EFFECT OF WATER RADIATOR ON AIR HEATING SOLAR COLLECTOR EFFICIENCY

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Abstract. The paper describes the results of the investigation, the aim of which was to find new air heating solar collector constructions to increase the collector efficiency especially at low solar radiation. The air heating degree at the same size and the same flowing through the air speed collectors with and without water radiator is compared. The results show a very strong correlation between the solar radiation and the water warm-up stage. It shows that the water radiator serves well to heat the air at low solar radiation (<300 $W \cdot m^{-2}$). The water in the radiator heats up more than 30-35 degrees compared with the atmospheric air temperature. Solar radiation heats the water and it returns the stored energy to the flowing air when the solar radiation falls. Water temperature falls during the experiment indicate that the water accumulated solar energy is returned to the air flowing through the collector and warming it. The collector with the radiator average outlet temperature was 1.9 ºC higher than the same collector without the radiator during 9.5 hours working with average radiation 598 $W \cdot m^{-2}$. The highest air heating solar collector efficiency $\eta = 0.89$ was achieved in the collector with the water radiator. Efficiency without a radiator was $\eta = 0.62$ at the same weather conditions. These researches show the applicability of air heated collectors with a water radiator for air heating at Latvia weather conditions.

Keywords: solar collector, air, water radiator, temperature, absorber.

Introduction

In many parts of the world there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in order to increase the productivity. Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agricultural application. The greatest advantage of solar energy as compared with other alternative sources of energy is that it is abundant, inexhaustible, clean and non-polluting.

Solar collectors are the key component of active solar-heating systems. They gather the sun energy, transform its radiation into heat, and then transfer that heat to a fluid (usually water or air). The solar thermal energy can be used in solar water-heating systems, solar pool heaters and solar space-heating systems. In general, solar water and solar air heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. Despite the similarity in designs, the different modes of operations and different properties of the heat transfer medium greatly affect the thermal performance and electric energy consumption for forcing the heat transfer medium through the collector. Solar water heaters are operated as a closed-loop system whereas, in most cases, solar air heaters are operated in the open-loop mode.

Solar air heaters are inherently low in thermal efficiency due to low heat capacity and low thermal conductivity of the air in comparison to the liquid-type solar collectors [1]. The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature, and wind speed), design parameters (type, materials, insulation) and flow parameters (air flow rate, mode of flow). The principal requirement for these designs is a large contact area between the absorbing surface and air.

The main problem is the low heat transfer coefficient between the absorber and air which reduces the thermal efficiency. Various absorber plates and glazing systems have been used in solar collectors. It is offered in a variety of design solutions [2-5], a variety of absorbent material solutions [6; 7] etc.

It should be noted that the solar radiation received by the collector is not constant. It is affected by clouds, dust, positioning of the absorbent. To align the collector heated air collector temperature is to put an additional source of energy that heats the air at low solar radiation. Such energy sources could provide water radiator to warm up at the sun rays and then heat the flowing air at low radiation. We want to study and compare hybrid (water radiator) air-heating solar collector operation with a collector without a water radiator. For experiments we used a sun tracked collector. The plane of FPC absorber is perpendicular to the flow of sun irradiance at this type of collector.

Materials and methods

The aim of our investigations was to compare the air heating degree at the same size and the same flowing through the air speed collectors with and without a water radiator.

The 0.1x0.5x1.0 meter long experimental solar collectors were constructed for the research Fig. 1. Both collectors are made with the same isolation and same absorbent material. We researched the situation when the absorber (black colored steel-thin plate) is put at the bottom of the collector. Air velocity in the collector was v = 0.9 m·s^{-1}. The open type water radiator Fig. 2 was made from copper pipes with a diameter 38 mm. Radiator dimensions 0.38x0.85 m, distance between sections 0.15 m. It was placed 2 cm from the absorber. This increases the contact surface area.

