POTENTIAL OF USING SOLAR ENERGY FOR HOT WATER SUPPLY OF GEORGIAN POPULATION. DIAGRAMS AND CLASSIFICATION OF CONTEMPORARY HELIO SYSTEMS

T. MIKIASHVILI, T. JISHKARIANI, G. ARABIDZE, O. KIGURADZE, B. CHKHAIDZE, R. KANDELAKI

Association of Georgian Energy Engineers

Results of systematization of diagrams of contemporary thermal (technologic) helio systems, classification of helio systems and comparative characteristics are provided. Power consumptions necessary for hot water supply of Georgian household sector and efficiency of using helio systems for these purposes are evaluated: structure of power consumed by Georgian population for hot water supply and ecological figures of its transformation obtained under experts evaluations based on particular assumptions are shown; savings achievable in the household sector by replacing the existing potentialities of the hot water supply by the solar energy are evaluated and investment effectiveness of the helio systems in case of such replacement are analyzed; prices of water heating helio systems at local and world markets are given. Simplified method for evaluating the space of solar collector absorption surface and hot water tank capacity – the main elements of helio equipment which are required for one average statistic (four member) family in Georgia is proposed.

Key words*:* helio system, insolation, hot water supply, solar collector, hot water tank.

1. Introduction

Usage of renewable energy resources at this stage is quite a an important issue for both power industry and household sector. Renewable Energy Technologies are widely introduced in various fields of human beings' activity. However, such technologies are often called unconventional, the majority is based on just very conventional energy source, i.e. solar energy which has the oldest history. Usage of the solar energy for household purposes is extremely topical and effective in many countries. For example, the share of the helio equipment in particular cities of the world[1] is shown on Figure 1. As it is obvious from Figure 2, Georgia is located in high insolation 5) and 6) zones (1200-1400 kW*hr (m*sec)) providing good conditions to effectively use the solar energy in the country. Preliminary assessment and analysis are necessary in order to realize such conditions.
Research works to study the potential of using the solar energy were performed within the frame of various projects[2] implemented in Georgia in the past years. However, the evaluation works need to be updated from time to time due to the enhanced development of helio equipment technologies and solar collector technique as well as due to significant changes in their costs.

---

[1] www.retscreen.net

[2] a) Least Cost Plan for Energy Sector. Georgia, 1998, Burns and Roe, ICF Kaiser, American Electric Power, Harza Engineering Company, Center for Energy Efficiency

b) In-depth Review of Energy Efficiency Policies and Programmes of The Republic of Georgia/Energy Charter Protocol on Energy Efficiency and Related Environmental Aspects (PEEREA)/ENERGY CHARTER SECRETARIAT, 2006

c) USAID/WINROCK/World Experience for Georgia/Under Sub-Agreement 5708-07-04/ "Renewable Energy Potential in Georgia and the Policy Options for Its Utilization".2008

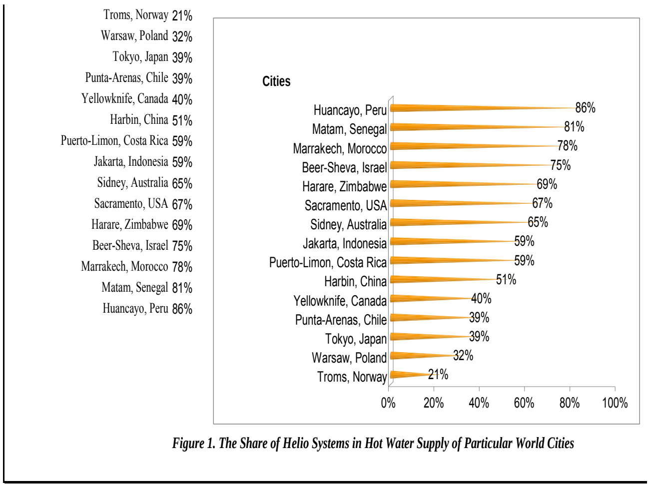


Figure. 1. Share of Helio Equipment in Hot Water Supply of Particular Cities of the World

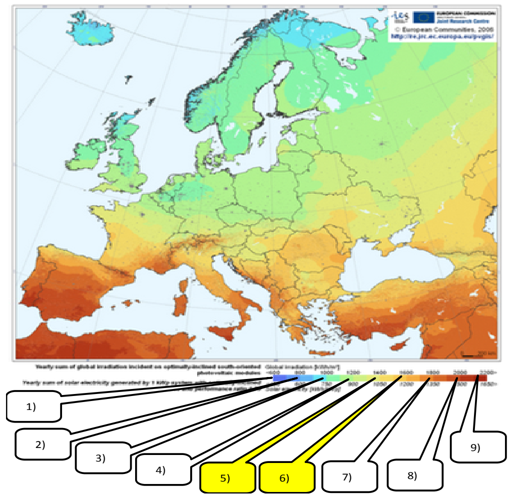


Figure. 2. Insolation Within Various Zones of Eurasia, kW*hr (m*min):
1)-600÷400; 2)-600÷800; 3)-750÷1000; 4)-800÷1200; 5)-1200÷1400; 6)-1300÷1400; 7)-1350÷1800; 8)-1500÷2000; 9)-1150÷2200.

2. Work Objective

Given the above, it is the intent of the authors to systemize thermal P&ID of the helio systems available at the world market and classify the equipment as per different features, and on the other hand, to evaluate power consumptions required for the hot water supply of Georgian population and determine technical and economic efficiency to use solar systems for such purposes.

3. Heating and Helio Systems of Hot Water Supply, Their Classification, Diagrams and Elements

Definitions

Insolation – capacity of solar radiation on the unit area of horizontal surface of the earth [v/m^2, $J/(m^2*sec)$, $kW*hr/(m^2*d)$, $kW*hr/(m^2*d)$, $kW*hr/(m^2*min)$].
Helio system – integrity of helio equipment and heating-hot water loop (Figure 3).
Purpose of the helio systems is to transform the solar radiation fallen on the earth into the technologic thermal energy.
Helio equipment – component of the helio system connecting the solar collector, solar collector loop, hot water tank and in most cases the heat exchanger between the collector loop and hot water tank (Figure 3).

Classification of the heating-hot water supply helio systems (Figure 4)

The heating-hot water supply helio systems can be classified according to the following features:

- way of using the solar energy;
- purpose of the helio system;
- operation duration;
- technical decision of the diagram;
- type of heat exchanger used in the solar collector loop and way of circulation;
- way of delivering hot water and heat to the consumer.

According to the way of using the solar energy there are high and low temperature helio systems. High temperature helio systems are equipped with the solar collectors with parabolic-mirror or other concentrators. They are used to obtain high parameter steam at the helio-power plants as well as used in water freshening equipment, etc. Low temperature helio systems are used in heating, hot water supply, ventilation-conditioning household and heat and cold supply industrial systems. Low temperature helio systems, from their side, are divided into passive and active systems. Passive is the system within which the element receiving the solar radiation and transforming it into the heat is the building or any of its particular elements – wall, roof, etc. Active is the system within which the element receiving the solar radiation and transforming it into the heat is the helio equipment.

