

Numerical and experimental study of building integrated solar tile collectors

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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 determine 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 it is viable to study the solutions how the structural elements of the buildings can also 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 shell-structured 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. Based on the measurements it can be stated that in the case of the simplest structural design (no thermal insulation, no surface covering) the working fluid can warm up to 20–25 °C. Concerning to the structural design the built-in pipe diameter cannot be increased over the half of the concrete tile thickness, and it is not suggested to increase the pipe length beyond 3 m within the tile. A recommended use of such architectural elements can be designed for renovation of buildings, along with the active utilization of solar energy in order to meet the increasingly stringent energy standards for buildings.

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1. Introduction

Major research and development activities in recent decades have led to the capture and exploitation of renewable energy resources (among them the solar energy), applications, equipment and commercially viable technologies.

The flat plate collectors are the most commonly used, traditional equipment to use the solar energy for making domestic hot water and heating of buildings (Fig. 1).

In furthermore, a short literature review is provided concerning to the main issues of the solar collectors. It includes the approaches for:

- the structural design,
- the thermal behaviour,
- the applied materials, and

- the environmental and social aspects.

Flat plate solar collectors (FPSC), a non-concentrating type of unit, consist of an absorber (made of copper or aluminium) and glazing, separated by an air layer. The absorber's bottom and sides are insulated. Many studies have been performed to understand the thermal behaviour of collectors whose efficiency depends on both the value of the incident solar radiation on the absorber and associated thermal losses [1–4]. According to these studies, it has been illustrated that the glazing collector is the most important source for thermal losses varying between 10% and 35%.

Many studies have been performed and techniques developed to reduce collector thermal losses, to modify the properties and form of the glazing, and to focus on the modification of the absorber shape. All of those studies gave an overview of FPSC's thermal behaviour and have provided many techniques to reduce their thermal losses but an economic approach has rarely been mentioned. The materials consumed for fabrication and so the final products are fairly expensive.

There are also some publications on the thermal behaviour

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Nomenclature		Δ	difference
A	surface (m ²)	η	efficiency (–)
c	specific heat (J/kgK)	ρ	density (kg/m ³)
d	diameter (m)	τ	transmissivity
E	energy loss (W/m ²)	<i>Subscripts</i>	
I	irradiance (W/m ²)	a	ambient
k	heat transfer coefficient (W/m ² K)	c	conveyed specific
m	mass (kg)	co	concrete
$\dot{m}$	mass flow rate of the working fluid (kg/s)	g	global
T	temperature (K)	gl	glass window
$\dot{T}$	temperature gradient/difference (K)	in	inlet
V	volume (m ³)	l	loss
w, h, l	geometric parameters (width, thickness, length) of tile (m)	m	average
<i>Greek letters</i>		o	optical
α	absorption coefficient	out	outlet
β	loss factor of glass	t	tile
		w	working fluid (water)



Fig. 1. The traditional structure design of solar collectors.

and performance estimations of polymer collectors [5,6]. The conclusion of these studies related to reductions in the weight by more than half of that in traditional collectors whilst providing similar performances. There must be a way for an appropriate development, junction of a cheap plastic water chamber, UV resistant PVC collector bodies to the heating and water preheating systems are to be considered.

Many studies have been performed so that the temperature difference existing, between urban areas and the surrounding suburban or rural areas, as much as 5 °C could be exploited. Nearly 40% of this increase is due to the prevalence of dark roofs, with the remainder coming from dark-coloured pavement. An urban heat island (UHI) is an urban or metropolitan area, which are significantly warmer than its surrounding rural areas due to certain human activities. The temperature difference usually is larger at night than during the day, and is most apparent when winds are weak. UHI is most noticeable during the summer and winter. The main cause of the urban heat island effect is originated from the modification of land surfaces. The heat island effect can be counteracted slightly by using white or reflective materials to build houses, roofs, pavements, and roads, thus increasing the overall albedo of the city. A cool roof made from a reflective material such as vinyl reflects at least 75% of the sun's rays, and emit's at least 70% of the solar radiation absorbed by the building envelope. Generally, any built-in solar collector can reduce the

overheating of the houses, as we transport the energy of the radiation arriving to the surface [7–10].

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

From an energy point of view, one might be less efficient, but with higher surface area of the solar tile system. At the same time, increasing the proportion of active solar energy use is of high importance and significance. There are significant subsidies to modernize the energy consumption, primarily for installation of solar collectors, which could help the structural revision of energy supply, and so use the newly considered solutions, as well.