Fig. 1. **View of the air heating solar collectors during the experiment**

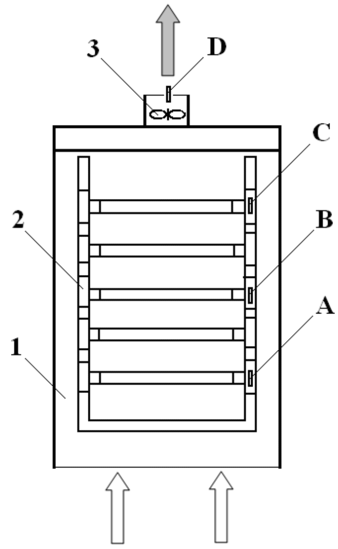

Fig. 2. **Scheme of hybrid collector:** 1 – collector body; 2 – water radiator; 3 – fan; A, B, C, D – places of temperature sensors

In the experiments, the collector cover material was a polystyrol plate. This material has gained immense popularity due to such properties as safety, mechanical crashworthiness, translucence and high UV radiation stability. The cover material – a polystyrol plate reduced the sun radiation by 12-15 %. The pyranometer was a solar radiation measuring instrument, which is used to measure total radiation.

The experimental data are recorded by means of an electronic metering and recording equipment for temperature, radiation and lighting REG “REG (2004)”. The pyranometer was the solar radiation measuring instrument.

The aim of our experiment was to investigate a possibility and analyze the use of water radiators in air heating solar collectors for Latvian climatic conditions. The experiments were made in 2012 in different weather conditions at different ambient air temperatures and wind speed.

Results and discussion

First, we compare the changes in water temperature in the radiator air inlet, depending on the distance. The data are shown in Fig. 3. The experiment took place on 2 August 2012. The results show a very strong correlation between the solar radiation and the water warm-up stage. The results show that the water radiator serves well to heat the air at low solar radiation (<300 W·m^{-2}). The water in the radiator heats up more than 30-35 degrees compared to flowing through the atmospheric air temperature. Solar radiation heats the water and it returns the stored energy to the flowing air when solar radiation falls.

Water temperature falls during the experiment indicate that the water accumulated solar energy is returned to the air flowing through the collector and warming it. At low solar radiation the absorber is unable to properly warm up the air and the radiator participating in air warming. Thus, the water radiator helps to smooth out the air temperature on cloudy days.

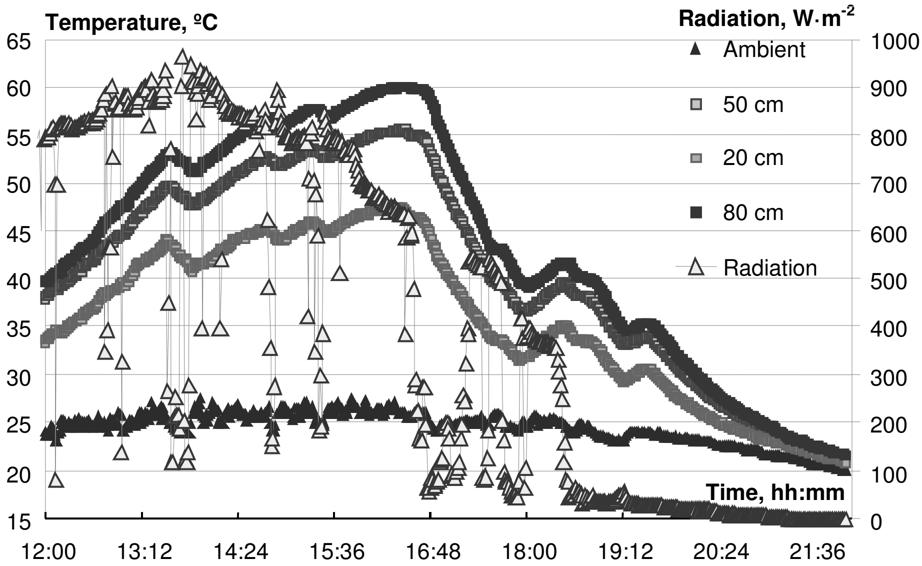

Fig. 3. **Radiator water temperature variations depending on solar radiation and distance from air inlet in collector** (A, B, C from Fig. 2)

With decreasing of solar radiation (evening hours) the radiator serves as an additional heat source for heating the air in the collector. It is easily seen in Fig.4. In all cases, at low solar radiation the atmospheric air warm-up ratio is higher in the collector with water heat radiators than the collector without the radiator.