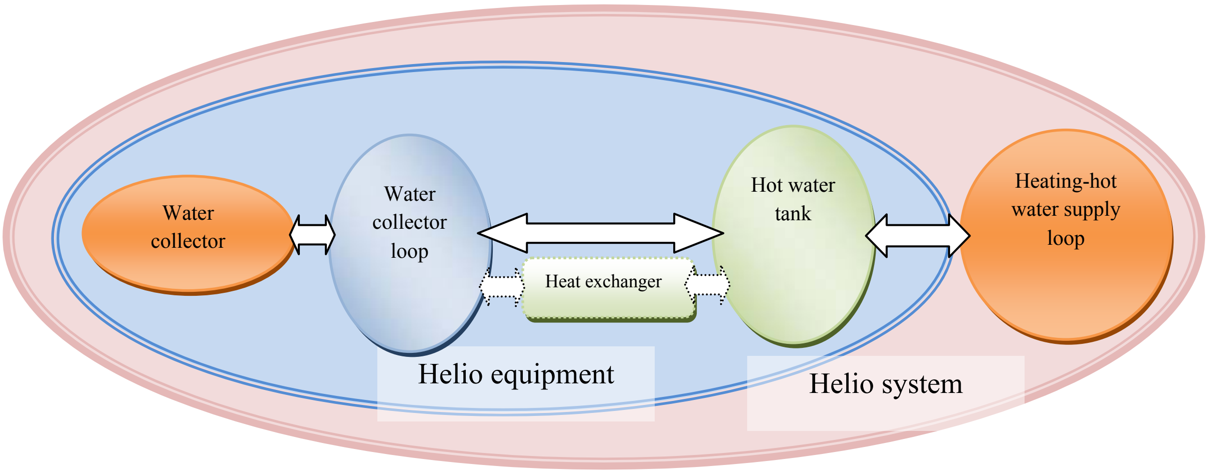


Figure 3. Elements of Heating-Hot Water Supply Helio Systems and Chart of Their Communication

According to their purpose there are just hot water supply, heating-hot water supply and other helio systems. The heating-hot water supply helio systems predominantly consist of two or more loops. In addition, different types of the heat exchangers may be used in various loops. The helio systems used for other purposes, i.e. the combined helio systems are basically designed for supplying heat and cold during the whole year.

According to the operation duration there are daily and seasonal helio systems. Daily systems, as a rule, operate in combination with water heating or heating boilers during the whole year. Seasonal helio systems are predominantly used for the hot water supply during summer or during transient season in positive environment temperatures.

According to the technical decision of the diagram, there are one loop, two loop and multi-loop helio systems.

According to the heat exchanger used in the solar collector loop, the helio systems are divided into liquid and gas heat transferring systems. Glycol, water as well as various types of heat transfer agents are used in liquid type heat exchangers and mainly air is used in gas type heat exchangers.

According to the way of the heat exchanger circulation into the solar collector loop, there are the helio systems operating with passive i.e. natural circulation and active i.e. forced circulation. Unlike the active systems, pumps and ventilators are not used in the passive helio system collector loop. Here, the heat exchanger circulates by the affect of natural gravitation forces.

According to the ways of delivering hot water and heat to the population, there exist opened i.e. direct and closed i.e. indirect helio systems. The consumer in the opened i.e. direct helio systems consumes water which circulates in the solar collector loop. Water shortage in the loop is compensated by adding drinking water and this occurs continuously in parallel to the water consumption. The solar collector loop in the closed i.e. indirect helio systems is an isolated unit with its "private" heat exchanger which is connected to the water loop meant for the consumer just through the recuperative heat exchanger (through the heat exchanger within which acting solids to be heated and acting heating solids are not mixed with one another and are separated by heating surfaces). The closed systems, from their side, are divided into the high and atmosphere pressure systems. Glycol or heat transfer agents which may work with both forced and natural circulation are used in the collector loop for the high pressure systems (i.e. run by applying pressure), and water is used in the loop for atmosphere pressure helio system loop. The loop is equipped with the hot water tank which at the same time is a drain tank. The capacity of this tank is sufficient for storing the collector loop water. Peculiarity of such systems is that in order to avoid water freezing during negative temperatures, the collector loop is discharged into the mentioned tank with the surfaces covered with thermal insulation. For visualization purposes, Figures 5-10 show principal thermal diagrams for contemporary helio systems. The diagrams were drafted and systemized based on the experience we gained as a result of analysing various publications, studying the devices available at the local market and implementing "projects on renewable energy"[3].

General description of the helio systems

From exploitation efficiency point of view, the pressures systems (classifier: 6.2, 7.2.1, figure 6 a, b, c; 7 c; 9 a, b; 11) operating on glycol are grouped according to common features and atmosphere (discharge) systems operating on water - according to natural and forced circulation of the heat exchanger (classifier: 6.2, 7.2.2, figure 5 a, b, figure 10; classifier: 6.1, 7.1, figure 7 a; classifier: 6.1, 7.2.2, figure 7 b; classifier: 6.2, 7.1, figure 8).

Pressure systems operating on glycol.

Such systems are used where water quality is not satisfactory or where there is a danger for water to freeze during the night time (in the solar collector loop).

System advantages are:

- glycol is used in the solar collector loop and it protects the collector loop from freezing;
- heat exchanger is constantly available in the collector loop, it is ready to work at all times and can heat water even in sunny winter weather;
- Circulation of the heat exchanger (glycol) in the collector loop is forced, and is fulfilled with the pump. Therefore, the angle and deviation of the pipes are not essential. Respectively, the system is easily installed on all types of buildings.

Fault of the system is the following:

- The heat exchanger is less efficient when using glycol rather than when using water. Under equal efficiency conditions, the systems with antifreeze are more expensive than the systems with water;

---

[3] a) USAID/WINROCK/World Experience for Georgia/Under Sub-Agreement 5708-07-04/ "Renewable Energy Potential in Georgia and the Policy Options for Its Utilization".2008
b) Dr. K.Kushashvili. Solar Hot Water and Heating Systems. "Therma.LTD". Tbilisi, 2009.
c) Artificial Intelligence in Energy and Renewable Energy Systems/Soteris Karogirou/Nova Science Publishers, Inc. New-York, ISBN 1-60021-261-1, 2006, 471 p.
d) "Johnson Controls", Renewable Energy Solution Presentation. Wisconsin, USA, 2009.
e) Federal Energy Management Program. Current Application and Research in Photovoltaic Technology of Buildings. 2009.
f) Ю.А.Табунщиков. Научные основы проектирования энергоэффективных зданий. АВОКб.№1/1998

- For keeping up antifreeze quality for a long time, periodic maintenance work should be done to the system;
- When the hot water consumption seizes, circulation of antifreeze into the collector loop seizes too which is often followed by the temperature and pressure increase exceeding the admitted value. In order to avoid failure of the system at this time, safety valve opens and excess antifreeze is displaced into the atmosphere resulting in environmental pollution, from one side, and the necessity to fill up the system, from another side. In addition, there arises the necessity to use environmentally safe and expensive antifreeze.

Water operated atmospheric (discharge) systems with natural and forced circulation of the heat exchanger

Systems advantages are:

- Water used as a heat exchanger in the collector loop has solid chemical structure and its thermotechnical features are better than antifreeze features;
- During winter time, when the system is not operating, water is discharged from the solar collector loop and hence, the system is well protected from freezing. Also, in sunny winter days there is no danger for pressure and temperature increase and system damage (failure) in the loop.

System faults are the following:

- When the loop is empty, the collector components are not cooled and there is the danger that they will overheat by the affect of the sun rays;
- In installing the systems operated by natural circulation, it is necessary to maintain the level difference between the hot water tank and the solar collector, which is not always possible due to the restriction of the building structure;
- It is necessary to accurately co-ordinate the pipeline (conduct accurate bending and exactly locate of the drainage points) in order to provide full emptiness of the system in winter time, which in some cases is not achieved either.

In appropriate provision of the information, we believe that the results of systematization and classification of the above given heating diagrams of the helio systems will be useful for a lot of consumers (individuals, hotels and camp owners, catering units and gyms, children's pre-school institutions, hospitals and outpatient clinics, industrial units, design and construction organizations, dealers, engineers, etc. interested in the sales of the helio systems) to make proper choice of the system package and dimensions considering the expected application conditions.

Power consumed for household hot water supply

Water consumption in the household sector is not individually recorded in post-social countries and in Georgia. Therefore, it is impossible to accurately estimate the energy required for the household hot water supply. For rough estimations we may use the norms of hot water consumption of other countries (Table 1). The values given in the last line and column are for Georgia and are obtained as a result of the calculations which are based on the calculation chart and assumptions set forth in the following paragraph.