In order to study the bodies of the developed new type of tile collector along with their thermal behaviour a mathematical modelling, simulation and experiments can be successfully applied. Additionally, for the investigation of the incident solar radiation characteristics several measurements have to be carried out on samples of different material surfaces to be used as absorber. The design of present heat exploitation solar collectors has a special structure in many cases, it uses special material

and therefore the expense of such energy production can be considered high [11,12].

For that reason, economic calculations have to be performed to examine the possibility of investment into a given solar water heating system including operational parameters and payback time. Consequently, it is needed to recognize the characteristics, advantages and disadvantages acknowledged in connection with the solar tile collector systems.

In this study, the development of a roof integrated shell-structured solar tile collectors is investigated for building use and to define their thermal efficiency. It includes the modelling and construction aspects and some remarks on the efficiency and economic issues, as well. An equipment is designed and built on the base of the abovementioned ideas in order to meet expectations in the most options.

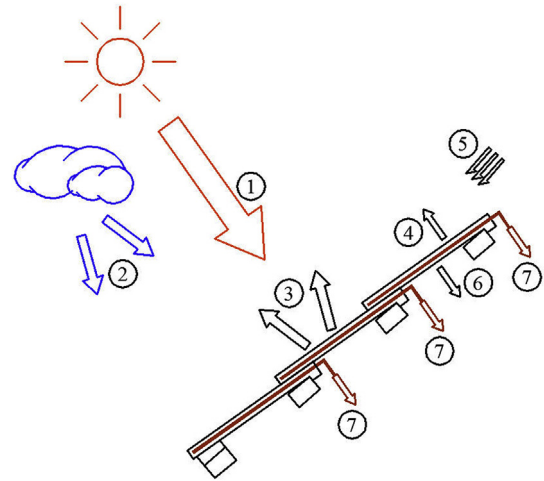


Fig. 3. Energy balance components of the solar tile collectors (1. Direct solar radiation, 2. Diffused solar radiation, 3. Reflection, 4. Losses from convection, 5. Wind, rain, snow convection, 6. Conduction losses, 7. Useful output).

2. Modelling aspects of roof integrated solar collectors

The required inspections and verification of theoretical calculations were carried out concerning the current design and manufactured equipment. The measurement site and the data logging system were designed so that could record more accurately the necessary climatic and collector specific site parameters. Matlab simulation software was used for handling and solution of the governing equations. In such a way, we were able to access different type of newer designs. This section contains only the main information concerning to the abovementioned issues. More details can be found in the reference of Fekete [12].

2.1. The useful amount of solar energy

In general, the geographical location of Hungary is appropriate for the use of solar energy. The amount of available solar energy reaches a significantly high level in this region, accordingly to the energy that may be produced by the collector bodies. Our experiments were carried out at Mezőtúr city which location is displayed in the country map along with the radiation values shown at the bottom of Fig. 2.

