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ANALYSE OF SOLAR COLLECTORS MAIN PARAMETERS AT OUTDOOR AIR HEATING

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It is possible to use the solar radiation energy for air and water heating not only in southern countries, where the intensity of solar radiation is high, but also at higher latitudes with lower intensity of solar radiation but longer sunny days in summer. Therefore considering these peculiarities we have to develop the constructions of solar collectors more appropriate for the Baltic States meteorological constructions. The paper discusses procedures of the design, manufacturing and experimental investigation of two solar energy collectors for outdoor air and water heating, where as the source of heat is used the energy of solar radiation. One of the collectors has a tube type solar energy absorber but another cylindrical type absorber. In order to heighten the efficiency of the collectors, there a parabolic solar energy concentrator is used. Both the collectors can be placed in the focus of a solar energy concentrator, where the radiation intensity is higher, or work without of the concentrator. Both variants were experimentally investigated.

Keywords: solar collectors, parabolic radiation concentrator, outdoor air heating.

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INTRODUCTION

Theoretical research, experimental investigation and practice show that it is possible to use the solar radiation energy for heating purposes not only in southern countries of low latitudes, but also at higher latitudes like the Baltic States (Ziemelis et all., 2009; Abdulhadi, Ghorayeb, 2006). At higher latitudes the intensity of solar radiation is lower, but days in summer are longer. Considering these differences we have to look for more corresponding constructions of solar collectors for the use at our conditions (Pelece, Shipkovs, 2016). In Latvia University of Agriculture Ulbroka Research Centre a parabolic shape solar radiation energy concentrator with aperture are 3.6 m^2 has been developed and experimentally investigated for outdoor air heating with a tube type and a cylindrical solar collector (Pelece, 2015.). Solar radiation energy concentrators are used to increase the intensity of solar energy flow per unit of an absorber surface area (Pelece, Shipkovs, 2016; Poulek, Libra, 2006).

The aim of the research was to study the heat transfer intensity from the solar concentrator to the air, running into the absorber tube, and through a two space cylindrical air heating solar collector (Pelece, 2015) depending on the air flow velocity, the solar radiation intensity, the outside air temperature, relative humidity, wind speed and other parameters.

The tasks of the research were to design and to manufacture the collectors, to work out the methodology and to accomplish the experimental research.

MATERIALS AND METHODS

The solar collector with an absorber tube (Figures1and 6) consisting of the tube type heat absorber manufactured from specific form separate aluminium elements (Figure 3) with a wall thickness 0.15 mm and painted in black tarnished colour, an electric motor (12 V, 4.5 W) of the ventilator (Figure 4) powered by the direct current from an amorphous silicon (Si-a) 97 W flexible PV module (Figure 2), provided the air flow of changeable intensity through the absorber tube (Figure 5) and made the air heated. The absorber tube with changing diameter of the aluminium elements made the air flow into the absorber tube turbulent, heightening the efficiency of the device (Ivanovs *et al.*, 2016; Ziemelis *et al.*, 2016; Ziemelis, Putans, Ivanovs, 2016). The velocity of the air flow into the absorber tube was measured and knowing the tube diameter calculated the through going and heated amount of air. The absorber tube is placed into the focus of a solar radiation concentrator, performing a solar collector (Figure 1; Figure 6).

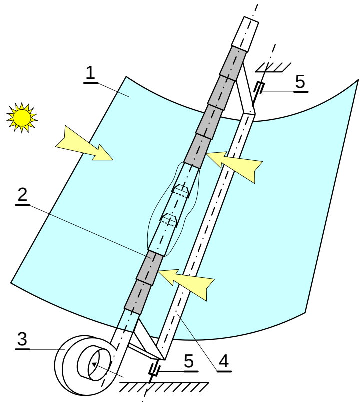


Figure1. The scheme of the solar collector with absorber tube: 1 – solar energy concentrator; 2 – absorber tube; 3 – air ventilator; 4 – frame; 5 – bearings.

Figure 2. An amorphous silicon flexible PV module 19V; 97W.