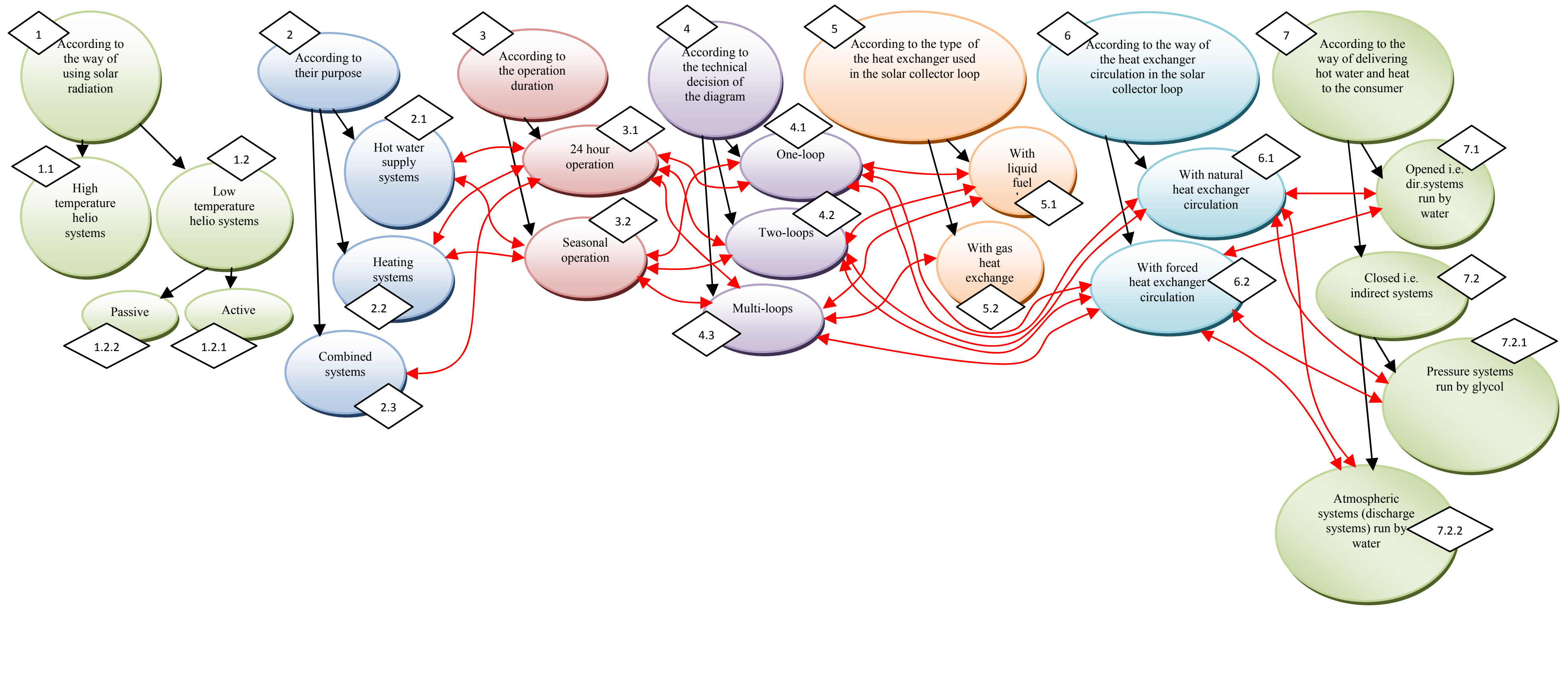


Figure 4. Classification of Heating – Hot Water Supply Helio Systems: 1 . . ., 11 Classifiers

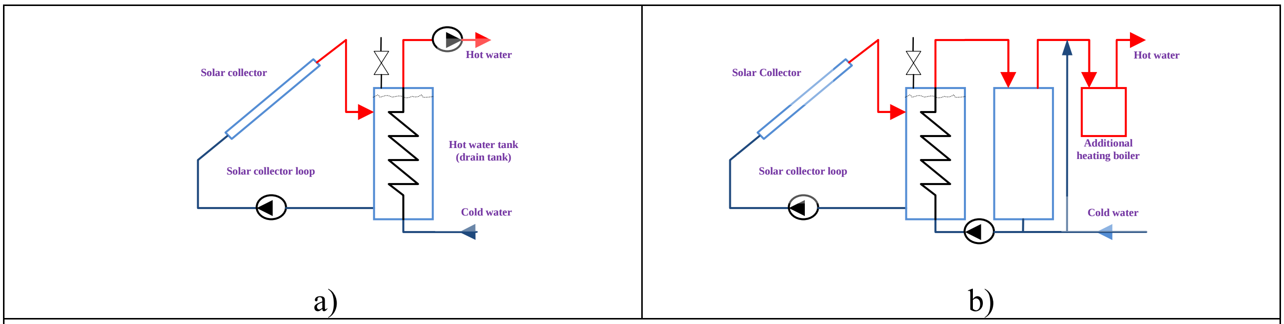


Figure 5. Atmospheric/discharge helio systems for hot water supply:

a) For high insolation climate conditions (classifiers: 1.2.1, 2.1, 3.2, 4.2, 5.1, 6.2, 7.2.2);

B) For low insolation climate conditions; with continuous additional heating of hot water (classifiers: 1.2.1, 2.1, 3.1, 4.2, 5.1, 6.2, 7.2.2)

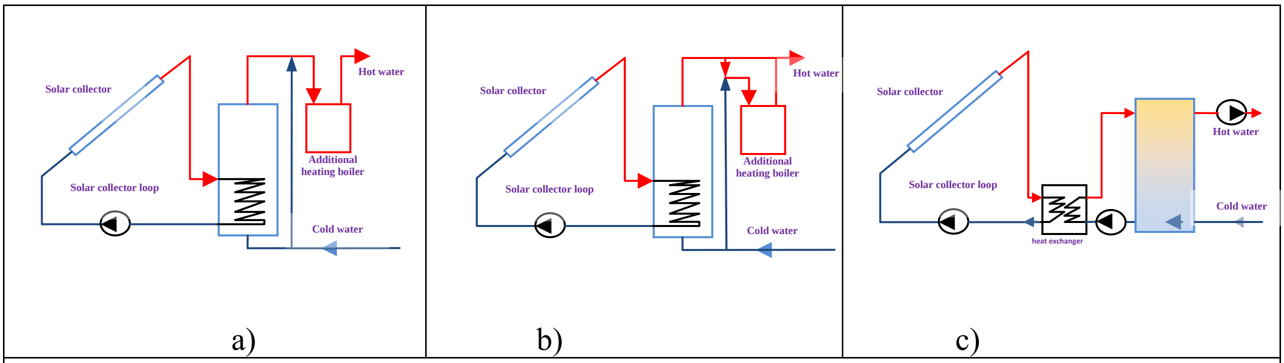


Figure 6. High Pressure Hot Water Supply Helio Systems:

a) For low insolation climate conditions, with continuous additional heating of hot water (classifiers: 1.2.1, 2.1, 3.1, 4.2, 5.1, 6.2, 7.2.1);

b) *For moderate insolation climate conditions; with periodic heating of hot water (classifiers: 1.2.1, 2.1, 3.1, 4.2, 5.1, 6.2, 7.2.1)*

c) *For high insolation climate conditions (classifiers: 1.2.1, 2.1, 3.2, 4.2, 5.1, 6.2, 7.2.1)*