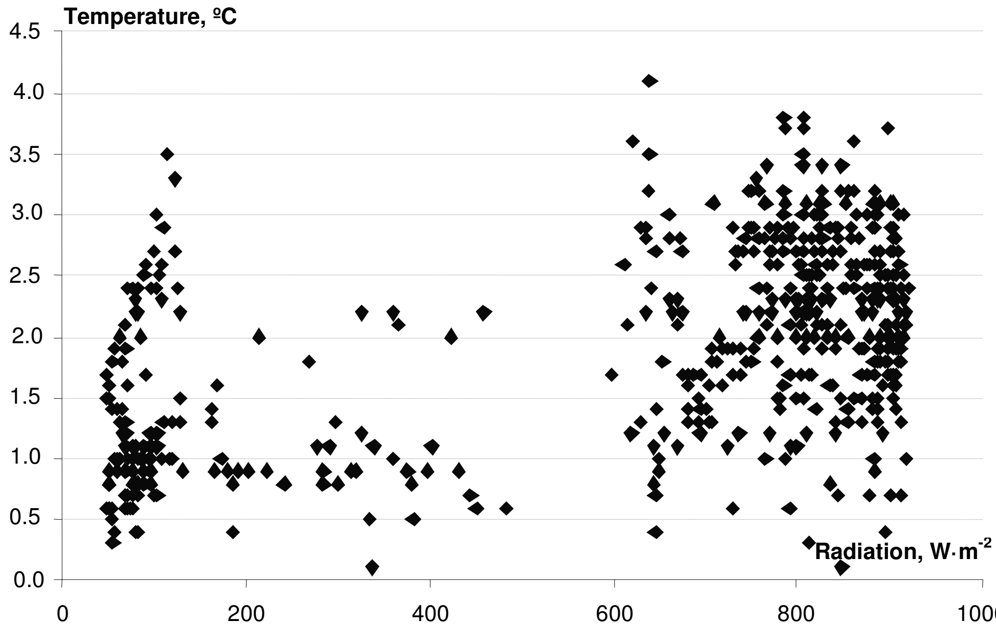

Fig. 4. **Outlet air temperature from collector with water radiator and without radiator difference depending on solar radiation (9:30-19:00 14.06.2012)**

The collector with the radiator average outlet temperature was 1.9 ºC higher than the same collector without a radiator during 9.5 hours working with average radiation 598 $W \cdot m^{-2}$ during the experiment.

The water radiator effect on the air flow outlet temperature in the solar collector, relative to the collector without a radiator can be seen in Fig. 5. At high radiation (>600 $W \cdot m^{-2}$) there is no significant difference in the atmospheric air preheating degree. Slightly higher temperature in the collector with the radiator can be explained by the greater air contact surface area.

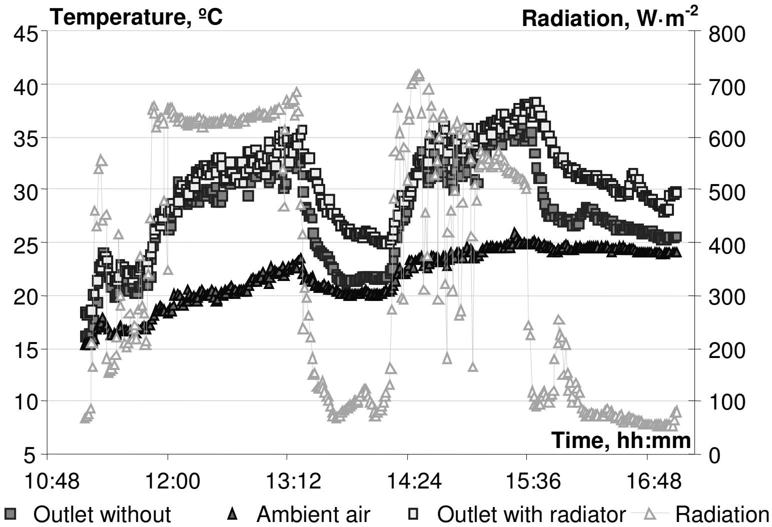

Fig. 5. **Outlet air temperatures from collector with water radiator and without radiator comparing with solar radiation and ambient temperature (11:00-17:10 11.09.2012)**

Much greater difference occurs when radiation falls fast, up to 100-200 W·m^{-2}. The solar absorber cannot absorb enough solar radiation to warm up itself and then heat the air. Then the hot-water radiator played the main role for air heating. The heated air temperature can vary by up to 4 degrees in our case.