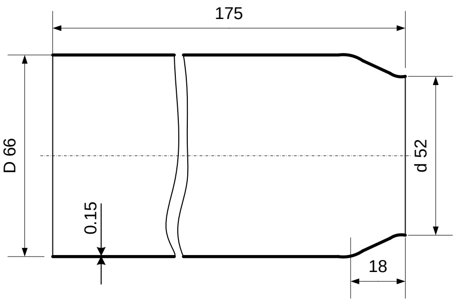


Figure 3. Aluminium element of the absorber tube.

Figure 4. Centrifugal ventilator with direct currant electric motor:12 V; 4.5 A.

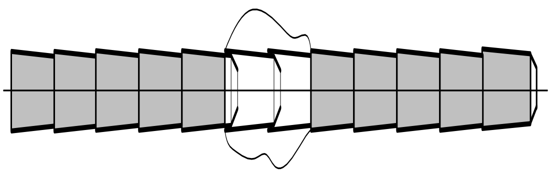


Figure 5. Absorber tube made of aluminium elements.

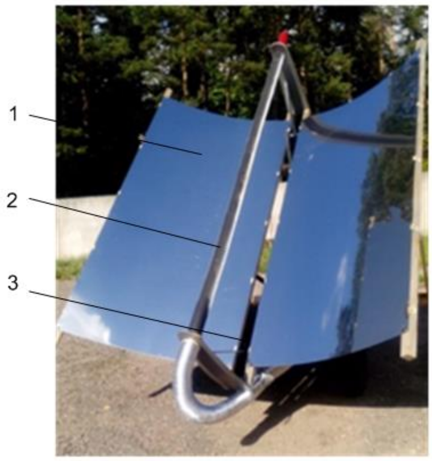
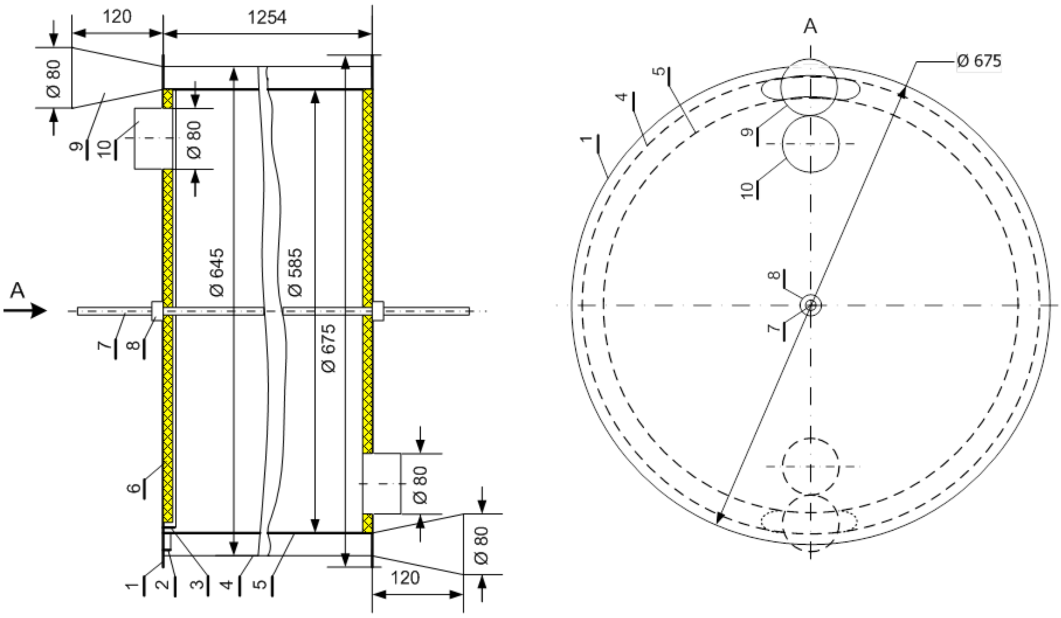


Figure 6. Solar collector with tube type absorber: 1 – solar energy concentrator; 2 – solar energy absorber tube; 3 – fram.

