Application Possibilities of Building Integrated Solar Tile Collectors

István Fekete[a] and István Farkas[b*]

[a]Faculty of Mechanical Engineering and Automation, Pallasz Athéné University
Tiszaligeti sétány 14., Szolnok, H-5000 Hungary
Email: feketei@szolf.hu

[b]Department of Physics and Process Control, Szent István University
Páter K. u. 1., Gödöllő, H-2100 Hungary

Abstract: This paper is dealing with the development of a new type of shell-structured solar collector for the heat exploitation of solar energy for building use and to define its thermal efficiency. The literature review confirms that solar collectors appreciated not only by their usefulness, but also according to their aesthetic considerations. In addition to traditional solar collectors is viable to study the solutions how the structural elements of the buildings can be used to capture solar energy, when the architectural design would not change, but the required surface operates as solar collector.

During the modelling and simulation of the solar system strong consideration was given to the efficiency issues. The energy balance equation of the collector includes the influencing factors especially the radiation and heat convection, which are expressed by their heat loss coefficients. The temperature distribution on the collector surface was validated by an infrared camera recording.

A recommended use of such protected architectural elements designed for the renovation of buildings, along with the active utilization of solar energy in order to meet the increasingly stringent building energy standards.

1. Introduction

Significant research and development activities for the capture and utilization of renewable forms of energy that led to the birth of applying them, and equipment, design of systems for the past decades, commercially viable technologies.

The literature review confirms that people appreciated with solar collectors not only by their usefulness, but also according to aesthetic considerations. In addition to the traditional solar collectors (Fig. 1) it is also required to study how reliable when the building's structural elements are also be used to capture solar energy. The mentioned idea initiated to take into account new, non-standard solutions as for example a building integrated tile collector system.

In order to study the bodies of the developed new type of collector along with their thermal behaviour a mathematical model and simulation experiments can be successfully applied. Additionally, in order to investigate the incident solar radiation energy characteristics several measurements were performed on samples of different material surfaces.

The equipment designed and built based on the abovementioned ideas in order to meet expectations in the most options. Preliminary economic calculations have to be performed to examine the possibility of investment in a given solar system parameters and economic return. That is why it is needed to recognize such characteristics, advantages and disadvantages acknowledged in connection with the solar tile collector systems.

*Corresponding author, Email: Farkas.Istvan@gek.szie.hu

Fig. 1. The traditional structure design of solar collectors

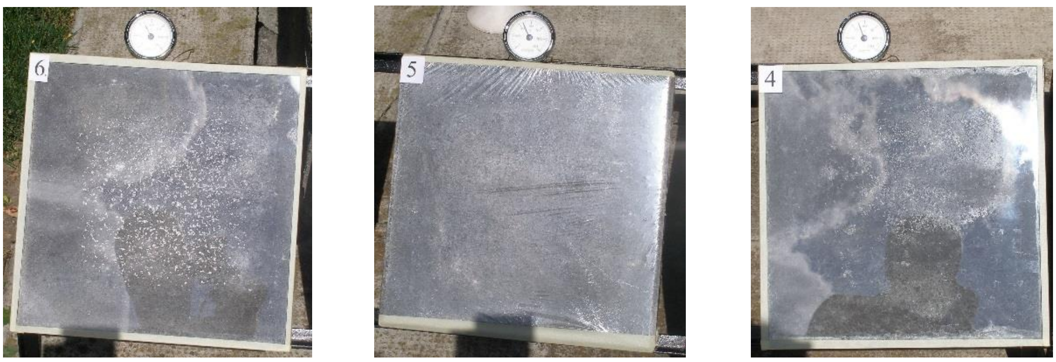
2. Roof integrated solar tile collectors

In this section, the development of roof-integrated solar thermal collector structures and their implementation possibilities of are discussed.

2.1. Materials to be used for tile collector

Simplified mathematical modelling approach along with measurements are to be carried out at different surfaces in order to decide about the most relevant solution for optimal capture of solar radiation. The probable test materials are shown in Fig. 2.

a) Black painted concrete b) Lacquered concrete c) Natural concrete



d) Plexiglass surface (1 mm) e) Thin plastic film surface f) Glass surface (2 mm)

Fig. 2. Different test examples

The absorbed radiation energy is partially lost by heat conduction to another parts of the collector layout and also by convection to the environment. The useful heat is transported by the collector fluid through the entire system. The level of radiation emissions, the environment and radioactive material depends on the temperature difference and the greater, the larger the temperature difference (Kendrick, 2009).