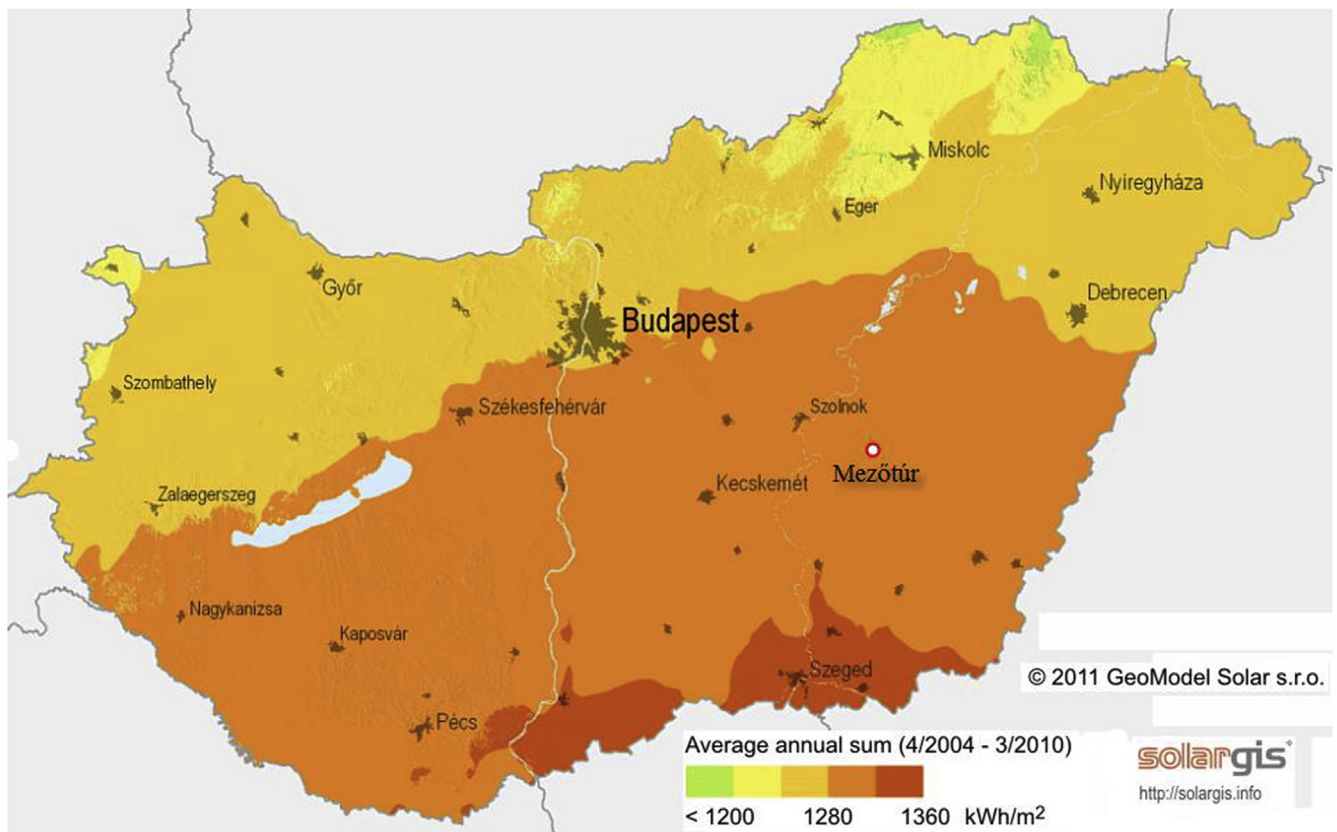


Fig. 2. The annual solar irradiation of Hungary (kWh/m², year).

The roof integrated collectors can convert solar irradiance into thermal energy with losses. These losses can be expressed as to optical and thermal losses. The major energy components can be seen in Fig. 3.

2.2. Mathematical modelling of the solar tile

The thermal behaviour of building integrated collector elements was analysed by simulation. The goal was to increase and optimize the thermal efficiency of the integrated shell-structured collector bodies. There is an opportunity to reach the technologically maximum efficiency by changing the structure and substance construction of the collectors [13–15]. The main influencing factors are the following: effective irradiation (I), ambient temperature (T_a), average temperature of working fluid (T_m), inlet temperature of working fluid to the collector (T_{in}). It is essential to measure the warming of the working fluid in order to calculate an accurate level of efficiency of collector according to the mass flow rate ($\dot{m}$). The temperature of solar tile (T_t) is mainly dependent upon the radiation intensity and the size of the absorber surface [16,17]. The input/output scheme of the solar tile element prepared for heat transfer modelling can be seen in

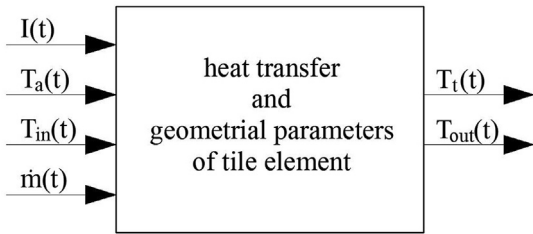


Fig. 4. The input/output scheme of the solar tile element.

