DIFFERENT MATERIAL INVESTIGATIONS IN AIR-HEATING FLAT-PLATE SOLAR COLLECTOR

Guntis Ruskis, Aivars Aboltins, Janis Palabinskis
Latvia University of Agriculture
guntisruskis@inbox.lv, aivars.aboltins@inbox.lv, janis.palabinskis@llu.lv

Abstract. The aim of the investigations was to compare different absorber material efficiency and also efficiency of isolated and non isolated collectors. The 0.1x0.5x1.0 meters long experimental solar collector was constructed for investigations and different types of absorber materials were made. We analyzed the manifold length, sun radiation effect on the degree of air heating. ASHARE used standard 93-2003 is calculated for each type of solar collector and absorber effectiveness. We determined the influence of sun radiation to the air heating degree for these types of absorbers. The experimental data were measured and recorded in the electronic equipment REG. The collector covered material was a polystyrol plate and different absorbers. We compared isolated and non isolated collectors to prove that the isolated collector is more effective. The isolated collector was made by the collector surfaces faced with cellular plastic 2 cm plates. Our task was to calculate the air heating solar collector efficiency. The collector efficiency coefficient is not significantly affected by the experiment time period. We can use a shorter time interval (up to 30 minutes) to determine the collector efficiency. Isolation shows great efficiency in windy weather conditions. The isolated collector gives almost two times more efficiency than non-isolated collector (up to 93 %) with absorbent material steal tinplates on top. Using this method we can compare different sizes, different air speeds, different coatings and insulating solar collectors.

Keywords: solar energy, absorber, air heating.

Introduction

Today, solar heating is becoming more important than ever before. Natural gas and oil which are burned to heat our homes and water are limited. As reserves of gas and oil shrink, these fuels become more expensive. If more people began using solar heating systems, fossil fuels such as oil and gas would become less expensive and last longer. Burning natural gas and oil in our heating systems also causes air pollution. So if more people used solar energy to heat the air and water in their homes, our environment would be cleaner [9].

For example, California set a target by the year 2017 to install 200 000 new solar hot water heaters, but Hawaii is the first U.S. state where the adoption of the law, that all of the new built homes must be equipped with solar panels, is obligatory energy-saving system. The law came into force in 2010 [10].

Under the Kyoto targets, the European Commission member states and stakeholders identified and developed a range of cost-effective measures to reduce emissions. The new package sets a range of ambitious targets to be met by 2020, including improvement of the energy efficiency by 20 %, increasing the market share of renewable to 20 % [1].

Solar energy is used to heat and cool buildings (both actively and passively), for drying products, heat water for domestic and industry use, to heat swimming pools, generate electricity, for chemistry applications and many more operations. In generally most of solar heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature and wind speed), design parameters (type of collector, collector materials) and flow parameters (air flow rate, mode of flow). The principal requirement of these designs is a large contact area between the absorbing surface and air [1].

The efficiency of solar collectors depending on the collector covered materials (polyvinylchloride film, cell polycarbonate PC, translucent roofing slate) absorber (black coloured wood, steel-thin plate etc.), with different air velocities in the collector was investigated. The main efficiency parameter of solar collectors is the air heating degree and it was chosen as the only criterion of efficiency [6-8].

The aim of our investigations was to compare new absorber material use and to make out their usability in sun air heating collectors. Our investigations are devoted the sun following collectors, which guarantee perpendicular location of the plane of absorber from the flow of sun radiation.

