CLASSIFICATION OF SOLAR COLLECTORS

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Abstract. In practice different kinds of solar collectors for hot domestic water heating worldwide are used. The amount of sunshine hours in Latvia is some 1800 hours a year in average what preclude it to use solar energy for water heating. However, areas of solar collectors installed in Baltic States increases with every year. With the increasing use of solar collectors the variety of constructions of solar collectors in order to improve its' efficiency gets wider. Wherewith, for the last time there are originated a large amount of modifications of solar collectors. To establish a solid classification of solar collectors the following research has been done. It is stated, that the basic constructions are kept the same, but new modifications of them are arisen up.

Key words: solar collector, classification, efficiency, temperature ratio.

Introduction

Situation in energetic become more acute with every year. With increase of manufacturing, increases both need for heat as well as for electrical energy. It is well known that great amount of total consumed energy is produced in way of combustion of several fossil fuels: solid, liquid and gaseous. As known fossil fuels are expensive, require for a stockroom, combustion of them makes pollution of the atmosphere and resources of fossil fuels in the nearest future will run away [1]. These are reasons why an alternative energy sources are becoming more and more charismatic. Latvia is not rich in natural energy sources - approximately 70 % of them have to be imported [1]. Solution of this problem is focusing to an alternative energy sources. Like an alternative energy sources in Latvia it is possible to use: biomass, biogas, waterpower, wind energy, geothermal heat and solar radiation. Solar radiation for water heating widely worldwide is used. In Latvia it is about 1800 sunny hours a year what preclude it to use solar energy for water heating. Also solar devices what are possible to use for efficient water heating in weather condition of Latvia are too expensive. A lot of constructions of solar devices worldwide are known and each one of them is efficient in some specific locations and weather conditions. To establish solid classification of solar collectors the following research has been done.

Materials and Methods

Solar energy can be used by three technological processes [2]: chemical, electrical and thermal (Fig. 1). Chemical process, through photosynthesis, maintains life on earth by producing food and converting CO_2 to O_2. Electrical process, using photovoltaic converters, provides power for spacecraft and is used in many terrestrial applications. Thermal process can be used to provide much of the thermal energy required for solar water heating and building heating. Another one form of converted solar radiation is mechanical energy as wind and water steams [3].

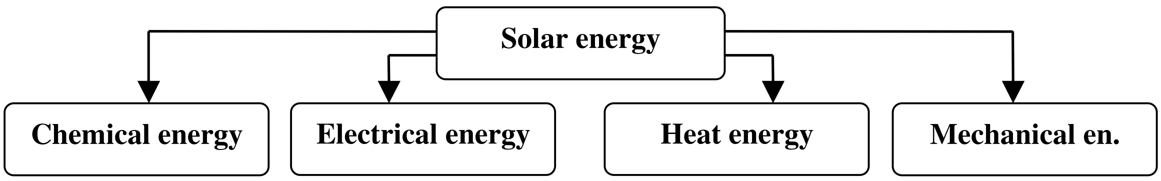

Fig. 1. **Conversion of solar radiation to other energy forms**

The most important and most expensive single component of an active solar energy system is the collector field, which may be performed in a several versions, as from constructions of solar collectors, as of collector configuration. *Solar collector* is a mechanical device which captures the radiant solar energy and converts it to useful thermal energy [4].

The use of solar energy for heat production dates from antiquity. Historically, methods used for collecting and transferring solar heat were passive methods, that is, without active means such as pumps, fans and heat exchangers. Passive solar heating methods utilize natural means such as radiation, natural convection, thermosyphon flow and thermal properties of materials for collection and transfer of heat. Active solar heating methods, on the other hand, use pumps and fans to enhance the rate of fluid flow and heat transfer. Passive systems are defined as systems in which the thermal energy flow is by natural means: by conduction, radiation and natural convection [5]. Passive features increase the use of solar energy to meet heating and lighting loads and the use of ambient air for cooling. For example, window placement can enhance solar gains to meet winter heating loads, to provide daylighting, or to do both, and this is passive solar use.

A distinction is made between energy conservation techniques and passive solar measures. Energy conservation features are designed to reduce the heating and cooling energy required to thermally condition a building. Such features would include the use of insulation to reduce heating or cooling loads. Similarly, window shading or appropriate window placement could lower solar gains, thus reducing summer cooling loads. An example of active solar system is solar collector and thermo battery and of passive solar system – south side windows and greenhouse.