We determined the efficiency of the solar collectors, as prescribed in ASHRAE Standard 93 2003. The efficiency of the solar collector can be calculated by the following equation [8]:

$$\eta = \frac{m \cdot c_p \cdot (T_{out} - T_{in})}{S \cdot R_T} \tag{1}$$

where η – efficiency coefficient of solar radiation converted into heat;
m – mass flow rate of air, kg·s^{-1};
c_p – specific heat, J·kg·ºC^{-1};
S – area of solar collector, m^2;
R_T – global solar irradiance incident upon aperture plane of collector, W·m^{-2};
T_{in} , T_{out} – inlet and outlet working air temperatures, °C.

The collector efficiency can be increased by increasing the mass flow rate and the differences in temperature (T_{out} - T_{in}). With equation (1) the effectiveness coefficient was defined over the all experimental time using average working air temperatures and radiation. In our case, the air heating solar collector efficiency coefficient η with the water radiator η = 0.89, without a radiator η = 0.62. It is higher than the absorber (black colored steel tin-plate) placed in the middle of the collector η = 0.76.

This increase is well shown in Fig. 6. Temperature increase dependence on solar radiation is characterized by coefficients of determination. The highest rate R^2 = 0.72 was with the data where the absorbent is in the middle of the collector. This indicates that such a collector reacts fastest to the radiation changes. The lowest coefficient of determination R^2 = 0.51 gives the data from the collector with a water radiator.

This indicates that the air warm-up ratio is not only dependent on the solar radiation but also on the water radiator size and the degree of warm-up, especially with the rapid changes in radiation. The results showed that the collector thermal efficiency increased by greater contact volume of air.

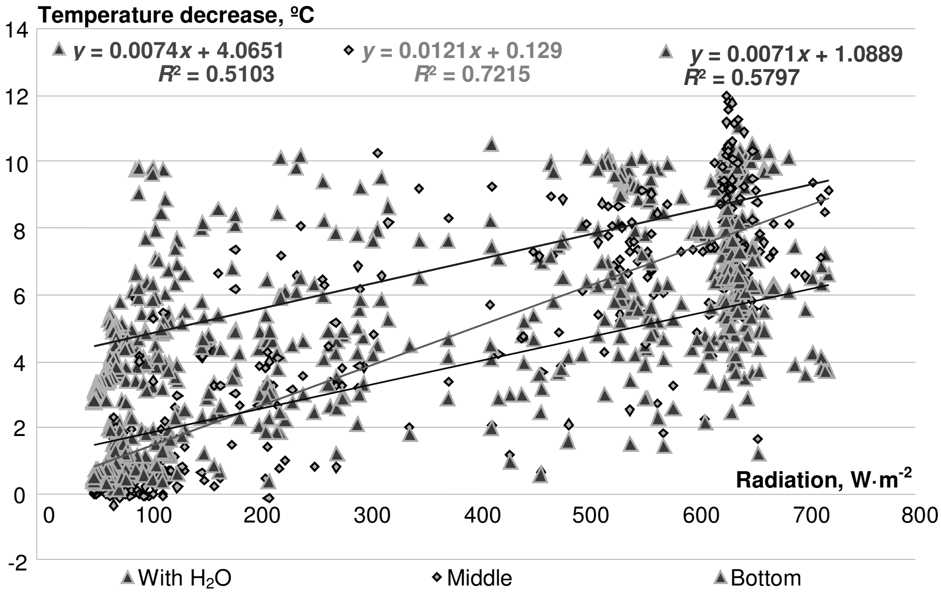

Fig. 6. **Outlet atmospheric air temperatures decreases (with collector with water radiator, without radiator and absorber steel tin-plate in middle) comparing with solar radiation and temperature decrease (11:00-17:10 11.09.2012)**

Conclusions

1. The same size and the same air mass flow rate 0.03 $kg \cdot s^{-1}$ collectors with and without a water radiator were tested. The highest air heating solar collector efficiency η = 0.89 was achieved in the collector with a water radiator. The efficiency without a radiator was η = 0.62 at the same weather conditions.
2. For the collector with the radiator average outlet temperature was 1.9 ºC higher than for the same collector without a radiator during 9.5 hours working with average radiation 598 $W \cdot m^{-2}$ during the experiment.
3. The air temperature heated in the collector with the water radiator is less dependent on rapid changes in solar radiation. The heated water radiator allows extending the air-heating solar collector duration of heating, especially in the evening hours, when sun radiation decreases.
4. The heated water radiator allows extended air heating solar collector duration of working. In addition, the heated water in the radiator can be used as washing liquid after the working day.

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