A desired temperature value of the absorber surface (T_t) can be reached when the heat formed by the incoming global radiation, and it is equal to the sum of heat loss and the conveyed heat energy:

$$I_g\, \alpha = f\,(T_t - T_a). \tag{1}$$

The proportionality factor (f) depends not only on the heat transfer factors, but also on the absorbing surface material and its design and quality. Furthermore it is influenced by temperature and distance from surrounding objects and wind speed, as well.

For example, in case of rough grey concrete surface with the following parameters of: I_g = 600 W/m^2 incoming radiation, T_a = 20 °C ambient temperature, v = 1 m/s wind speed, k = 20 W/m^{2}K heat transfer coefficient and for concrete α_{co} = 0,6 the expected temperature can be calculated as follows:

$$T_t = \frac{I_g\ \alpha_{co}}{k} + T_a = \frac{600\ 0{,}6}{20} + 20 = 38\,°C\,.$$

If the absorbing surface is covered with a transparent layer, the heat loss is reduced and the body temperature is increased under the same incoming radiation conditions. The surface temperature of the absorbing concrete, if there is a layer behind the glass, and it is insulated from its surroundings ideally with the parameters, incoming radiation I_g = 600 W/m^2, ambient temperature T_a = 20 °C, α_{co} = 0.6, β = 5 W/m^{2}K, a_{gl} = 0.8 is:

$$T_t = \frac{I_g\ a_{gl}\,\alpha_{co}}{\beta} + T_a = \frac{600\ 0.8\ 0.6}{5} + 20 \cong 77.6\,°C\,.$$

For example, if the conveyed specific performance E_c = 200 W/m^2. The surface temperature of the absorbing layer behind a glass can be as:

$$T_t = \frac{I_g\ a_{gl}\,\alpha_{co} - E_c}{\beta} + T_a = \frac{600\ 0.8\ 0.6 - 200}{5} + 20 \cong 37.6\,°C\,.$$

The resulting energy can be conveyed by liquid or air according to the type of collector working medium. Based on the discussed examples it can be stated that the uncovered surfaces behave more dynamically, while the covered surfaces showed a slower warming or cooling.

2.2. Construction of the shell-structured collector system

Positioning the solar collectors are usually done on roof surface. In this context of the before mentioned application, the main goal is here to replace the traditional collectors with aesthetic reasons, so concrete tile form was considered to design and use.

The converted corresponding load elements were made of a painted surface. The planning process is to illustrate two examples shown in Figs 3-4.

The concrete made tile shape and sizing constraints were part of the heat exchanger construction and its positioning. The pipe distance should follow the formal characteristics and dimensions of the original concrete tiles. Due to the better heat transfer processes the heat exchanger has to be located close to the planned absorber layer. However, this design, where the pipe system is positioned in touching the tile surface is not been very adequate for strength reasons (Fig. 3).

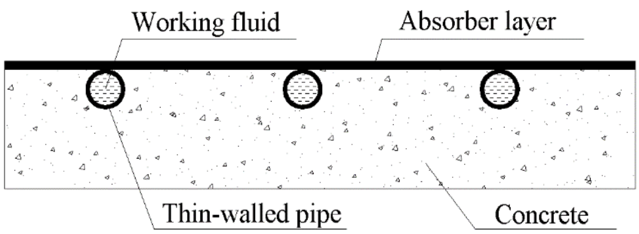


Fig. 3. Structure of tile element with touched absorber and the pipe

Another type of layer-planning design structure of the solar tile collector system, where the thin-walled pipe system is installed inside of the concrete made layer, is shown in the Fig. 4.