Converting the suns' radiant energy to heat is the most common and well-developed solar conversion technology today. The temperature level and amount of this converted energy are the key parameters that must be known to match a conversion scheme to a specific task effectively. Possible achievable temperature depending of concentration level in Table 1 [4] is shown.

Table 1

Classification of solar collectors according to concentration degree

Category	Example	Temperature range, ºC	Efficiency, %
No concentration	Flat-plate Evacuated tube	up to 75 up to 200	30 – 50
Medium concentration	Parabolic cylinder	150 - 500	50 – 70
High concentration	Parabodial	1500 and more	60 - 75

In most cases solar collectors in order to reduce heat losses are covered (exception is pool collector, when necessary achievable temperature level is some 10 – 20 ºC above ambient temperature). Classification of solar collectors depending of number of covers in Fig. 2 is shown.

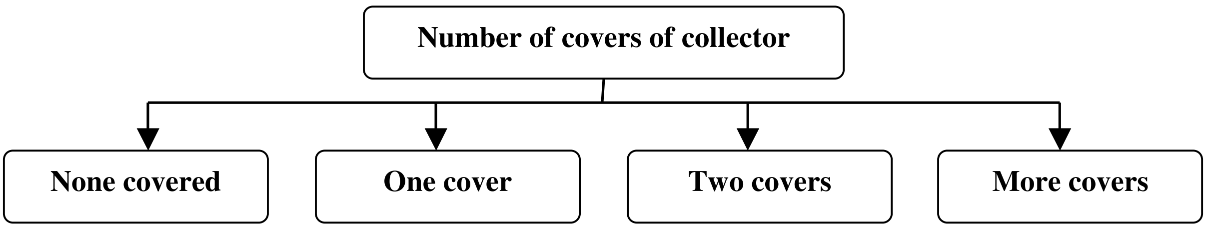

Fig. 2. **Number of covers of solar collector**

In way of enlarge of number of covers heat loses become reduced, but it must be taken into account that solar income are reduced too. For a system of *N* covers all of the same materials, a following analysis yields. Equation for estimation of transmittance for both parallel and perpendicular components of polarization τ_{rN} for a several number of cover *N* by following equation is given [6]:

$$\tau_{rN} = \frac{1}{2}\left(\frac{1-r_{II}}{1+(2N-1)r_{II}} + \frac{1-r_{\perp}}{1+(2N-1)r_{\perp}}\right), \tag{1}$$

where r_{II} – parallel component of unpolarized radiation, non dimensional value;
$r_{\perp}$ - perpendicular component of unpolarized radiation, non dimensional value;
N – number of covers.

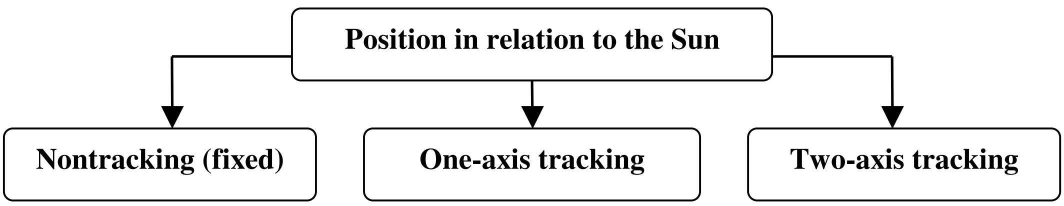

Fig. 3. **Equipment ratio of the collector**

It is well known that the maximum gain from solar collector it is possible to obtain when solar rays are striking solar device perpendicularly because of reflective losses from device surface. In that case solar collectors are divided in three designs shown in Fig. 3. Must be mentioned, that the equipment of collector with tracking devices increase its costs.

Results and Discussion

Consider accordant literature where gathered information about five mine types of solar collectors described below.

1. Tank-type collector

In an Integral Collector Storage unit, the hot water storage tank is the solar absorber. The tank or tanks are mounted in an insulation box with glazing on one side and are painted black or coated with a selective surface. The sun shines through the glazing and hits the black tank, warming the water inside the tank. The single tanks are typically made of steel, while the tubes are typically made of copper [7]. Achievable temperature with such collectors is a little bit less than in flat-plate collectors (see Table 1 and below).