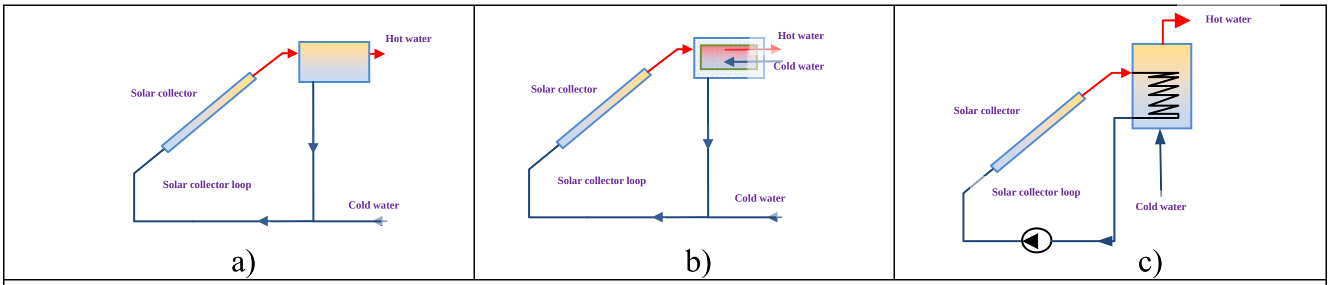


Figure 7. Hot Water Supply Helio Systems for High Insulation Climate Conditions with Natural and Forced Heat Exchanger Circulation

a) Opened i.e. direct system (classifiers: 1.2.1, 2.1, 3.2, 4.1, 5.1, 6.1, 7.1);

b) Closed i.e. indirect system (classifier: 1.2.1, 2.1, 3.2, 4.2, 5.1, 6.1, 7.2.2);

c) Closed i.e. indirect system for high insolation climate conditions with heat exchanger tube bundle installed into the tank (classifiers: 1.2.1, 2.1, 3.2, 4.2, 5.1, 6.2, 7.2.1)

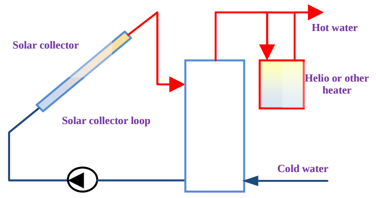


Figure 8. Opened i.e. Direct Helio Systems for Hot Water Supply for Moderate Insolation Climate Conditions with Forced Heat Exchanger Circulation
(classifiers: 1.2.1, 2.1, 3.1, 4.1, 5.1, 6.2, 7.1)

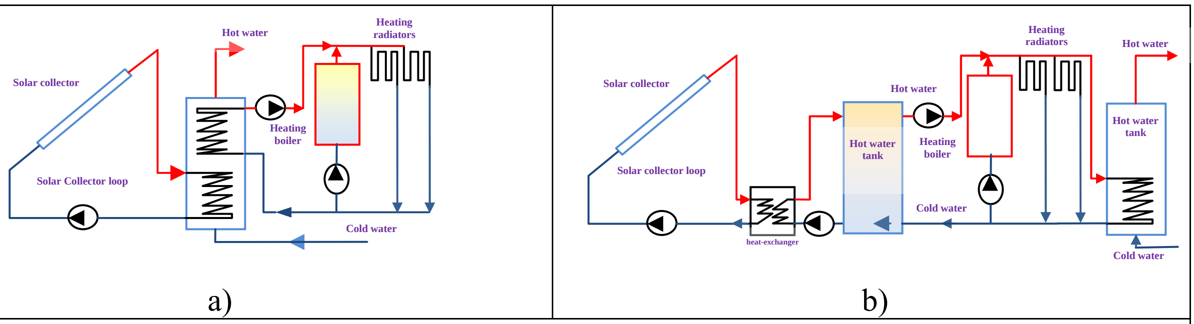


Figure 9. High Pressure Helio Systems for Heating – Hot Water Supply

a) For moderate and high insolation climate conditions; with periodic additional heating of heating water; with heat exchanger tube bundle installed into the tank (classifiers: 1.2.1, 2.2, 3.2, 4.3, 5.1, 6.2, 7.2.1);

b) For low insolation climate conditions; with continuous additional heating of heating water separated by heat exchanger (classifiers: 1.2.1, 2.2, 3.1, 4.3, 5.1, 6.2, 7.2.1)

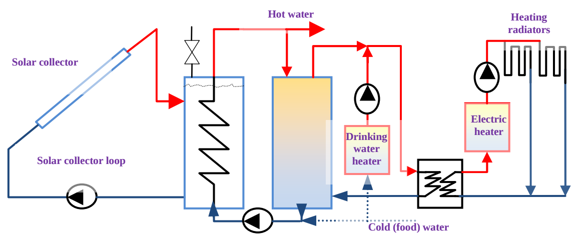


Figure 10. Atmospheric/Discharge Helio System for Heating – Hot Water Supply:
For high insolation climate conditions; with continuous additional heating of heating water (classifiers: 1.2.1, 2.2, 3.2, 4.3, 5.1, 6.2, 7.2.2)

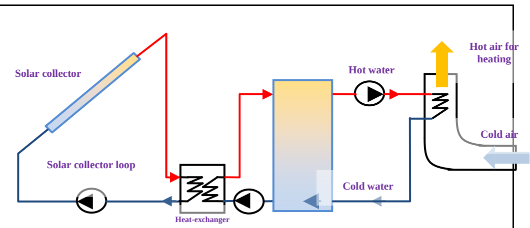


Figure 11. High Pressure Helio System for Air Heating with Air Blowing Heat Exchange
For high insolation climate conditions (classifiers: 1.2.1, 2.2, 3.2, 4.3, 5.1, 6.2, .2.1)

Table 1. Household Hot Water Consumption Norms for Various Countries and Energy Required for Heating Water

Country	Norm of Hot Water Consumption		Energy Required For Heating Water kW*hr/(family*d)		
	l/(person*d)	l/(family*d)	t_1=5°c	t_1=10°c	t_1=15°c
USA, [a]	47	188	9	8	7
Soviet Union.[b], Min.	80	320	15	13	11
Max.	130	520	24	21	18
Europe[)]	30	120	6	5	4
Georgia[d)]	30	120	6	5	4

Sources:

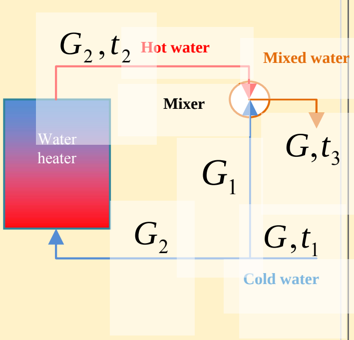
a) "Johnson Controls", Renewable Energy Solution Presentation. Wisconsin, USA, 2009.
b) СНиП 11-36-93
c) Artificial Intelligence in Energy and Renewable Energy Systems/Soteris Karogirou/Nova Science Publishers, Inc. New-York, ISBN 1-60021-261-1, 2006, 471 p.
d) USAID/WINROCK/World Experience for Georgia/Under Sub-Agreement 5708-07-04/ "Renewable Energy Potential in Georgia and the Policy Options for Its Utilization".2008

Energy Required for Heating Water

Calculation of energy required for heating water the results of which are provided in the Table 1 was conducted according to the diagram given in inclusion 1.

Inclusion 1. Diagram for Calculating Energy Required for Water Heating

Diagram:



Marks:

G - Hot water consumption norm, l/(family*d);
t_1 - Cold (drinking) water temperature, °C
G_2 - Consumption of heated water, l/(family*d)
t_2 - Heated water temperature, °C
G_1 - Mixing (cold) water consumption, l/(family*d)
t_3 - Mixed (final use) water temperature, °C
c - Specific heat capacity of water, kJ/(l*°C);

Assumptions:

$t_1 = 5/10/15$, °C
$t_3 = 45$, °C
$c \approx 4.2$, kJ/(l*°C)

Equations:

Material balance:

$G = G_1 + G_2$ ------------------------ (1)

Heat balance:

$Gct_3 = G_1ct_1 + G_2ct_2$ -------------- (2)

Formula for calculating energy required for heating water:

$Q = G_2c(t_2 - t_1) \approx Gc(t_3 - t_1)$ ---- (3)