The cylindrical solar collector (Figure 7; Figure 8) for air heating consists of two coaxial cylinders: the inner cylinder 5 is made of galvanized 0.5 mm thick steel sheet, coated with black tarnished silicon color, but the outer cylinder 4 is transparent 1 mm thick PET material, coated with UV protective film. Diameter of the inner cylinder 4 is 0.59 m, but of the outer cylinder the diameter is 0.67 m; the length of both cylinders is 1.3 m. Both cylinders are mounted on one axis pointed to the Polar star to ensure perpendicular striking of solar beams on the collector surface all the day. Ends of the cylinders are closed with metal discs1, from inside covered with 3 cm thick rock wool heat insulation 6. There are openings 9 and 10 in the discs for inlet of the cold outdoor air and outlet of the heated air (Pelece at al., 2016; Pelece, Shipkovs, 2016). Both the discs are joined together by a joining screw 7 and two screw nuts 8. There are two spaces in the collector: one between outer 4 and inner 5 cylinder surfaces and another inside the inner cylinder 5. Through two openings 9 and 10 cold outdoor air is flowing into the collector`s two spaces and after being heated flowing out of the collector`s two spaces.



a) **b)**

Figure 7. Construction of the cylindrical solar collector, a) side view and b) top view: 1 – end disc; 2 – outer ring; 3 – inner ring; 4 – outer cylinder; 5 – inner cylinder; 6 – heat insulation; 7 – discs joining screw; 8 – screw nut; 9;10 – air inlet-outlet openings.

Figure 8. Cylindrical solar collector for air heating.

Figure 9. Cylindrical solar collector device: 1 – solar collector; 2 – solar radiation concentrator; 3 – frame.

Both cylinders are placed on the axis directed from South to North and the North end is lifted at the angle 90^0 minus height of the sun in midday. Such a position allows gaining maximum amount of solar heat energy.

The air flow velocity into the absorber tube was measured by the air flow meter Lutron YK-2001TM with anemometer AM-04 (Figure 10).

Figure 10. Air flow velocity meter LutronYK-2001TM with anemometer AM-04

The air temperature at the inlet and outlet of the collectors, the solar radiation intensity, outside air temperature and wind speed permanently was metered and registered in every 2 minutes. For recording the obtained experimental results a data register logger HOBO-H08-007-02 was used. The solar concentrator with the collectors and measuring equipment was mounted on a specific movable platform manually tracking the sun.

For the calculation of the power of the absorber tube solar collector formula (4) was used, obtained from commonly known air heating expression (1)

$$P_{col} = \varrho \cdot g \cdot \Delta I, \quad (1)$$

where P_{col} – power on the collector, W; ϱ – density of air, kg/m^3; g – amount of air flowing through the absorber tube, m^3/s; ΔI – change of air enthalpy, kJ/kg.

From *I-d* diagram at the air temperature difference (decrease) by ΔT = 100 °C the change of air enthalpy ΔI = 25 kcal/kg. Then for ΔT = 1 °C the change of enthalpy ΔI = 0.25 kcal/kg. As 1 kcal/kg = 4.184 kJ then for the temperature difference ΔT = 1 °C the change of enthalpy will be ΔI = 0.25×4.184 = 1.046 kJ or the air enthalpy difference will be

$$\Delta I = \frac{\Delta T}{1.046}. \quad (2)$$

Amount of air flowing through the absorber tube can be calculated as

$$g = S \cdot v, \quad (3)$$

where S – cross sectional area of the air inflow opening, m^2; v – velosity of the air flow into the opening, m/s.

Consuming the air density ϱ = 1.2 kg/m^3 and inserting formula (2) into formula (1) the following was obtained

$$P_{col} = 1.2 \cdot g \cdot \frac{\Delta T}{1.046}, \quad (4)$$

where P_{col} – collector`s power, W; g – amount of air flowing through the absorber tube, m^3/s; ΔT – difference between the absorber outlet and inlet air temperature, °C;

The collector's efficiency was stated as (5):

$$\eta = \frac{P_{col}}{P_{sun} \cdot S_{ap}}, \quad (5)$$

were P_{sun} – power of solar radiation, W/m^2; S_{ap} – collector's aperture area, m^2.