2. Pool collector

The single largest application of active solar heating systems is in heating swimming pools. Special collectors have been developed for heating seasonal swimming pools: they are unglazed and made of a special copolymer plastic. These collectors cannot withstand freezing conditions. Approximate maximum operating temperature of such type of solar collector is 10 – 20 ºC [8] above ambience.

3. Flat-plate collector

Flat-plate collectors are the most widely used kind of collectors in the world for domestic solar water heating and solar space heating applications [7]. Flat-plate collectors are used typically for temperature requirements up to 75 ºC (Table 1) although higher temperatures can be obtained from high efficiency collectors (there water must be changed to other heat transfer liquid because of its boiling temperature of 100 ºC).

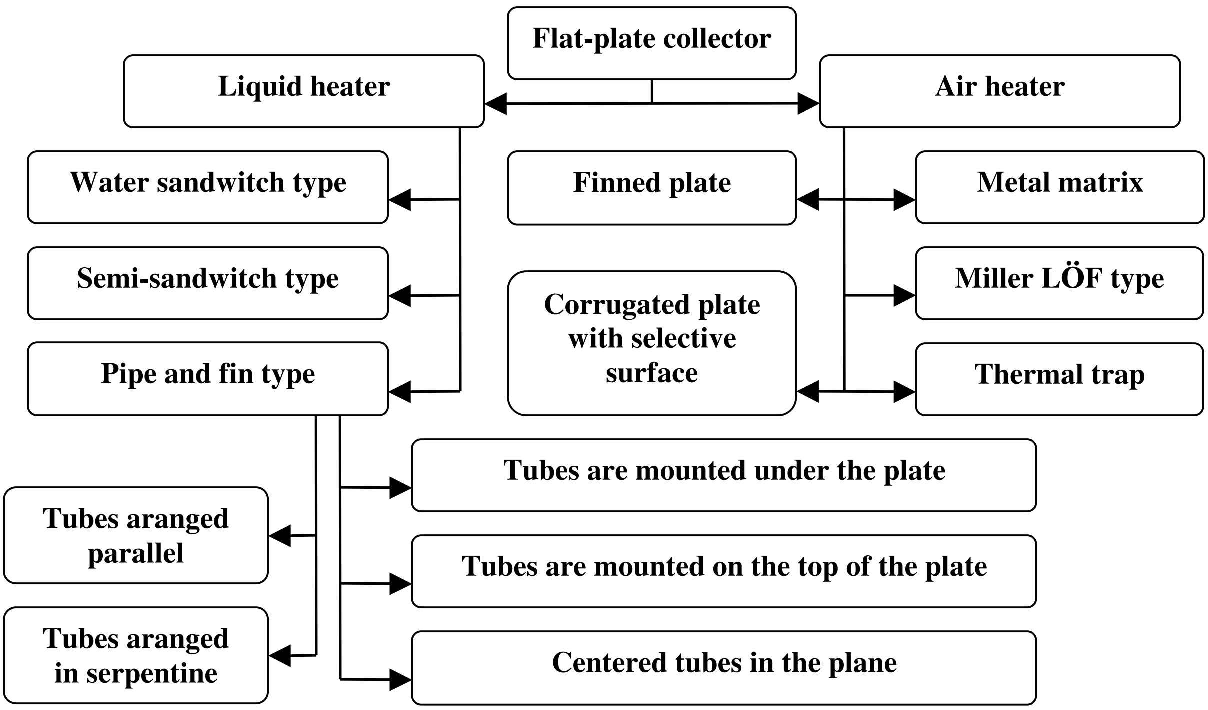

Fig. 4. **Classification of flat-plate solar collectors [2]**

These collectors are of two basic types based on heat transfer fluid [5]: liquid type and air type (Table 2). Flat-plate collectors use both beam and diffuse solar radiation, do not require tracking of the sun, and require little maintenance [6], is usually planed on the top of a building or other structures. Flat-plate collectors are durable and effective. These collectors have a distinct advantage over other types in that they shed snow very well when installed in climates that experience significant snowfall. They are the standard to which all other kinds of collectors are compared [7]. Depending on absorbers' construction and configuration flat-plate collectors are divided in several types (Fig. 4).