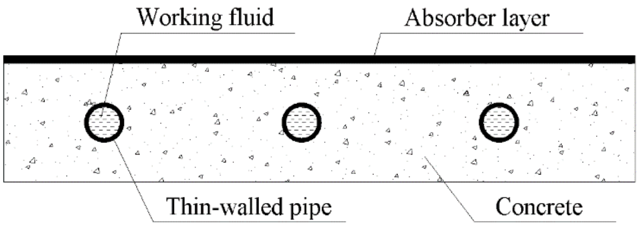


Fig. 4. Structure of tile element without touched absorber and the pipe

The actually produced tile element, which has the same size of a commercially available ordinary roof tile, is shown in Fig. 5. For better illustration purposes, the internal heat exchanger is placed on the interface. The entire collector surface design of about 2 m^2 is shown in Fig. 6.

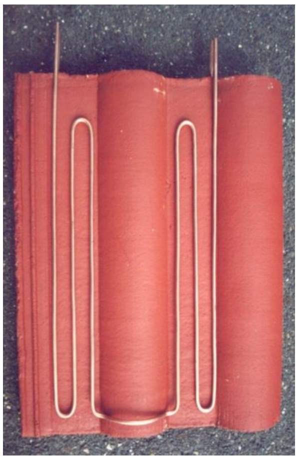


Fig. 5. The tile element design

Fig. 6. Surface of the tile collector

Based on the modelling and simulation results a pilot system was planned and constructed. The system can serve to perform comparative measurements as expected in the course of modelling simulation processes. The tilt angle of the equipment can vary between 30°- 45° and additionally, the azimuth angle is adjustable in the range of 0°- 360° degrees. Fig. 7a shows how the complete pipe junction system was installed along with the closer fitting arrangements in Fig. 7b.

a) pipe junction system b) fitting arrangements

Fig. 7. Rear surface of the tile collector

For illustrating the influences of heat flow, in Fig. 8 the infrared camera recording shows the temperature distribution of the tile surface. In the bottom of tile it can be seen that the outlet fluid is still cold. In top of the tile a constant, controlled state can be observed, where the temperature of the outlet fluid and the surface are nearly the same.

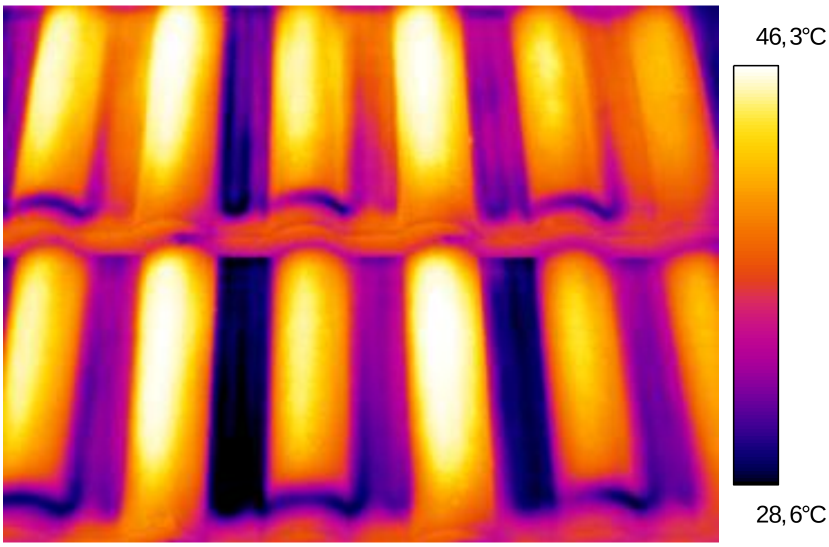


Fig. 8. Visualization the temperature distribution of the tile collector

3. Efficiency range of the tile collector

A comparative study, produced for the first time on a typical solar thermal collector has been examined and verified as a method for calculating efficiency. The experiment has been performed with a Vitosol 100, AP-20, 2 m^2 surface of Cu-based solar absorber for determining the efficiency along with 800 W/m^2 of solar radiation intensity which is a normal value for summer period.

The collector efficiency can be calculated with the usual second order power function described as follows:

$$\eta = \eta_o - k_1 \frac{\Delta T}{I_g} - k_2 \frac{\Delta T^2}{I_g}, \tag{2}$$

$$\Delta T = T_m - T_a, \; T_m = T_{in} + \frac{T_e - T_{in}}{2},$$

where: T_m [K], average temperature of fluid; T_a [K], ambient air temperature; T_{in} [K], inlet temperature of fluid; T_e [K], outlet temperature of collector fluid; I_g [W/m^2], the global radiation; k_1, heat dissipation factor (thermal conductivity); k_2, heat loss coefficient (thermal radiation) and η_0, optical efficiency. The comparative values of optical efficiency and heat dissipation factors of factory data based in the case of Vitosol 100 were as follows: η_0= 81%, k_1 = 3,78 W/m^2K and k_2 = 0,013 W/m^2K^2.