For the evaluation of the cylindrical collector's efficiency, the global solar radiation was measured using ISO 1-st class piranometer CMP 6 from "Kipp&Zonen". Then the energy received by the cylindrical collector has been calculated accordingly to the methodology, explained in (Pelece, Shipkovs, 2016; Slama, 2009), using formula (6):

$$I = I_0\left(cos\beta + \frac{\sqrt{1-sin^2h}+sin\beta}{sinh}\right), \quad (6)$$

where I – irradiance of slope surface, W/m^2; I_0 – global solar irradiance, W/m^2; β – tilt angle of receiving surface, degrees; h – height of the sun, degrees.

RESULTS

Solar collector's sufficiency traditionally is characterized by its efficiency – as ratio between the heat produced by a solar collector and that received by the collector from the sun. It is easy to calculate these amounts for a flat plate solar collector, but a complicated task in case of indefinite shape of the collector.

Experimental investigation of the described solar collectors was carried out according to the described methodology in 2015, on August 3, 9, 12 and 15, and September 11 and 13. Measurements and recordings of the solar radiation intensity, the airflow velocity into collectors, the outdoor air temperature and increase in the heated air temperature, were taking place in every 2 minutes. The obtained daily graphs have been analyzed and used for the calculation of the necessary parameters. As an example the daily course of the heated air temperature for the collector with tube type absorber in Figure 11, and for cylindrical collector in Figure 12 are given.

In order to calculate the power of the tube type solar collector, formula (4) was used. The amount of the heated air was calculated knowing the diameter of the air inflow opening (0.095 m) and the air flow velocity into the opening, which was permanently measured and recorded. During the experimental investigation also solar radiation intensity, the outdoor air temperature and from the collector outflowing heated air temperature has been measured and recorded, and its difference ΔT computed. At the collector's aperture area 3.6 m^2 using formula (5) the efficiency of the tube type collector was calculated.

The heat energy received by the cylindrical collector was calculated using the methodology given in literature (Pelece, Shipkovs, 2016), using formula (6).

Both of the developed collectors can be used either as tracking the sun or stationary oriented to the south. In both cases (Figure 11 and Figure 12), the day was rather cloudy, as it can be seen from the course of the irradiance. As it was anticipated, the cylindrical collector received more heat energy in the morning and evening in comparison with a flat plate solar collector, but in midday at equal aperture areas, they were similar.

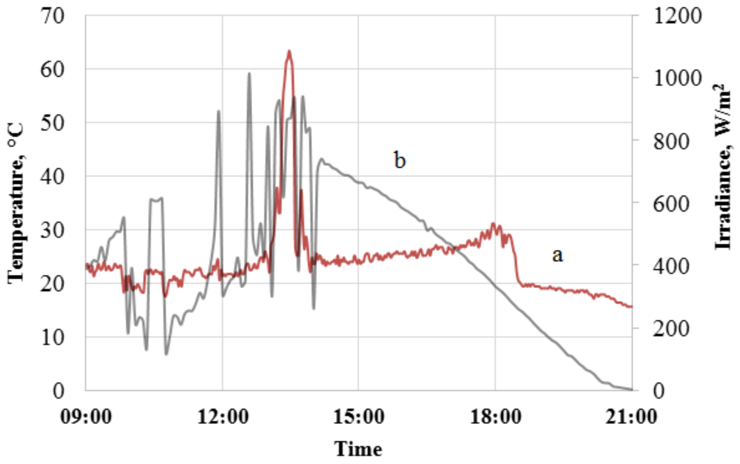


Figure 11. Daily course of outlet air temperature of the tube type absorber collector: a – the outlet air temperature; b – solar irradiance (August 3, 2015)