Table 2

Classification of collectors according to heat transfer medium

Heating matter	Efficiency, %	Achievable temperature, ºC
Liquid heaters	30 - 75	75 – 1500 and more
Air heaters	30 – 65	30 – 80

Because of their high heat loss coefficient, ordinary flat-plate collectors are not practical for elevated temperatures, say above 80 ºC. When higher temperatures are desired, one needs to reduce the heat loss coefficient. This can be accomplished principally by two methods: evacuation and concentration, either singly or in combination. While several attempts have been made to build evacuated flat plates, they do not seem to hold any promise of commercial success.

4. Evacuated tube collector

While plat-plate collectors are all essentially made the same way and perform the way from one brand to other, evacuated tube collectors vary widely in their construction and operation. Evacuated tube collectors are constructed of a number of glass tubes. Each tube is made of annealed glass and has an absorber plate within the tube, because tube is the natural configuration of an evacuated collector [8]. During the manufacturing process in order to reduce heat losses through conduction and convection, a vacuum is created inside the glass tube. The only heat loss mechanism remaining is radiation [2]. The absence of air in the tube creates excellent insulation, allowing higher temperatures to be achieved at the absorber plate. In order to improve an efficiency of evacuated tube collector there are several types of concentrators depending on its concave radius established. Classification of evacuated solar collectors in Fig. 5 is shown. There are many possible designs of evacuated collectors, but in all of them selective coating as an absorber is used because with a nonselective absorber, radiation losses would dominate at high temperatures, and eliminating convection alone would not be very effective [8].

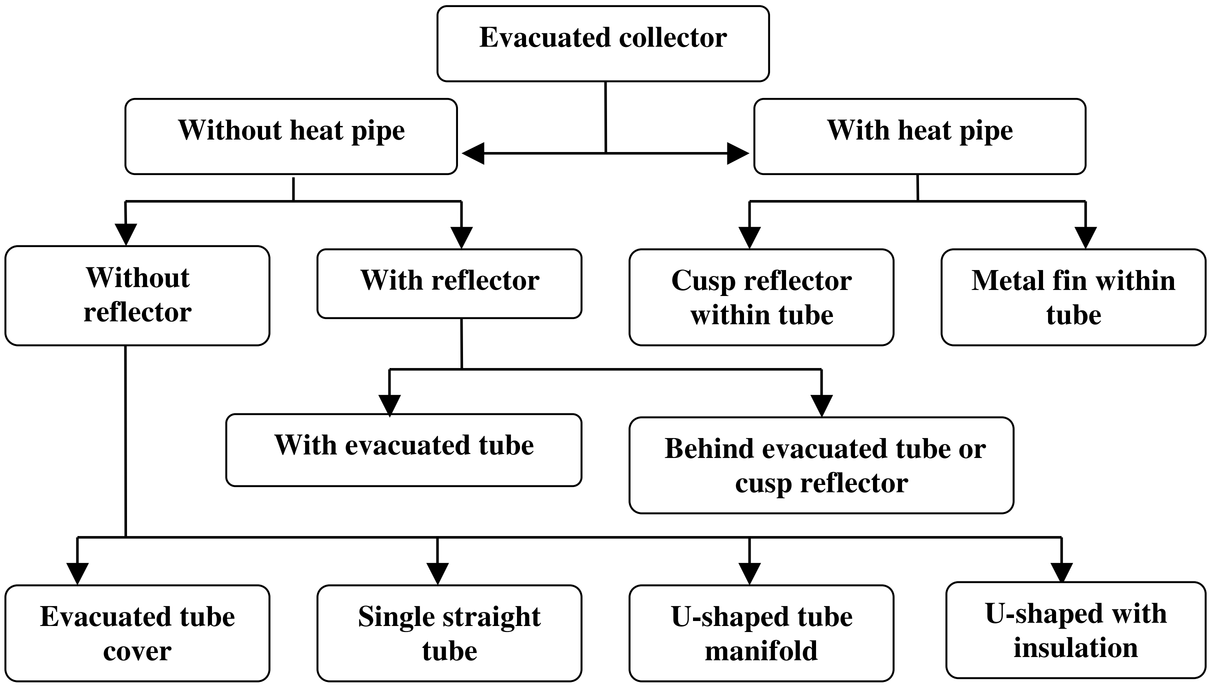

Fig. 5. **Classification of evacuated solar collector [2]**

A heat pipe provides the most elegant way of extracting heat from an evacuated collector. Heat pipe is hermetically sealed tube that contains a small amount of heat transfer liquid. When one portion of tube is heated the liquid evaporates and condenses at the cold portion, transferring heat with great effectiveness because of the latent heat of condensation. The heat pipe contains a wick or is tilted (or both) to ensure that the liquid follows back to the heated portion to repeat the cycle. It is easy to design a heat pipe (e.g., by giving it the proper tilt) so that it functions only in one direction. This thermal diode effect is very useful for the design of solar collectors, because it automatically shuts the collector off and prevents heat loss when there is insufficient solar radiation. Also, heat pipes have lower heat capacity than ordinary liquid-filled absorber tubes, thus minimizing warm-up and cool-down losses [8].