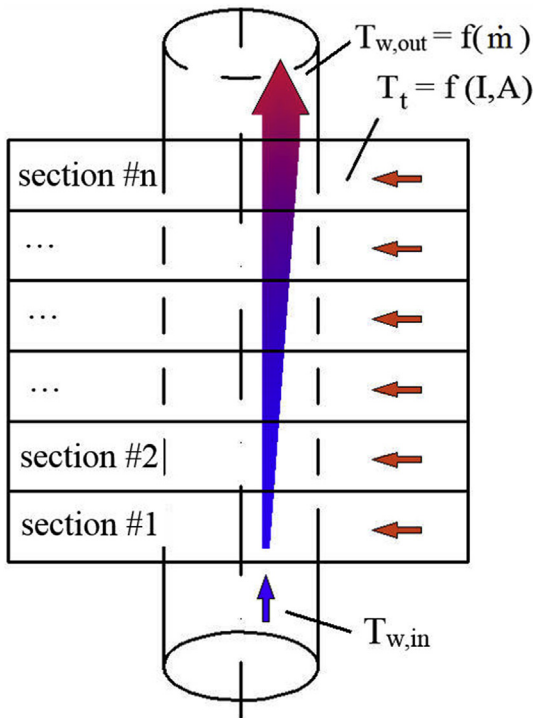


Fig. 5. Energy transfer scheme of tile element.

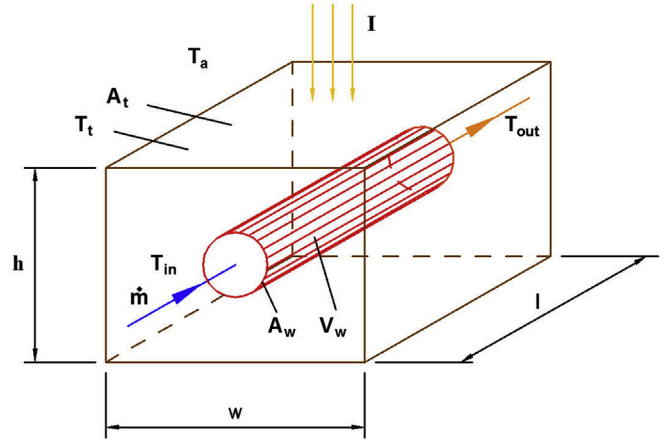


Fig. 6. Structure and heat balance scheme of tile element.

Fig. 4.

Based on the differential equation of heat transfer, the energy is conveyed from one section to another section discretized along the length of the tile elements depending on the mass flow rate (Fig. 5). In the figure there are displayed the section discretization, the inlet and outlet working fluid temperatures ($T_{w,in}$, $T_{w,out}$) and the tile element temperature (T_t).

In Fig. 6 the structure of a tile element can be seen along with the variable notations related to heat balance.

The details of the governing equations for the Matlab coded simulations are as follows:

Surface of the tile element in the direction of the ambient:

$$A_{ta} = 2 A_t + 2 l h. \quad (1)$$

Volume and mass of the tile element:

$$V_t = h w l, \quad (2)$$

$$m_t = V_t \rho_t. \quad (3)$$

The effective radiation intensity on the tile is a difference of global and loss intensities:

$$I = I_g - I_l. \quad (4)$$

The heat balance between the water and the tile can be written as:

$$c_w m_w \dot{T}_w = k_{wt} A_w (T_t - T_w). \quad (5)$$

The heat balance between the element of the tile and the ambient:

$$c_t m_t \dot{T}_t = I A_t + k_{ta} A_{ta} (T_a - T_t) - k_{wt} A_w (T_t - T_{out}). \quad (6)$$

The water temperature inside of the tile:

$$c_w \rho_w V_w \dot{T}_{out} = k_{wt} A_w (T_t - T_{out}) - \dot{m} c_w (T_{out} - T_{in}). \quad (7)$$

Realizing Eqs. (5)–(7) for the Matlab simulations finally we can get the following terms for the tile and outlet water temperature differences:

$$\dot{T}_t = \frac{I A_t + k_{ta} A_{ta} (T_a - T_t) - k_{wt} A_w (T_t - T_{out})}{c_t m_t}, \quad (8)$$

$$\dot{T}_{out} = \frac{k_{wt}A_w(T_t - T_{out}) - \dot{m}_w c_w (T_{out} - T_{in})}{c_w \rho_w V_w} \quad (9)$$

In order to calculate the final outlet working fluid temperature from the tile along its length a step-by-step calculation has to be applied based on section discretization.

Realization of the model for the Matlab simulation based on Eqs. (8)–(10) can be seen in Fig. 7 including the following notations:

$$U[1] = T_t; \quad U[2] = T_{out}; \quad U[3] = T_{in}. \quad (10)$$

2.3. Simulation results

Table 1 shows the physical and material parameter values used in the experiments and in the course of Matlab simulation concerning to the heat transfer process.