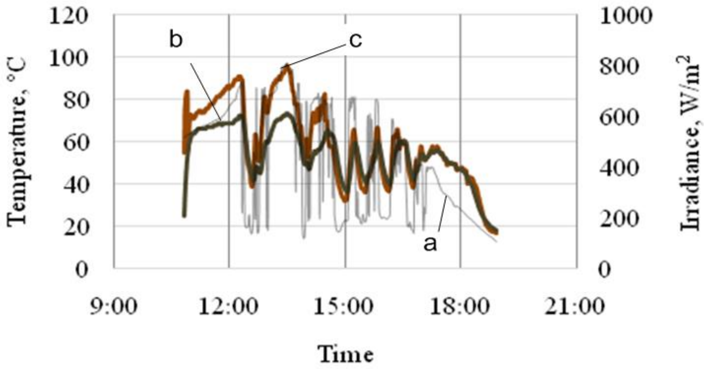


Figure 12. Daily course of outlet air temperature of the cylindrical collector: a – in the space between black absorber and transparent coating; b – inside of the absorber; c – solar irradiance (August 9, 2015)

Because of fast changing weather conditions (cloudiness) and large heat capacity of collectors leading to slow changes in temperature, an instant efficiency was not applicable in this case. Therefore the efficiency of the collectors was evaluated graphically as coefficient of slope of graph showing collector's power against collector's irradiance.

CONCLUSIONS

1. Both of the collectors can work with or without solar energy concentrator, depending on the necessary value of the end temperature.
2. The outlet air temperature of the absorber tube collector operating with the solar radiation concentrator was up to 80 ºC, and the efficiency up to 76 % depending on the solar radiation intensity, amount of air heated and outdoor weather conditions.
3. The outlet air temperature of the cylindrical collector operating without the radiation concentrator was up to 40-60 ºC without, and up to 90 ºC, if the parabolic concentrator was used.
4. The cylindrical collector receives solar radiation energy from all sides during all the day.

REFERENCES

[1] M.Abdulhadi, F.Ghorayeb. A self-tractable solar collector. *International Journal of sustainable energy*, 2006. Vol. *25, is. (2), p.p.63*–78. http://dx.doi.org/10.1080/14786450600594939

[2] S.Ivanovs, I.Pelece, I.Ziemelis, A.J asinskas, H.Putans, L.Kancevica. Device for air heating by solar energy. Latvian patent LV 15142, 2016.

[3] I.Pelece. 2015. Cylindrical solar collector with reflector. *Engineering for Rural Development: Conference Proceedings.* Jelgava, Latvia, May 20–22, 2015, p.p. 408-413.

[4] I.Pelece, P.Shipkovs. Theoretical and experimental investigations of cylindrical solar collector. *Latvian Journal of Physics and Technical Sciences. 2016, Vol.* 53, Is. (3), p.p.11–21. doi: 10.1515/lpts-2016-0017

[5] I.Pelece, S.Ivanovs, H.Putans, I.Ziemelis, A.Ilsters, L Kancevica.. *Device for rolled up stalk plant mass desiccation.* Latvian patent LV 15077, 2016.

[6] V.Poulek, M.Libra. Solar energy, photovoltaic – promising trend for today and close future. CUA, Prague, 2006, 153 p..

[7] R. B.Slama.. Incidental solar radiation according to the solar collector slope. *The open Renewable Energy Journal.* 2009, Vol. 2, p.p.52–58.

[8] I.Ziemelis, H.Putans, A.Jasinskas, L.Kancevica. Investigation of air heating solar collector with energy concentrator. *Engineering for Rural Development: Conference Proceedings*. May 25–27, 2016, Jelgava, Latvia, p.p.312-317.

[9] I.Ziemelis, H.Putans, S.Ivanovs. 2016. A solar device with the energy concentrator for air heating. *Theoretical and Scientific-practical Journal Innovations in Agriculture, 5(20),* 208-214 p. (in Russian).

[10] I.Ziemelis, L.Kancevica, H.Putans. Efficiency of energy produced by different types of solar collectors. In: *6th Research and Development Conference of Central and Eastern European Institutes of Agricultural Engineering Proceedings*. June 30–July 02, 2009, Raudondvaris, Lithuania, p.p.191-197.

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