Materials and methods

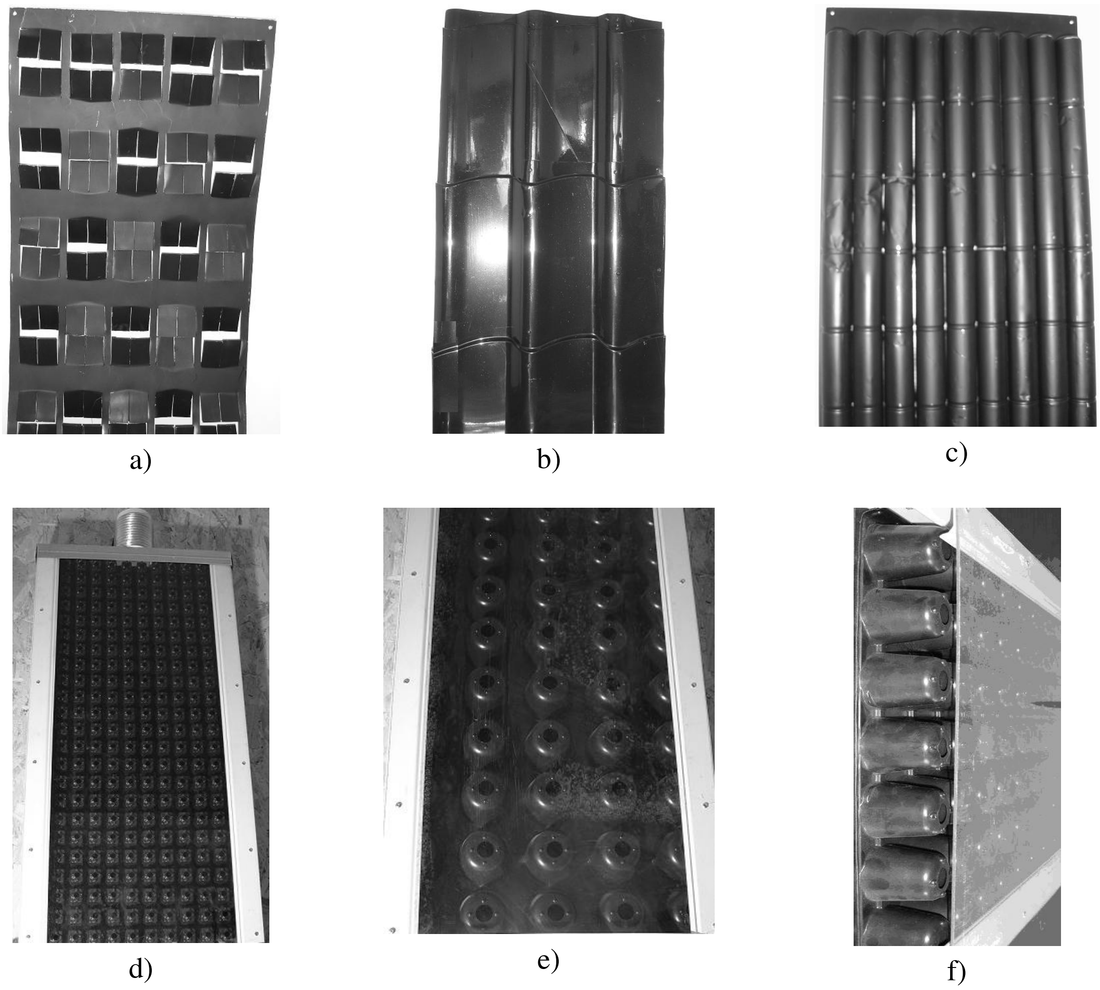
We compared isolated and non isolated collectors to prove that the isolated collector is more effective, because heat always tries to move from a hotter object to a colder one. Insulation is what prevents or slows down the movement of heat. Because insulation prevents the heat inside a solar collector from moving to outside where the temperature is lower, it is an important part of any solar collector [5].

The solar radiation measuring instrument was the pyranometer which is used to measure total radiation within its hemispherical field of view. In the laboratory a 0.1x0.5x1.0 meters long experimental solar collector was constructed for research into the properties of absorber materials. The air velocity at the experiments was v=0.9 $m \cdot s^{-1}$. In the collector we used a fan with power 100 $m^3 \cdot h^{-1}$.

The isolated collector was made by the collector surfaces faced with cellular plastic 2 cm plates. In the experiments, the collector covered material was polystyrol plate. The covered material – polystyrol plate reduces sun radiation by 12-15 %.