The figure for the hot water consumption which for Georgia makes approximately 30 l per person per day was obtained within the frame of the Project - USAID/WINROCK/World Experience for Georgia/Under Sub-Agreement 5708-07-04/ "Renewable Energy Potential in Georgia and the Policy Options for Its Utilization", 2008. The survey run at this time as one of the issues involved evaluation of the hot water consumed by the consumers living at multi-apartmental buildings of Tbilisi. Ten families with the amount of members ranging from 4 to 5 were observed. Socially they were the families having the jobs and consisting of parents and 2-3 school age children. The families for the hot water supply used similar 1.5 kW capacity and 80 l capacity electric water heating tanks. The survey showed that the water consumption during three hottest summer months (June, July, August) made approximately 50 l/(person*d), and within the remaining 9 months – approximately 20 l/(person*d). In addition, water in summer was heated from 15°C to 39°C, and within the remaining period – from 10°C 45°C. Total continuous operation time of the electric water heater as proved by the evaluations made 370-400 hours in summer (within three months), and 670-800 hours within the remaining period. Respectively, the coefficient of their technical utilization did not exceed (400 hr + 800 hr)/8760 hr = 14%, and average annual figures of the daily power consumption for hot water and for heating up water respectively made 30 l/(person*d) and 4-5 kW*hr/(family*d). The estimations did not include heat losses from the outside surfaces of the water heating tank, although their temperature did not actually differ from the interior temperature indicating that the losses were insignificant. Eventually, we may say that the figures given in Table 1 match quite well. Just soviet norms are the exception. The data for Georgia and Europe are almost similar. In further analysis, given that the data accepted for Georgia did not include the hot water consumption in the kitchen, it will be better to apply to the USA norms: 47 l/(person*d) for the hot water consumption; 8 kW*hr/(family*d) for the water heating.

Power consumed for the hot water supply

Power consumptions for the hot water supply – power consumed by water heating device exceeds the energy required for heating water with the losses which occur as a result of transferring power to water. In the estimations such losses will be considered with the efficiency coefficient of the water heating devices. When the device type is known, knowledge of its efficiency coefficient is quite enough for specifying the power consumed for the hot water supply of a specific consumer with an acceptable accuracy. Determination of the power consumptions for the hot water supply for the entire Georgia is far difficult since there are no statistic data about the devices used by the population. In such case, we should limit ourselves with just rough estimations which taking particular risk could be based on study results run within the previous years, following year tendencies and limited volume of polling recently run specifically for such work. Such pollings showed that among the water heating devices available in Georgia, the most popular are 50-200 l capacity electric water heating tanks and direct flow water heaters operated by natural gas (the so called gaysers). The residents use direct flow electric water heating devices (the so called "Atmor") rather rarely. Particular place in the household sector is taken by the combined heating-hot water supply systems in which compact heating (15-35 kW capacity) boilers are utilized.

Figure 12 shows the layout estimating the resources usage in the hot water supply of Georgian household sector.

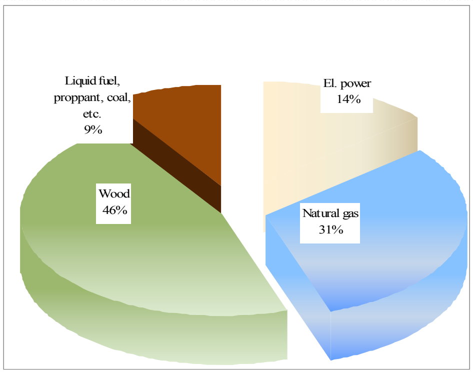


Figure 12. Layout of Resource Usage for Hot Water Supply of Georgian Household Sector, Experts Evaluation, 2009

Table 2 shows the figures describing the power consumed for the hot water supply as well as ecological data based on the following assumptions:

1) 80% of the families with gas supply uses liquid fuel, proppant, coal and other resources, and approx. 75% uses wood; 2) the efficiency coefficient of the water heating devices operated by natural gas is an average of 85%, i.e. the efficiency of natural gas usage makes

As shown in this table, it is likely that 377000 m^3 of natural gas, 1425000 kW*hr of electric power and 5900 m^3 of wood are daily consumed for the hot water supply of Georgia.

As for the estimation of the annual electric power consumed for the hot water supply, based on the concept that hot water consumption during the whole year can be assumed as a constant value (as mentioned already), we will get the picture which is shown on Figure 13.

Table 2. Estimative Figures of Power Consumed for Hot Water Supply and Ecological Figures for Georgian Household Sector

Consumer	Family with gas supply 470,680		Family without gas supply 750,320			Total, family 1,221,000
for hot water supply	natural gas[1] 80%	el. power[2] 20%	el. power[2] 10%	wood[3] 75%	Other means 15%	
efficiency of the resource usage	85%	95%	95%	50%	not estimated	
energy required for heating water , kW*hr/(family*d)	8	8	8	8	8	
power consumption on hot water supply, kW*hr/d	3,543,944	792,724	631,848	9,003,840	not estimated	13,972,356
resource usage, m^3/d	376703 N. Gas	60187. N.Gas	47973. N.Gas	5893. N.Gas	not estimated	
carbon dioxide emission[4], $kgCO_2/d$	760,941	121,579	96,906	not estimated	not estimated	

1) lowest natural gas burning heat - 33 868 kJ/nm^3; its composition in volumetric processes:
CH4-93.97%, C2H6-2.97%, C3H8-0.43%, C4H10-0.12%, C5H12-0.1%, N2-1.78%, CO2-0.62%, O2-0.01%;
2) share of thermal power plants in balance of power generation in Georgia - 20%; average weighted efficiency coefficient of thermal power plants - 28%;
3) 10000 kJ/kg is taken as the lowest heat for wood burning, and 550 kg/m^3 as a density
4) it is calculated by stoiciometric equation and for the above mentioned natural gas [1] it is: 2.02 $kgCO_2/m^3$ natural gas

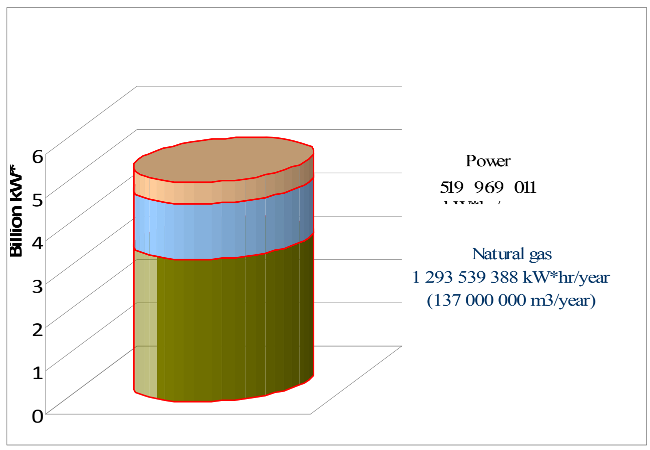


Figure 13. Annual Consumption of Electric Power for Hot Water Supply in Georgian Household Sector. Experts conclusion. 2009

Possibility of replacing the energy resources used for hot water supply by the solar energy. Expected results.

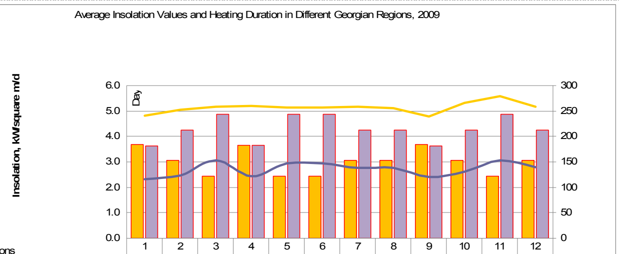
In order to replace the existing means used for the hot water supply by the solar energy, we should know:

1. if there is sufficient solar energy in Georgia;
2. For which period of the year and for what amount of the population this is more reasonable from technical point of view;
3. What kind and what range of restrictions there may exist in case of using the solar equipment;
4. What are the economics of hot water obtained with the solar energy.

Is there sufficient solar energy for the hot water supply in Georgia?

