 28-31.

Dąbrowski, J., Hutnik, E., Tatko, R. (2006). Szacowanie ilości cieplnej możliwej do pozyskania przez kolektory słoneczne. *Inżynieria Rolnicza, 2*(66), 205-212.

Dąbrowski, J. (2009). *Kolektory słoneczne do podgrzewania wody użytkowej. Efektywność i opłacalność inwestycji.* Wrocław, Wydawnictwo UP, ISBN 978-83-60574-77-5.

Dehmlow, M. (2011). Affordable Universal Solar Tracker. ASME 2011 *5th International Conference on Energy Sustainability*. Washington, DC. Paper No. ES2011-54379, pp. 653-661.

Jeleń, I. (2013). *Sprawność kolektora słonecznego w badaniach i w praktyce*. Instal Reporter, 3, 50-54. Obtained from: http:/instalreporter.pl.

Latała, H. (2006). Sprawność kolektora cieczowego w funkcji kąta padania promieniowania słonecznego. *Inżynieria Rolnicza 11(86)*, 299-306.

Neupauer, K., Magiera, J. (2009). Analiza sprawności kolektorów słonecznych różnych typów. *Czasopismo techniczne*. *Chemia*, *1-Ch, z. 4*, 57-65.

Obstawski, P. (2013). *Identyfikacja parametryczna w diagnostyce słonecznych instalacji grzewczych.* Warszawa, Wydawnictwo SGGW, ISSN 9788375834420.

Romański, L. (2013). *Odnawialne źródła energii.* Wrocław, Oficyna Wydawnicza ATUT.

Trząski, A., Wiszniewski, A. (2010). Kolektory słoneczne. Obtained from: www. citesonpower.eu/upload/ file/kolektory.pdf

Web pages:

(www 1) http://www.viessmann.pl/pl/informacje-dla/projektanci-i-architekci/oprogramowanie.html

(www 2) http://www.kotly.pl/doborkolektora/

(www 3) http://www.viessmann.pl/pl/informacje-dla/projektanci-i-architekci.html

(www 4) http://ag-dar.vaillant-partner.pl/kalkulatory-on-line/kalkulator-doboru-plaskich-kolektorow-slonecznych-dla-podgrzewania-cwu/

(www 5) http://calculator.fakro.com/

(www 6) http://re.jrc.ec.europa.eu/pvgis/

PORÓWNANIE APLIKACJI WSPOMAGAJĄCYCH DOBÓR I PROJEKTOWANIE DOMOWYCH INSTALACJI SOLARNYCH

Streszczenie. W celu wspomagania procesu projektowego oraz doboru podzespołów instalacji tworzone są specjalistyczne aplikacje komputerowe. W pracy porównano wybrane aplikacje poprzez wykorzystanie ich do projektowania hipotetycznej instalacji solarnej dla domu jednorodzinnego przy różnej liczbie mieszkańców. Przy użyciu poszczególnych aplikacji wykonano obliczenia dla tych samych założeń wejściowych. Odniesieniem były wyniki uzyskane przy zastosowaniu tradycyjnej metody obliczeniowej. Aplikacje porównano pod względem rodzaju i ilości możliwych do wprowadzenia parametrów wejściowych, rodzaju i ilości wielkości wyznaczanych, a także ich wartości. Na podstawie uzyskanych wyników oceniono przydatność i zakres stosowania aplikacji.

Słowa kluczowe: energia słoneczna, instalacje solarne, kolektory, projektowanie