The experimental data ared recorded by means of an electronic metering and recording equipment of temperature, radiation and lighting REG [2].

We use different absorber materials: black coloured energy drink cans, 5 seed boxes in line, 7 seed boxes in line, 12 seed boxes in line, 22 seed boxes in line, black coloured steal tinplate in base, black coloured steal tinplate in the middle, black coloured bended steal tinplate in the centre, black coloured steal tinplate in base + black coloured bended steal tinplate in the centre, steal tinplate on top, roof material in the centre, energy drink cans on the steal tinplate. Some of those absorbents are very specific (Fig. 1).



a) b) c)

d) e) f)

Fig. 1. **Absorbers visual view:** a – bended steal tinplate; b – roof material; c – energy drink cans on steal tinplate; d – 12 seed boxes in line; e – 5 seed boxes in line; f – 7 seed boxes in line

The experiments were made in 2010 from spring to autumn in different weather conditions at different ambient air temperatures and wind speed.

Our task was to calculate the air heating solar collector efficiency. For calculations we used daily average atmospheric temperature, the average outgoing air temperature and average daily radiation. To compare different weather conditions influence we used constant radiation conditions not less than 0.5 hours and calculated the average atmospheric temperature, air temperature leaving the collector and average sun radiation in this time.

Results and discussion

The thermal performance of a flat plate solar collector relates the solar radiation input (I_T), the useful energy gain (Q_u), and the heat losses (Q_L), expressed as [3]:

$$Q_u = S \cdot I_T(\tau\alpha) - Q_L, \tag{1}$$

with

$$Q_L = S \cdot U_L \cdot (T_{abs} - T_a). \tag{2}$$

Here, $\tau\alpha$ represents the fraction of the solar radiation absorbed by the collector and depends mainly on the transmittance of the transparent covers and on the absorbance of the absorber. The higher this parameter, the better the collector. U_L is the collector overall heat loss coefficient. The smaller this parameter, the best the collector. S is the collector area in meter squared, T_{abc} and T_a are absorber and ambient temperatures. Eqs. (1) and (2) can be combined and rewritten as [3]:

$$Q_u = S \cdot F[I_T(\tau\alpha) - U_L(T_{abs} - T_a)]. \tag{3}$$

F is the collector efficiency factor. It depends on the details of the construction [3].

The overall heat loss coefficient is a complicated function of the collector construction and its operating conditions, given by the following expression [1]:

$$U_L = U_t + U_b + U_e, \tag{4}$$

where U_t = top loss coefficient, W·m^{-2}-K^{-1};
U_b = bottom heat loss coefficient, W·m^{-2}-K^{-1};
U_e = heat loss coefficient from the collector edges, W·m^{-2}-K^{-1}.

The energy losses from the top of the collector:

$$U_t = \frac{1}{\dfrac{N_g}{\dfrac{C}{T_p}\left[\dfrac{T_p - T_a}{N_g + f}\right]^{0.33} + \dfrac{1}{h_w}}} + \frac{\sigma\left(T_p^2 + T_a^2\right)\left(T_p + T_a\right)}{\dfrac{1}{\varepsilon_p + 0.05N_g\left(1 - \varepsilon_p\right)} + \dfrac{2N_g + f - 1}{\varepsilon_g} - N_g}, \tag{5}$$

where $f = (1 - 0.04h_w + 0.0005h_w^2)(1 + 0.091N_g)$
$C = 365.9(1 - 0.00883\beta^2)$
$h_w = \dfrac{8.6V^{0.6}}{L^{0.4}}$
ε_p = infrared emissivity of absorber plate;
ε_g = infrared emissivity of glass cover;
T_p = plate temperature, °C;
T_a = ambient air temperature, °C;
N_g = number of coated glass;
σ = Boltzmann constant;
β = collector slope angle, degrees.