Orientation measurements were also carried out in advance. Expected amount of heat was resulting from solar radiation on this basis. The results of the efficiency approximation curve is shown in Fig. 9.

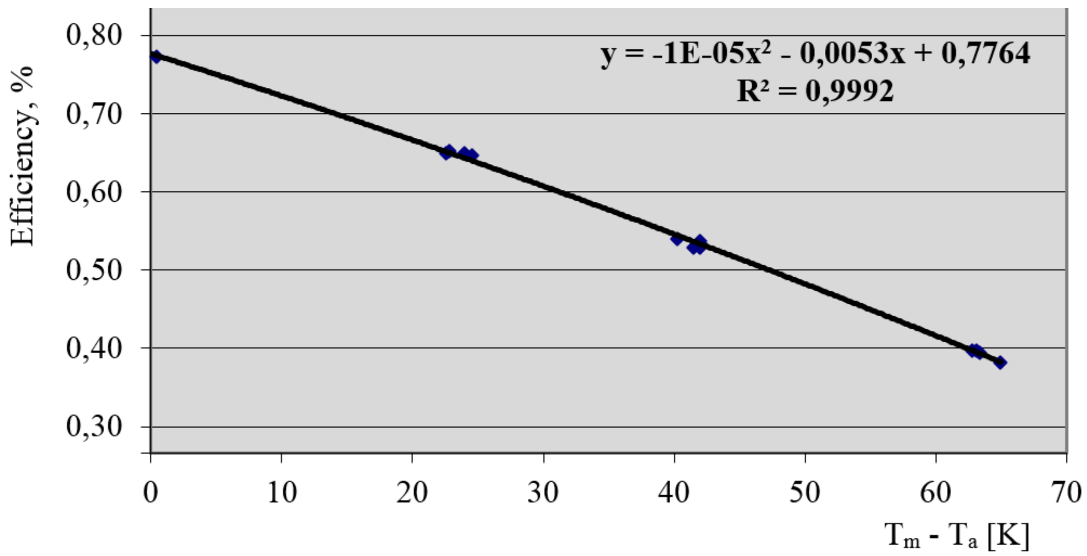


Fig. 9. Solar collector efficiency curve (I_g = 800 W/m^2)

The test efficiency parameters (η_0) cannot be measured directly, therefore the estimated parameters were determined using extrapolation. Calculated from the measured data the optical efficiency was $\eta_0 = 0,776$.

The parameters of the efficiency curve of Eq. (2) were identified as the first degree heat loss (thermal conductivity) characteristic value $k_1 = 4,24$ W/m^{2}K and the second-degree heat loss (radiation) typical value $k_2 = 0,008$ W/m^{2}K^2.

The efficiency calculation results show a reasonably good coincidence with the standard values used for comparison. The fluctuations between the actual operating conditions are differing only in a few percentages in the worse characteristics points compared to the test values of Vitosol 100 collector.

The measured data of the tile collector, converge properly, according to the calculations of expected. Based on the data (Farkas, 2011), the efficiency calculations were performed with several cases which shows that the values are within an appropriate area as shown in Fig. 10 in comparing to traditional solar collectors.