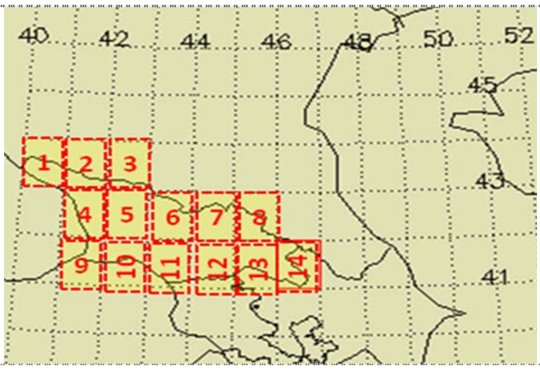
Obviously, such a formulation needs more clarification (since any amount of the solar energy at any place can be obtained by using unlimited amount of solar collectors). Sufficient solar energy means the quantities acceptable for engineering calculations which are based on the concept of acceptable spaces and prices of the solar collectors. Although these quantities are specified for each specific occasion in order to make optimal decision, their approximate values can be estimated under the project recommendations which are based on the experience obtained. According to one of these recommendations[4], as an average quantity of the solar energy to be

[4] Ю.А.Табунщиков. Научные основы проектирования энергоэффективных зданий. АВОКб.№1/1998



Georgian regions	1	2	3	4	5	6	7	8	9	10	11	12
Summer duration, days	184	153	122	183	122	122	153	153	184	153	122	153
Heating (remaining period), kW*hr/(m2*d)	181	212	243	182	243	243	212	212	181	212	243	212
Average insolation in "summer", kW*hr(m2/d)	4.8	5.1	5.2	5.2	5.1	5.2	5.2	5.1	4.8	5.3	5.6	5.2
Average insolation in the "remaining period", kW*hr/(m2/d)	2.3	2.5	3.1	2.4	3.0	2.9	2.8	2.8	2.4	2.6	3.1	2.8

Figure 14. Average Insolation Figures and Heating Duration in Various Georgian Regions. 2009: Map of provisional division of Georgian regions



used is: 3.5 kW*hr/(m^2*d) "for summer period" (April-September); 2.5 kW*hr/(m^2*d) for the remaining period.

Figure 14 shows average insolation figures for various Georgian regions for "summer" and "remaining" periods (NASA-s monacemebi/www.retscreen.net). It is obvious from the comparison of these figures with the above given project recommendations that there is sufficient solar energy in Georgia for the hot water supply.

For which period of the year and for what amount of the population this is more reasonable from technical point of view?

In solving this issue we should consider equipment of the population and the existing heating-hot water supply conditions. As mentioned above, where there is the availability of natural gas, the population for heating-hot water supply uses direct flow water heaters (geysers), heaters run by natural gas ("Karma", "Nikala", etc.), combined systems of heating-hot water supply (heating boiler+water radiator network) as well as electric heating tanks and direct flow electric water heaters ("Atmor", etc.)
Table 3 shows combinations of heating-hot water supply equipment and distribution in Georgian household sector (based on the experts evaluations, 2009). It is evident from the table that replacement of the existing water heating devices by the helio systems is important for almost the entire population. The exception might be just the minority of the population (approximately 21000 families) which use the combined heating-hot water supply systems and for which getting hot water with the heating is a natural process in winter period.

Table 3. Combinations of Heating-Hot Water Supply Equipment and Distribution in Georgian Household Sector (experts evaluation, 2009)

Combination	Purpose	Device	Distribution			Note
			Population with gas supply 470680		Population without gas supply (including: Tbilisi - 10500 families, other cities and regions - 205820 families, villages - 543000 families)	
			Tbilisi, families 304500	Other cities/regions, families 166180	750320	
1	Hot water supply	Water heating geysers operating on natural gas	73%	77%	-	Families with average revenues as well as the families where old radiator system is damaged and it is expensive to install a new one.
	Heating	Heaters operating on natural gas (Karma, Nikala, etc.)	222285	127958.6		
2	Hot water supply	Water heating tanks operating on el. power (Thermex, Ariston, etc.) or direct flow power heaters (Atmor, Kemsan, etc.)	20%	20%	-	Families with average revenues as well as the families where the space to install geysers is limited
	Heating	Heaters operating on natural gas (Karma, Nikala, etc.)	60900	33236		
3	Hot water supply	Combined system for heating-hot water supply=heating boiler+water radiator network	7%	3%	-	Financially capable families
	Heating		21315	4985.4		
4	Hot water supply	Wood furnaces	-	-	75%	Typical village families
	Heating				562740	
5	Hot water supply	Liquid fuel, proppant, coal and other furnaces as well as electric power	-	-	15%	Villages and regions where it is restricted to deliver and produce wood
	Heating				112548	
6	Hot water supply	Water heating tanks operating on el. power (Thermex, Ariston, etc.) or direct flow power heaters (Atmor, Kemsan, etc.)	-	-	10%	Tbilisi families mainly with no gas supply and also villages and regions where it is restricted to deliver and produce wood.
	Heating	Wood and other furnaces			75032	

What kind and what range of restrictions there may exist in case of using the solar equipment

First of all, there may exist technical problems[5] relating to the difficulties to install the helio systems in dwelling houses.

For instance, in multistory apartment houses it is possible to install the helio systems on the roofs, however they do not always satisfy the requirements of all the residents, since the roof space is not enough for providing the required capacities. As for locating the solar collectors on building walls, this is not always possible due to the structural or architectural peculiarities of the building or due to its unfavorable location against the sun rays. In other cases, this is associated with inappropriate and large expenses. There also exists the difficulty with respect to piping. Thus, the most suitable case for installing the helio systems is private house. Under the data of Statistics Department, the share of such helio systems in Georgia makes 66% including 25.5% in Tbilisi, 38.1% in other towns and regions and 99.5% in villages.
Based on these figures, it is possible for approximately 887000 families making approximately 73% of the Georgian population to use the solar energy for the hot water supply of Georgian household sector without specific technical problems. In addition, the possibility of the replacement of currently used energy resources can be considered in two options: first is "nominal replacement", when the available sources are replaced by the solar energy during the

[5] Problems relating to the legislation and safety are not meant in the work

whole year (365 d/year) and second – "minimum replacement", when the existing means are replaced by the solar energy in just "summer" period (approximately 151 d/year). Savings corresponding to these options are given in Table 4.

Table 4. Expected Results In Case of Replacing Hot Water Supply Means Available in Georgian Household Sector with Solar Energy (Experts evaluation, 2009)

"nominal replacement"			
Energy resource	Resource saving	Unit price	Money saving
Natural gas	41178370. cub.m/min	0.506	20836255. GEL/min
Electric power	316126134. kW*hr/min	0.16 GEL (kW*hr)	50580181. GEL/min
Wood	2140343. cub.m/min	50 GEL/cub.m.	107017186. GEL/min
Other	not estimated	not estimated	not estimated
Carbon dioxide emission (excluding wood) CO2/year	131,664	not estimated	not estimated

"minimum replacement"			
Energy resource	Resource saving	Unit price	Money saving
Natural gas	17035435. cub.m/min	0.506 GEL/cub.m.	8619930. GEL/min
Electric power	130780948.cub.m/min	0.16 GEL (kW*hr)	20924951. GEL/min
Wood	885457. cub.m/min	50 GEL/cub.m.	44272863. GEL/min
Other	not estimated	not estimated	not estimated
Carbon dioxide emission (excluding wood) CO2/year	54,469	not estimated	not estimated

Economics of hot water obtained with the solar energy.