The energy loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transfered to the surrounding ambient air. Because the temperature of the bottom part of the casing is low, the radiation term ($h_{r,b-a}$) can be neglected; thus the energy loss is given by [1]:

$$U_b = \frac{1}{\frac{t_b}{k_b} + \frac{1}{h_{c,b-a}}} \tag{6}$$

In a similar way, the heat transfer coefficient for the heat loss from the collector edges can be obtained from [11]:

$$U_e = \frac{1}{\frac{t_e}{k_e} + \frac{1}{h_{c,e-a}}} \tag{7}$$

where t_e , t_b = thickness of insulation /edge, back/, m;
k_e, k_b = conductivity of insulation /edge, back/, W·m^{-1}-K^{-1};
$h_{c,e-a}$, $h_{c,b-a}$ = convection heat loss coefficient from /edge, back/ to ambient, W·m^{-2}-K^{-1}.

As you can see it is very difficult to calculate total energy loses. Therefore, for efficiency calculation we use a different method.

The useful heat gain can also be expressed from the working mass flow rate (m) through the collector and the inlet (T_{fi}) and outlet (T_{fo}) working air temperatures as [3]:

$$Q_u = m \cdot c_p (T_{fo} - T_{fi}) \tag{8}$$

The collector instantaneous efficiency $\eta(t)$ is influenced by several factors such as the material used, the design of the absorber, the properties of glass, air and operating conditions. It is defined as the ratio of the useful heat gain (Q_U) to the solar radiation intensity $I_T(\tau\alpha)$ [3].

$$\eta = \frac{Q_u}{S \cdot I_T \cdot (\tau\alpha)} \tag{9}$$

We accepted the coefficient $\tau\alpha$ in all cases equal to 1 because the covered material is the same for all collectors and the collectors have the same construction. We determined the efficiency of the solar collector, as prescribed in ASHRAE Standard 93 2003, the efficiency of the solar collector can be calculated by the following equation [4]:

$$\eta = \frac{m \cdot c_p \cdot (T_{fo} - T_{fi})}{S \cdot I_T} \tag{10}$$

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·°C^{-1};
S = area of solar collector, m^2;
I_T = global solar irradiance incident upon the aperture plane of collector, W·m^{-2}.

With the equation (11) were defined the effectiveness coefficient over the whole experimental day and the same experiment day time interval of 30 min, when radiation is high and constant. The calculated results for non isolated collectors with different absorbent materials are shown in Table 1.

In Table 1 we can see that 12 seed boxes in line absorbent are most effective. But we calculated the efficiency coefficients using equation (11) also for the isolated collector model. The calculated results for isolated collectors with different absorbent materials are shown in Table 2. This correlation is used in the collector area comparison, it should be noted that the absorbent surface area is larger than the collector area. And, therefore, to compare the effectiveness of the absorbent, we should use the absorbent surface area. It also notes that with a rugged absorber surface absorption is better.

Table 1

ASHRAE Standard 93 – 2003 efficiency coefficients for non isolated collectors

Non isolated collector with absorbent material:	On average in half an hour	On average in experiment day
5 seed boxes in line	0.89	0.91
7 seed boxes in line	0.98	1.04
12 seed boxes in line	1.24	1.38
22 seed boxes in line	0.60	0.69
Steal tinplate in base	0.41	0.42
Steal tinplate in a middle	1.16	1.13
Bended steal tinplate in a centre	1.15	0.99
Steal tinplate in base + Bended steal tinplate in a centre	0.94	1.11
Steal tinplate on top	0.46	0.44
Roof material in a centre	0.72	0.63
Energy drink cans on steal tinplate	0.95	0.89

Table 2

ASHRAE Standard 93 – 2003 efficiency coefficients for isolated collectors

Isolated collector with absorbent material	On average in half an hour	On average in experiment day
Steal tinplate on top	0.89	0.87
Energy drink cans on steal tinplate	1.60	1.44
Steal tinplate in a middle	1.23	1.25
Bended steal tinplate in a centre	1.47	1.56

We compared isolated and non isolated collectors with the same absorbent material and the results are shown in the diagram (Fig. 2). In it we can see that the isolated collector is more effective than the non isolated collector.