The temperature distributions in the shell-structured tiles calculated by simulations were first analysed. Fig. 8 shows the warming process until steady state is reached. Based on the aforementioned parameters, the maximum available tile surface temperature difference (ΔT_t) is about 27 °C, the outlet fluid difference temperature (ΔT_{out}) is about 25 °C, and the inlet temperature (T_{in}) is 18 °C. The ΔT_t and the ΔT_{out} temperature differences mean the over-raised values above the starting ones.

The calculated temperature field was verified by thermal camera images. A representative image is shown in Fig. 9. The fluid enters at point A, and leaves the tile at point B. Point C shows the tile surface maximum temperature value, which is about 45 °C in the experiment. In this area, there is no heat extraction. The intensity of scale shows the approximate temperature values. The thermal image software accuracy was ± 0.1 °C.

Studying the influence of pipe length, in the related experiment the radiation was 1000 W/m² and the length of the pipe built into tile was 2 m and 3 m, respectively. The ambient air temperature was 20 °C and the temperature of the constant inlet working fluid was 18 °C.

Fig. 10 shows the warming process to steady state conditions. In case of 2 m long pipe length parameter, the available maximum temperature difference of tile surface (ΔT_t) is about 30 °C, and the outlet fluid temperature difference (ΔT_{out}) is about 28 °C. In the other case of 3 m length, the available maximum temperature difference of tile surface (ΔT_t) is about 32 °C, and the outlet fluid temperature difference (ΔT_{out}) is about 30 °C. In the second embodiment, the built-in tube is longer, obviously, the output temperature of the fluid is higher. It has been experienced that

Table 1
Parameters and additional variables used for simulation.

Parameters	Values	Parameters	Values	Variables	Values
l	2.5 m	k_{wt}	150 W/m ² K	$\dot{m}$	0.01 kg/s
d_w	0.005 m	c_t	900 J/kgK	I	600 W/m ²
w	0.02 m	c_w	4196 J/kgK	T_a	20 °C
h	0.015 m	ρ_t	2000 kg/m ³	T_{in}	18 °C
k_{te}	20 W/m ² K	ρ_w	1000 kg/m ³		

further increase in tube length is not advisable, as the tile collector reaches a maximum performance.

2.4. Parameter sensitivity study

The simulation results can be used to determine the parameters and the operational variables of the solar tile system with the most influence, which can be used in the development and design of a new collector structure. In Table 2, the most influencing parameters and operational variables are shaded along with some practical notes.

During the operation of the solar tile collector, definitely the most important variable is the surface temperature. It is of paramount importance that the collector surface temperature is increased to maximum, thus capturing the highest radiation energy should be pursued. Maximising the captured energy could be

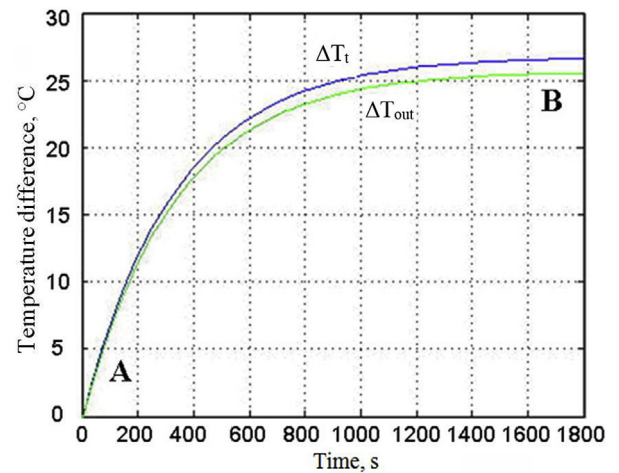


Fig. 8. Calculated temperature differences of tile and outlet working fluid.