Heat pipe provides the method of transferring larger amounts of heat from the focal area of a high-concentration solar collector to a fluid with only small temperature difference. It consists of a circular pipe with an annular wick layer situated adjacent to the pipe wall. The circular pipe is perfectly insulated from outside to avoid thermal losses from the circular pipe. Solar energy falls on evaporator and the fluid inside evaporator boils. The vapor migrates to the condenser where heat of vapor is transferred to a circulation fluid loop. The heat available with circulating fluid is further carried away to the end use point. The circulation fluid after releasing its heat is transferred to the boiler by capillary action in the wick or by gravity and cycle repeats. Gravity return heat pipes can operate without wick but cannot be operated horizontally as a result.

5. Concentrating collector

A concentrating collector utilizes a reflective parabolic-shaped surface to reflect and concentrate the sun's energy to a focal point or focal line where the absorber is located. To work effectively, the reflectors must track the sun. These collectors can achieve very high temperatures (Table 1) because the diffuse solar resource is concentrated in a small area. The area geometrical concentration ratio according to [2, 6] is

$$C = \frac{A_a}{A_r} = \frac{R^2}{r^2} = \frac{1}{\sin^2 \theta_s}, \qquad (2)$$

where C – concentration ratio, non-dimensional value;
A_a – area of the collecting aperture, m^2;
A_r – area of the absorber, m^2;
R – distance from the sun to the concentrator, m;
r – radius of the sun, m;
θ_s – half of an angle subtended by the sun, °.

This ratio has an upper limit that depends on whether the concentration is a three-dimensional (circular) concentrator such as a paraboloid or two-dimensional (linear) concentrator such as a cylindrical parabolic concentrator. Thus, the maximum possible concentration ratio in air for circular concentrators is 45, and for linear concentrators the maximum is 212 [6].

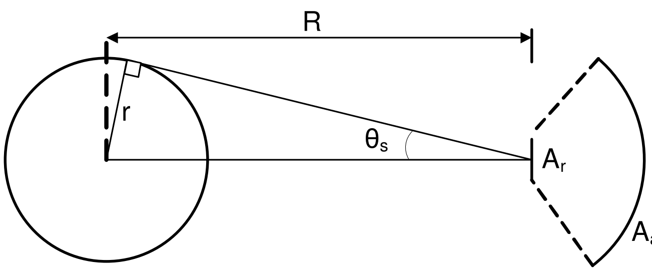

Fig. 6. **Schematic of the sun at a distance R from a concentrator [2, 5, 6]:** R – distance from the sun to the concentrator, m; r – radius of the sun, m; θ_s – half of an angle subtended by the sun, °; A_r – area of the absorber, m^2; A_a – area of the collecting aperture, m^2

Solar concentrator may be classified as tracking type and non-tracking type. Tracking may be continuous or intermittent and may be by one-axis or two-axis (Fig. 3). As the sun may be followed by moving either the focusing part or the receiver or both; concentrators can be classified accordingly.

Further, the system may have distributed receiver or central receiver. The concentrators may also be classified on the basis of optical components. They may be reflecting or refracting type, imaging or non-imaging type, and line focusing or point focusing type. The reflecting of refracting surface may be one piece or a composite surface; it may be a single or two stage type systems and may be symmetric or asymmetric. In practice, however, hybrid and multistage systems, incorporating various levels of the features, occur frequently. Types of concentrators in Fig. 7 are shown.