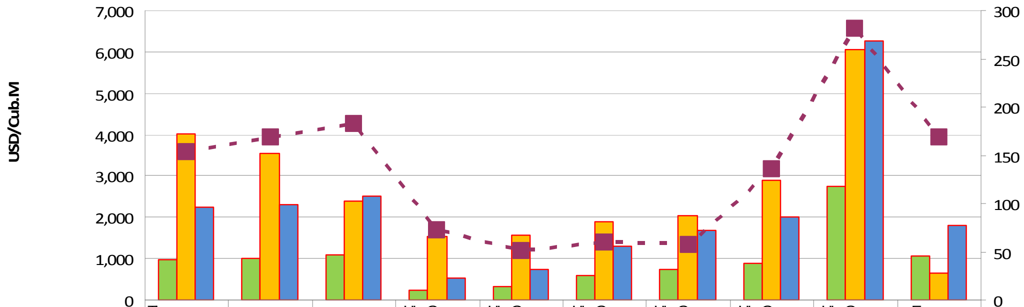
In order to estimate the price of hot water obtained by means of the solar energy, it is necessary to know the prices of the water heating helio systems and their dimensions. Prices and price layout for the helio systems available at the local market are provided on Figure 15. For comparison purposes, an example of European prices of the helio systems is provided too[6]. Determination of the system dimensions which includes specification of the solar collector surface area and the hot water tank capacity is possible based on simple methods provided in the inclusion 2[7].

In order to obtain guaranteed results, it is essential to correctly estimate the efficiency of the solar collector (η_{sc}). The estimation results run for these purposes are given on Figure 16, where together with the basic diagrams the approximation lines are provided too, two out of them have higher correlation coefficient (R=0.469, R=0.334). Based on these lines, for calculations we select more or less guaranteed (the least) value – 50% for the collector efficiency. As a figure for calculating insolation, we select its maximum value, for the so called remaining period (Figure 14.) – 3.1 kW*h/(m2*d). Respectively, the average space of the solar collectors (absorption surface space) necessary for the hot water supply of each family makes: $8/(3.1*0.5*0.95)N \approx 5\ m^3$/family hot water tank capacity is determined based on the household hot water supply and daily insolation diagrams (Figure17.) where one can see, that the active insolation duration during 24 hours makes approximately 8 hours from 10.00 through 18.00. Beyond this period, the demand on hot water should be satisfied from the hot water reservoir. Respectively, the area bounded with the insolation

[6] Artificial Intelligence in Energy and Renewable Energy Systems/Soteris Karogirou/Nova Science Publishers, Inc. New-York, ISBN 1-60021-261-1, 2006, 471 p.

[7] a) J.A.Duffe, W.A.Beckman. Solar Energy Thermal Processes. A Wiley-Interscience Publikation. New-York, London, Sydney, Toronto, 1974. 6

b) Ю.А.Табунщиков. Научные основы проектирования энергоэффективных зданий. АВОКб.№1/1998 curve from the below and with the hot water supply curves from the above, shows the capacity of the mentioned reservoir (Figure 18.).



	Thermarsenal Limited - 160 flat	Skyline - 190, flat	Skyline - 303, flat	Idio Group - 100, with vacuum	Idio Group - 140, with vacuum	Idio Group- 200, with angled	Idio Group - 240, with angled	Idio Group - 200, with strong	Idio Group - 300, with strong	European prices - 190, flat
Price depending on the collector space, USD	981	1,018	1,100	234	330	578	743	880	2,750	1,063
Price depending on hot water tank capacity, USD/m3	4,015	3,530	2,393	1,541	1,554	1,903	2,039	2,900	6,042	638
Total price, USD	2,235	2,313	2,500	531	750	1,313	1,688	2,000	6,250	1,808
Price depending on the collector space USD/m2	153	169	182	72	51	59	57	135	281	169

Figure 15. Prices of Hot Water Supply Helio Systems at the Local Market, 2008-2009.

Inclusion 2: Methods to Estimate Absorption Surface Space of Solar Collector and Hot Water Tank Capacity

Definitions:

Q - Energy required for heating water, kW*hr/(family*d);

$I_{(24)} = \int_0^{24} i(\tau)\,d\tau$ - Daily insolations (maximum between the average daily insolation of "summer" and "remaining" periods), kW*hr/(m²*d);

- time, hour

$i(\ )$ - current insolation (indicative), kW/m² or v/m²'

c_0

$k_{\alpha\tau}$ - solar energy retaining effectiveness;

c_1 - coefficient of the collector angle;

c_2 - first member coefficient, v/(m²*⁰C);

T_i - second member coefficient, v/(m²*⁰C);

T_a - heat exchanger (water, antifreeze, etc.) temperature in entering the collector, ⁰C;

$i_{(24)}$ - environment temperature, ⁰C;

η_p - average daily insolation, v/m²;

- efficiency coefficient which includes heat losses from the pipeline systems of the solar collector loop, %

Calculation formulas:

So

$$\eta_{sc} = c_0 k_{\alpha\tau} - c_1 \frac{T_i - T_a}{i_{(24)}} - c_2 \frac{(T_i - T_a)^2}{i_{(24)}} \ \%$$

Space of the solar collector absorption surface:

$$A_{sc} = \frac{Q}{I_{(24)}\eta_{sc}\eta_p}, \ m^2$$

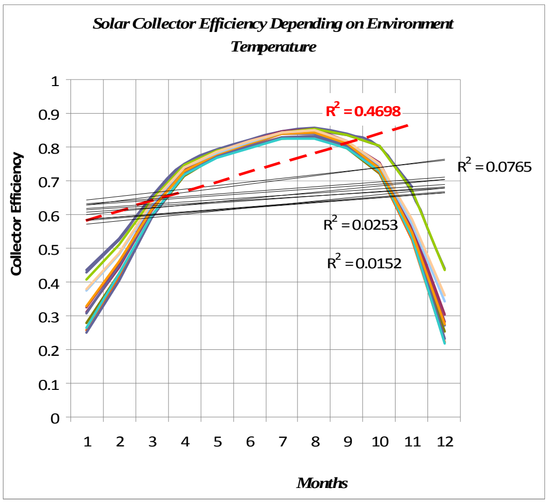


Figure 16. Solar Collector Effectiveness Depending on Environment Temperature for Fourteen Georgian Regions (see a map of regional division of Georgia on Figure 14.):

Calculations were run for flat collectors covered with rough glass painted in black in the following conditions: Angle of collector installation - 45^0; $c_0=0.792$; $k_{\alpha\tau}=0.9586$; $c_1=6.67$; $c_2=0.06$; $T_i=10^0$ c; T_a and $i_{(24)}$ change depending on environment temperature (taken from the climate data of the regions) $\eta_p=95\%$.

For further analysis, we select USA norm – 130 liters from the values given on the Figure.

From the obtained values we determine the estimated price of the hot water supply helio systems and savings for one family (table 5). Figure 19 illustrates the charts for capital expenditure – savings for various helio systems.

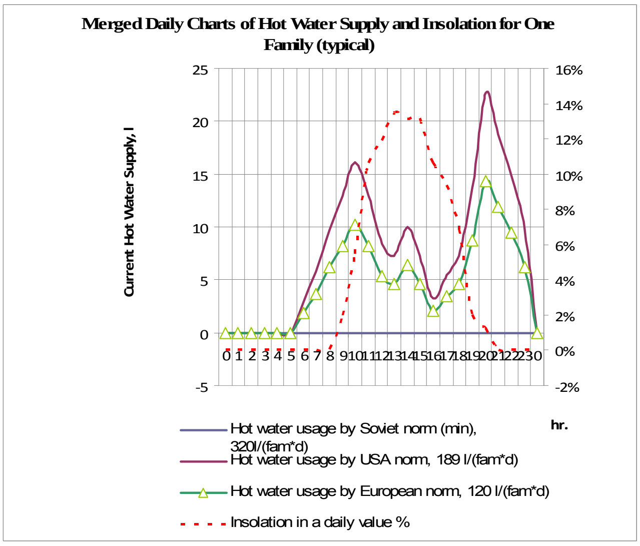


Figure 17. Merged Daily Charts for Hot Water Supply and Insolation for One Family (typical)