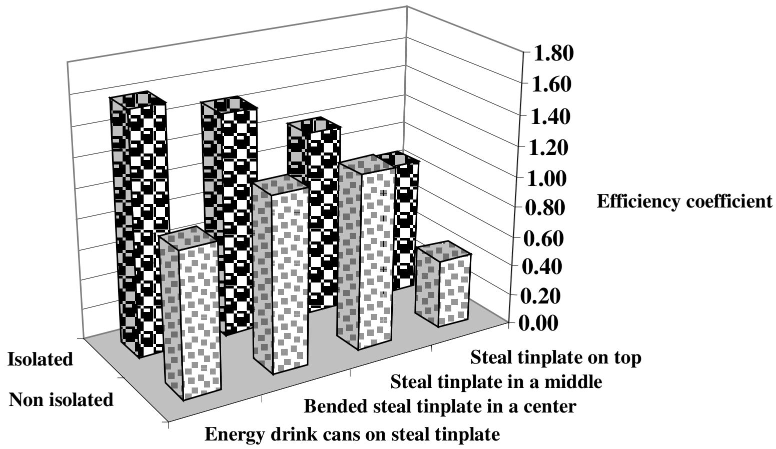


Fig. 2. **Efficiency diagram of isolated and non isolated collectors**

Conclusions

1. The collector efficiency coefficient is not significantly affected by the experiment time period. We can use a shorter time interval (up to 30 minutes) to determine the collector efficiency.
2. We must be careful with shorter time intervals when determining the collector efficiency (especially at changing weather conditions) because the collector keeps the absorbent temperature inertia.

3. Isolation shows great efficiency in windy weather conditions. The isolated collector gives almost two times more efficiency than the non-isolated collector (up to 93 %) with absorbent material steal tinplates on top.
4. Using this method we can compare different sizes, different air speeds, different coatings and insulating of solar collectors.

References

1. Kalogirou S. Solar energy engineering: processes and systems. First edition, USA: Academic Press Elsevier Inc., 2009. 760 p.
2. REG Technical description and using instruction, 2004. 11 p. (in Latvian).
3. Andoh H.Y., Gbaha P., Koua B.K., Koffi P.M.E., Toure S., Thermal performance study of a solar collector using a natural vegetable fiber, coconut coir, as heat insulation. Energy for Sustainable Development, vol. 14, 2010, pp. 297-301.
4. Morson I., Performance Review of the SH 1500G Solar Air Heater, Manufactured by Your Solar Home, April 17, 2007, pp. 3.
5. Clearinghouse, Energy Efficiency and Renewable Energy, DOE/CH10093-272, FS 118, August 1994, pp. 2.
6. Aboltiņs A., J. Palabinskis, G. Ruskis, The Investigations of Heating Process in solar Air Heating Collector. Agronomy Research, “Biosystems engineering”, May 27-28, 2010, Jelgava, Latvija, pp. 5-11.
7. Aboltins A., Palabinskis J., Lauva A., Ruskis G., 2009. Investigations of Air Solar Collector Efficiency. In: Malinovska, L. (eds.), Proceedings of the 8th International Scientific Conference. “Engineering for Rural Development”, May 28-29, 2009, Jelgava, Latvija, pp. 176-181.
8. Aboltins A., Palabinskis J., Lauva A., Ruskis G., Steel-Tinplate Absorber Investigations in Air Solar Collectors In: Malinovska, L. (eds.), Proceedings of the 8th International Scientific Conference. “Engineering for Rural Development”, May 28-29, 2009, Jelgava, Latvija. pp. 182-187.
9. Mechanical technologies. Air conditioning/refrigeration/low temperature. [online] [20.04.2011.]. Available at: http://www.epmechtech.com/sun_power.html.
10. Kalifornija ieguldīs trīs miljardus dolāru saules enerģijas izmantošanā. (In Latvian). [online] [20.04.2011]. Available at: http://www.delfi.lv/news/world/other/kalifornija-ieguldis-tris-miljardus-dolaru-saules-energijas-izmantosana.d?id=13310998.