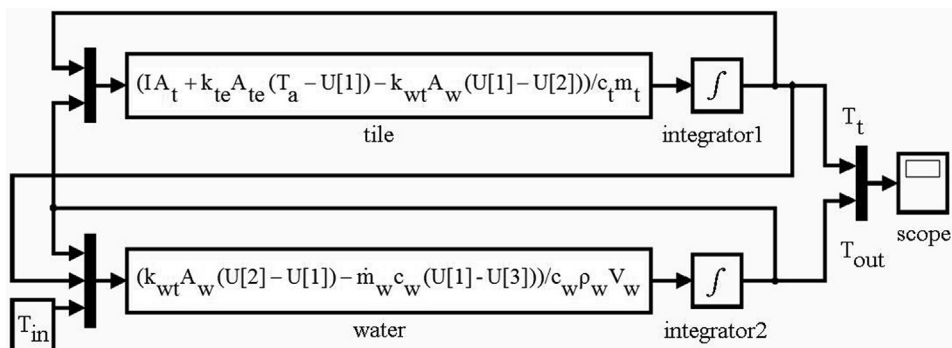


Fig. 7. Matlab realization of the tile collector model.

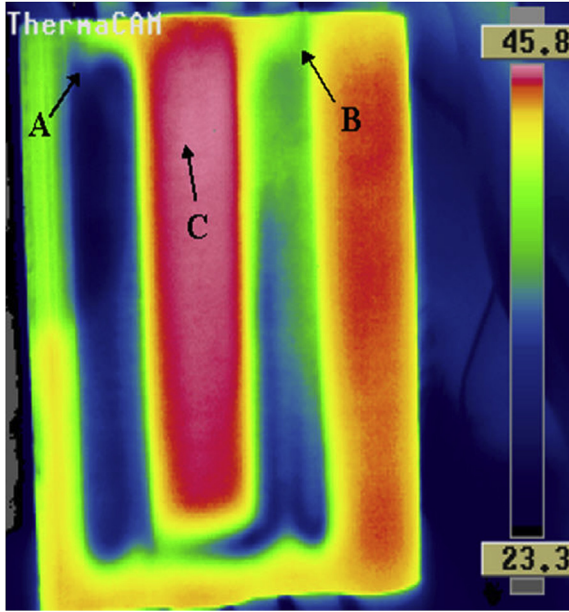


Fig. 9. Temperature distribution of a tile element.

the cost function to the geometrical design. Making use of the simulation results during the preparation, the experimental elements and their structure can be optimized. Finally, it could be determined the most appropriate values for the parameters and variable as tube length, tube diameter, section size, mass flow rate, etc.

3. Construction of shell-structured collector system

Many materials with grey and black surfaces have measurable absorption and emissivity values. The performance of a solar thermal system is higher when the reflectivity is low and the absorption is high. Therefore, the construction of the absorber should include the best absorption and lowest heat loss properties. It can be said that the characteristics of the best absorbing materials with solid, opaque and low reflective capabilities [18].

3.1. Use of different test materials

Different radiation and heat absorbing materials were studied to determine the potential ability in designing and manufacturing the

building integrated collectors. Measurements were carried out at different surfaces in order to compare the actual capture of solar radiation. Fig. 11 shows the concrete made test example units with various surfaces. The geometric size of the test units was $30 \times 30 \times 5$ cm.

If solar radiation reaches the surface of a material, a part of the energy absorbed is converted into heat. The absorption coefficient (α) depends significantly on the quality and the geometric tick of the absorber surface.

The steady-state temperature of the absorber surface (T_t) can be reached when the heat developing by the absorbed radiation equals to the sum of the heat loss and the conveyed heat. There is a proportionality factor (overall heat transfer coefficient – k), which depends not only on the heat transfer, but also on the absorbing surface material, its design and quality, furthermore it is influenced by temperature and distance from surrounding objects and wind speed.

For example, the expected temperature of the rough, grey concrete surface with the following parameters and variables: $I_g = 600 \text{ W/m}^2$ incoming radiation, $T_a = 20^\circ \text{C}$ ambient temperature, $v = 1 \text{ m/s}$ wind speed, $k = 20 \text{ W/m}^2\text{K}$ heat transfer coefficient (estimated value), $\alpha_{co} = 0,60$ was as follows:

$$T_t = \frac{I_g \alpha_{co}}{k} + T_a = \frac{600 \cdot 0,6}{20} + 20 \approx 38^\circ \text{C}.$$