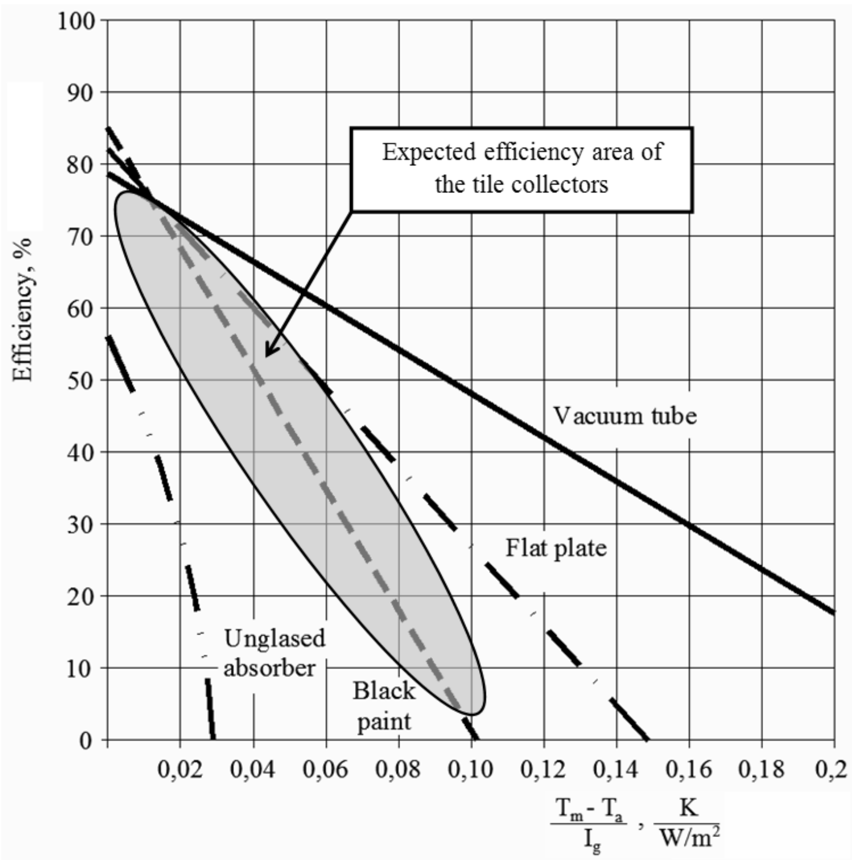


Fig. 10. Efficiency range of solar tile collectors system

4. Economic issues

There are several calculation methods to estimate the economics of solar thermal systems, for instance the multiple calculation method (Varian, 2005).

The preliminary financial analysis of the solar system, adverse, longer-term returns indicated. However, the actual increase in energy prices (electricity and/or natural gas) significantly shortened it. The price of solar collector system reduces the entire production. It seems, that a detailed financial analysis based on total energy price changes in a period of 10 years is an appropriate evaluation approach.

The improvements, efficiency of production processes are constantly evolving, so they can be observed decrease in the price. In addition to production costs, installation costs can be taken into account (Strategic research and innovation agenda for renewable heating & cooling, March 2013). The research and industry more and more attention is given to system integration, thus it is expected that installation costs will decline in the coming years.

5. <u>Conclusions</u>

Nowadays, high-rising pollution problems associated with sustaining economic growth. The renewable energy including solar energy available to all, decentralized exploitation could reduce it significantly. In addition to today's efficiency-driven, but costly development concepts exploiting the necessary working less efficiently but cheaper options available. The design is simple and easy to assemble machines that are suitable for a specific period of solar radiation energy cost of capturing the first conclusions of the results of that structural element formed by collector items.

The suggested building-integrated solar collector tile elements formed on the basis of the experimental and modelling results are efficient in the sense of energy saving, but also in the cases when they are replacing the conventional solar collectors due reference to aesthetic reasons. Thus, the solar tile collectors are recommend also to reduce the urban heat-island effect, when the heating of buildings worsens human comfort.

A commendable use of such protected architectural elements designed the renovation of buildings, increase the active utilization of solar energy in order to meet the increasingly stringent building energy standards.

6. <u>References</u>

Farkas, I. (2011), Solar energy applications, in Hungary, Renewable Energy Handbook 2011, /ed. by Kovács R./, Poppy Seed 2002 Bt, 2011.

Fekete, I. (2015), Building integrated shell-structured solar collectors, Thesis of PhD Dissertation, Szent István University, Gödöllő, Hungary, 2015.

Kendrick, C. (2009), Metal roofing on residential buildings in Europe: A dynamic thermal simulation study, Report 090903ECC, Oxford, September 2009.

Strategic research and innovation agenda for renewable heating & cooling, March 2013, http://decarboni.se/publications/strategic-research-and-innovation-agenda-renewable-heating-cooling/32-solar-thermal-technologies#fig_10 (2015.02.10.).

Varian, Hal R., (2005), Intermediate Microeconomics: A Modern Approach, 715 pages, published August 2005 by W. W. Norton & Company.