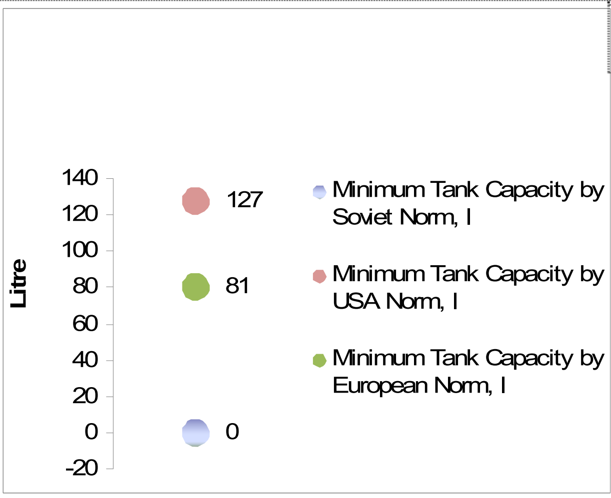
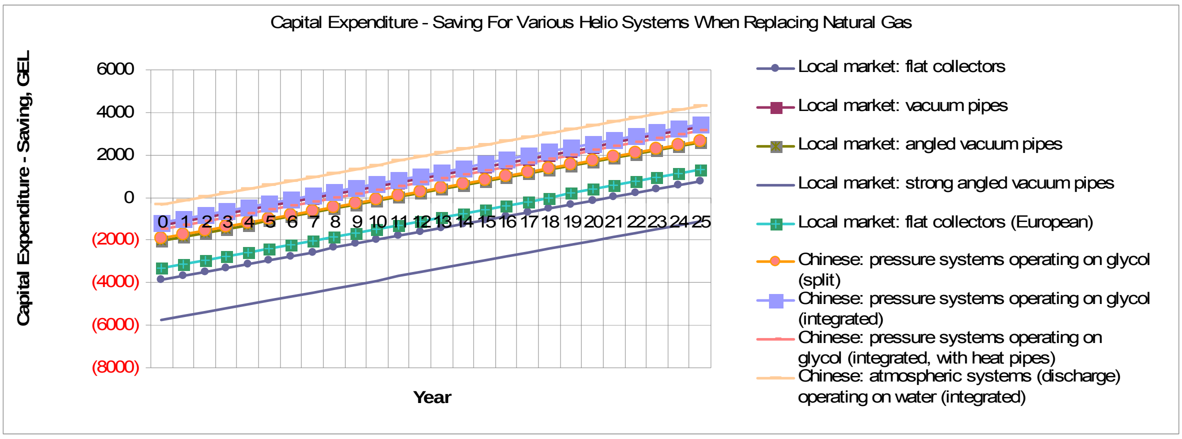


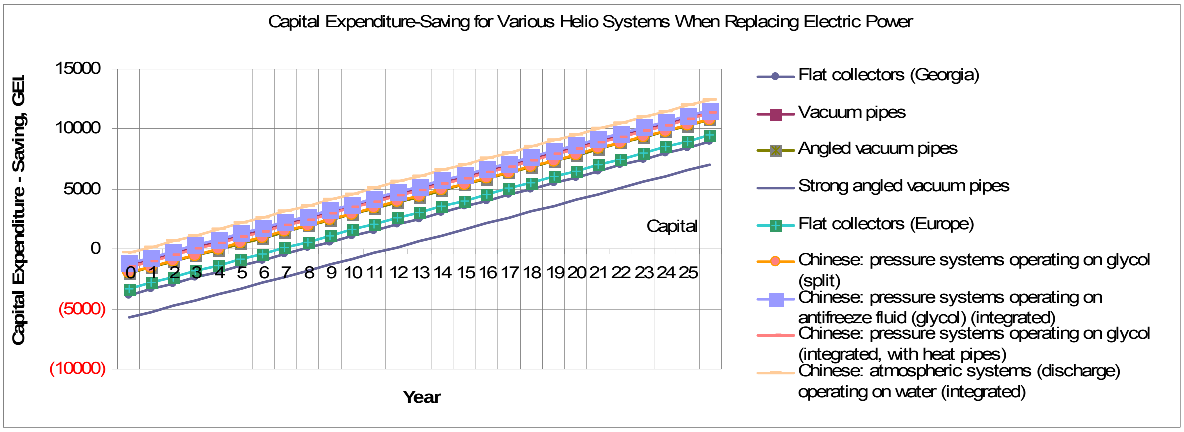
Figure 18. Estimated Capacity of Hot Water Tank in Using Hot Water Supply Helio Systems (for one family)

Table 5. Money Saving in Replacing Various Resources (collector absorption space 5 m^3, hot water tank capacity 130+/-+/l)

Helio Systems Saving	
Saving vs Natural Gas	185 Anual Gel per Family
Saving vs Electricity	492 Anual Gel per Family
Saving vs Wood	191 Anual Gel per Family



a)



b)

Figure 19. Capital Consumption-Saving Charts for Various Helio Systems

Conclusion

1. For high insolation mountainous regions where financial capabilities of the population are limited, the priority should be given to cheap helio systems, in particular: 1) atmospheric/discharge helio systems of the hot water supply with integrated and/or separated hot water tank and collectors (Figure 5., a); 2) high pressure helio systems with glycol (Figure 6., c) and 3) helio systems with natural or forced heat exchanger circulation (Figure 7., a, b, c). For moderate and low insolation regions where population's financial capabilities are higher, it is possible to use practically all the helio systems considering particular installation difficulties and further development opportunities (for instance, further usage of the systems for heating purposes).
2. As a standard value for the hot water supply of Georgian population we may take 47-50 l/member*d); as a standard value of energy required for heating water for one typical family (four member family) – approx. 8 kW*hr/(family*d).
3. Under the experts evaluation, usage of energy resources in the hot water supply of Georgian population is distributed in a following manner: share of wood – 45, share of natural gas – 31, share of electric power – 14 and share of other resources (liquid fuel, coal, etc.) – 10%.
4. Poll results run within the scope of the work show that approximately 80% of Georgian population with the gas supply uses natural gas for the hot water supply, and 20% uses

electric power. Usage of the electric power by this part of the population is caused by objective circumstances – delivery of natural gas to the hot water supply points of their houses is almost impossible. Approximately 10% of the families with no natural gas supply uses electric power for heating water, 75% uses wood, and 15% uses other (diesel fuel, liquid gas, coal, etc.) resources. In addition, the efficiency of usage of electric power is approx. 95%, natural gas – 85%, wood – 50%. Respectively, annual power consumption for the hot water supply of Georgian population makes approx. 520 000 000 kW*hr/year, natural gas consumption – 137 000 000 m^3/year, and wood consumption – 2 150 000 m^3/year.

5. As an average value for using the solar energy in Georgia we may accept: 3.5 kW*hr/(m^2*d) for summer period (April-September); 2.5 kW*hr/(m^2*d) for the remaining period; according to heating degree-days, average duration of "summer period" is approx. 151 days, and the duration of the remaining heating period – 214 days; replacing the energy resources used for the hot water supply of the population by the solar energy is possible in approx. 73% of the population. This allows to annually save approx. 41 000 000 m^3/year natural gas which according to the current prices is an equivalent of ~20 800 000 GEL, ~316 000 000 kW*hr/year electric power (~50 000 000 GEL) and ~2 000 000 m^3/year wood which will decrease carbon dioxide emission by ~131 000 t/year. In addition, each family will annually save (according to the prices of 2009): 185 GEL in replacing natural gas; 492 GEL in replacing electric power and approx. 191 GEL in replacing wood.
6. The space of the solar collector absorption surface required for the hot water supply of one typical (four member) family in Georgian conditions makes ~5 m^2/family, and the hot water tank capacity is no less than 130 l. Based on the data of the years 2008-2009, the prices for the integration of such helio systems at Georgian market change from 1300 to 5800 GEL depending on the equipment constructions (flat collectors with flat and vacuum pipes, the so called heat pipes, integrated systems, etc.), respectively, the simple payback period for capital expenditure/investments ranges from 1.5 to7 years.

Temur MIKIASHVILI, Doctor of Technical Science, Professor,
Technical University of Georgia
Tel.: (995 32) 365172; mob.: (995 99) 720382;
E-mail: temurmikiashvili@yahoo.com