If the absorbing surface is covered with a transparent layer, the heat loss is reduced and the body temperature is increased under the same (I_g) incoming solar radiation. The coverage is also reducing body convection losses. A 2–3 mm thick glass window has a transmissivity of $\tau_{gl} = 0,8$. The effect of glass layers can approach the loss factor (β). In the case of single layer glass, loss factor: $\beta = 5 \text{ W/m}^2\text{K}$. The energy loss (E_l) can be expressed as:

$$E_l = \beta(T_t - T_a). \quad (11)$$

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 following parameters and variables: incoming radiation $I_g = 600 \text{ W/m}^2$, ambient temperature $T_a = 20^\circ \text{C}$, $\alpha_{co} = 0,6$, $\beta = 5 \text{ W/m}^2\text{K}$, $\tau_{gl} = 0,8$ can be calculated as:

$$T_t = \frac{I_g \tau_{gl} \alpha_{co}}{\beta} + T_a = \frac{600 \cdot 0,8 \cdot 0,6}{5} + 20 \approx 77,6^\circ \text{C}$$

To determine the conveyed portion of the radiation heat energy the balance equation is as follows:

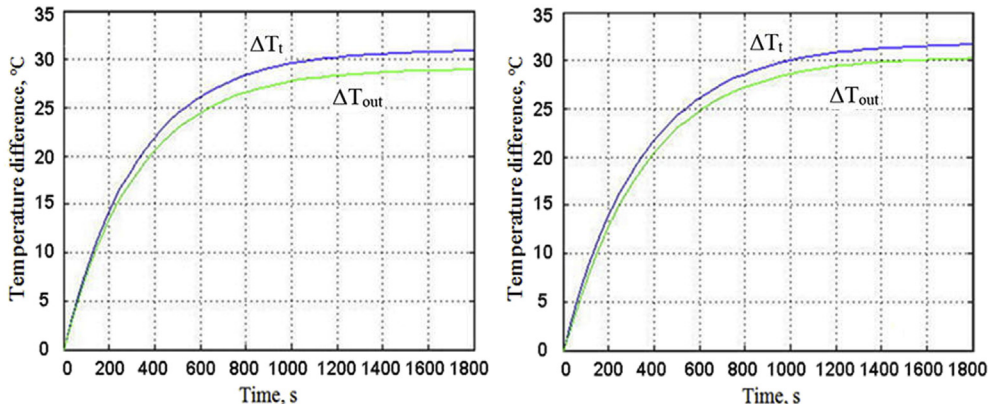


Fig. 10. Simulation results influenced by pipe length, (a) pipe length of 2 m, (b) pipe length of 3 m.

Table 2

The list of the most influencing parameters and operational variables.

Parameters/variables	Notes
length of tube (l):	can be used for optimization of heat transfer, number of serial elements
diameter of tube (d_w):	can be used for optimization of flow resistance, $d_w < h$; $d_w < w$; d_w max. is about $h/2$ and $w/2$ can be used for pump optimization
mass flow rate of water ($\dot{m}$):	
volume of tube (V_w):	can be used for optimization of heat transfer
surface of tube (A_w):	can be used for optimization of heat transfer
specific heat of working fluid (c_w):	can be considered as other than water
density of working fluid (ρ_w):	can be considered as other than water

$$I_g \tau_{gl} \alpha_{co} = E_c + E_1 = E_c + \beta(T_t - T_a). \quad (12)$$

For example, if the conveyed specific performance $E_c = 200 \text{ W/m}^2$. The surface temperature of the absorbing layer behind a glass was:

$$T_t = \frac{I_g \tau_{gl} \alpha_{co} - E_c}{\beta} + T_a = \frac{600 \cdot 0.8 \cdot 0.6 - 200}{5} + 20 \approx 37.6 \text{ }^\circ\text{C}.$$

The resulting energy can be conveyed by liquid or air according to the type of collector working medium. During the measurements, the heating and cooling dynamics and extremes of temperatures were basically monitored. Based on the experiments performed an example, it can be generally stated that the uncovered surfaces behave more dynamically, while the covered surfaces showed a slower warming or cooling. Further studies are planned in this direction to find the most appropriate absorber materials to

be used as a raw material for the building integrated solar tile collectors.

3.2. Construction of the tile collector system

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

The solar tile elements were made of a painted surface. The planning process is to illustrate two examples shown in Figs. 12 and 13.

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. 12).

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, as it is shown in Fig. 13.

3.3. Layout of the solar tile collector

The actually manufactured tile element, which has the same size of a commercially available ordinary roof tile, is shown in Fig. 14. 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. 15.