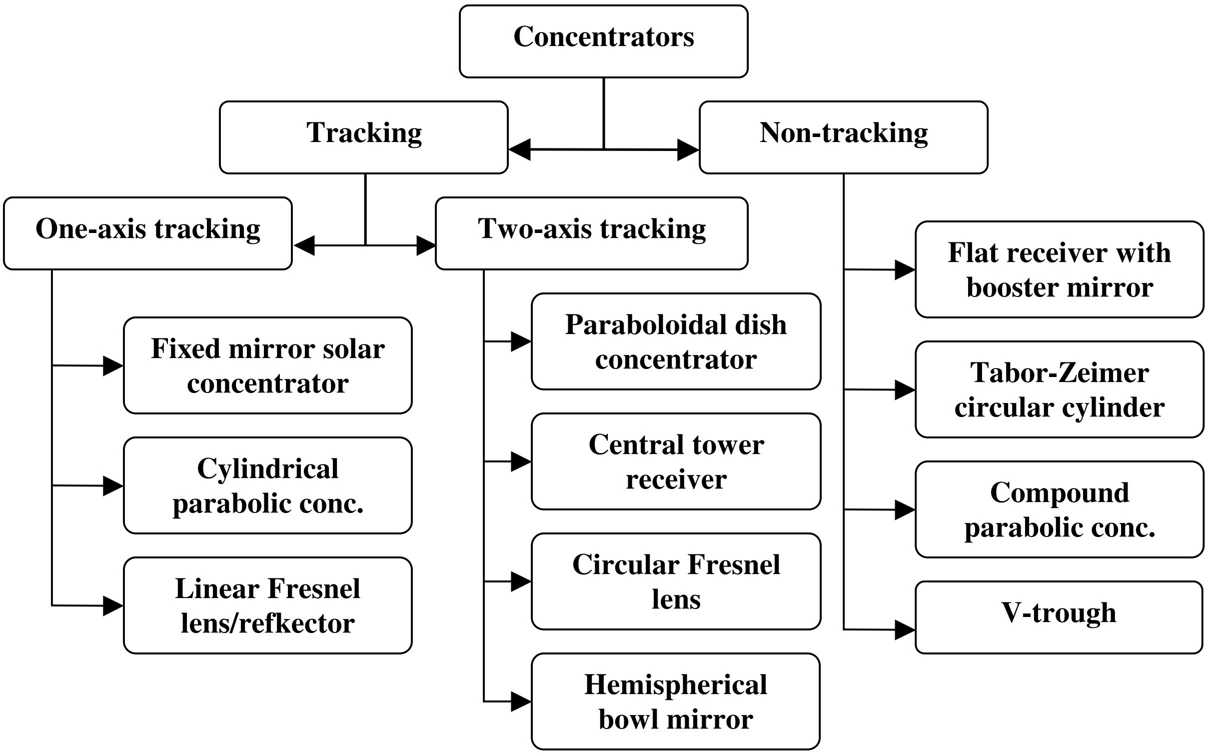

Fig. 7. **Classification of concentrators**

Conclusions

Considering to the existing situation in the energetical field, it is foreseeable that an alternative energy sources will become more and more charismatic and remarkable part in this section will be realized by solar collectors.

References

1. Jesko Ž., Kancevičа L., Ziemelis I. Comparison of Solar Collectors and Conventional Technologies Used for Water Heating in Latvia // Engineering for Rural Development: proceedings, May 24 - 25, 2007, Jelgava, Latvia. – Latvia University of Agriculture, Faculty of Engineering, 2007 - p. 35 - 40.
2. Tiwari G.N. Solar Energy. Fundamentals, Design, Modeling and Applications. – New Dehli: Alpha Science International Ltd, 2006. – p. 525.
3. Weiss W., Themessl A. Training Course – Solar Water Heating. Latvia – Baltic States. – Helsinki: Solpros AY, 1996. – p. 55.
4. Direct Thermal Conversion and Storage [online] [viewed 2007.11.25.]. Available: www.osti.gov/accomplishments/pdf/DE06877213/10.pdf.
5. Yogi Goswami D., Kreith F., Kreider J.F. Principles of Solar Engineering. – New York: Taylor & Francis Group, 2000. – p. 694.
6. Duffie J.A., Beckman W.A. Solar Engineering of Thermal Processes. – New Jersey: John Wiley & Sons, Inc, 2006. – p. 908.
7. Ramlow B., Nusz B. Types of Solar Collectors [online] [viewed 2007.11.25.]. Available: http://oikos.com/library/solarwaterheating/collector_types.html.
8. Rabl A. Active Solar Collectors and Their Applications. – New York: Oxford University Press, 1985. – pp. 503.