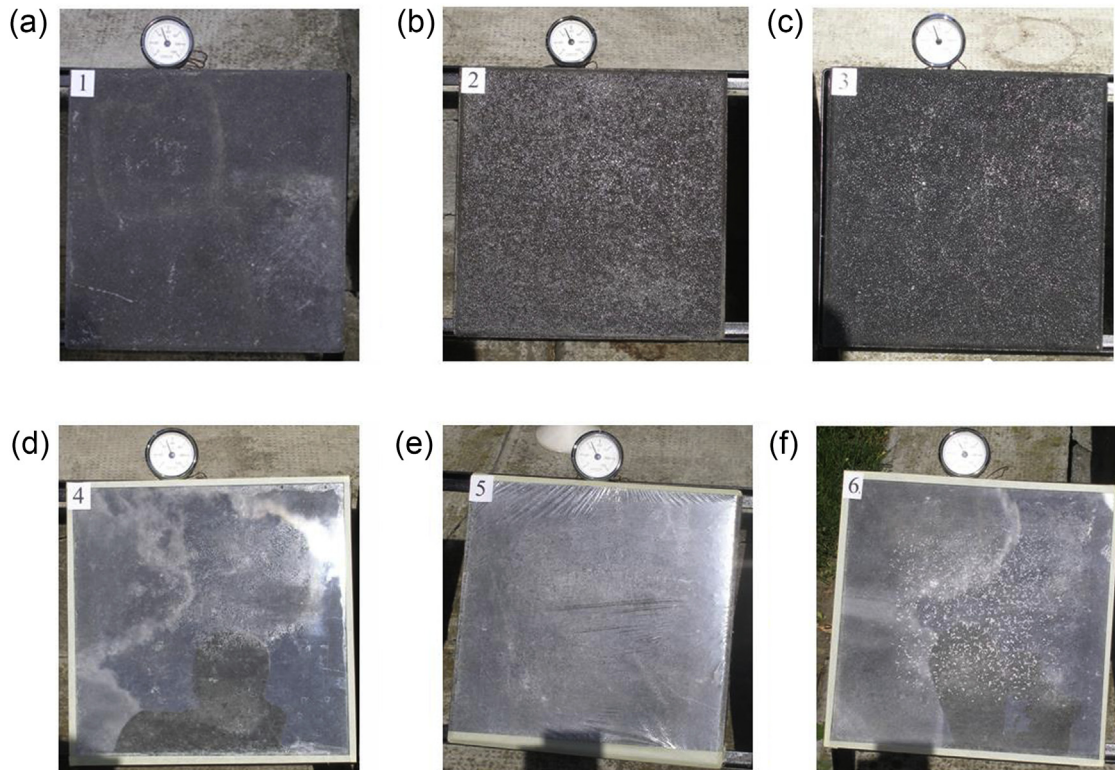


Fig. 11. Different test examples of absorbing materials, (a) Natural concrete, (b) Lacquered concrete, (c) Black painted concrete, (d) A glass surface (2 mm), (e) Thin plastic film surface (0.1 mm), (f) Plexiglas surface (1 mm).

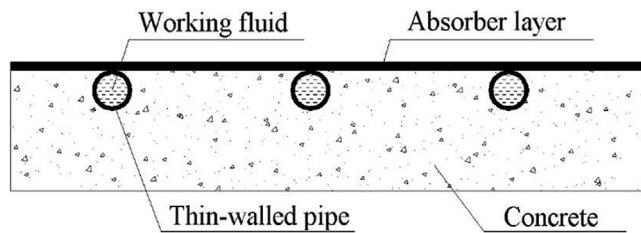


Fig. 12. Structure of tile element with touched absorber and the pipe.

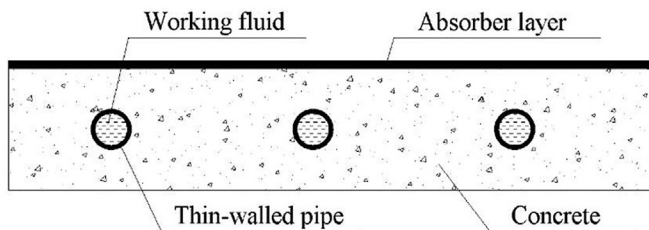


Fig. 13. Structure of tile element without touched absorber and the pipe.

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 advised tilt angle of the equipment can vary between 30 and 45°. Fig. 16a shows how the complete pipe junction system was installed along with the closer fitting arrangements in Fig. 16b. This is one of the most critical assembling

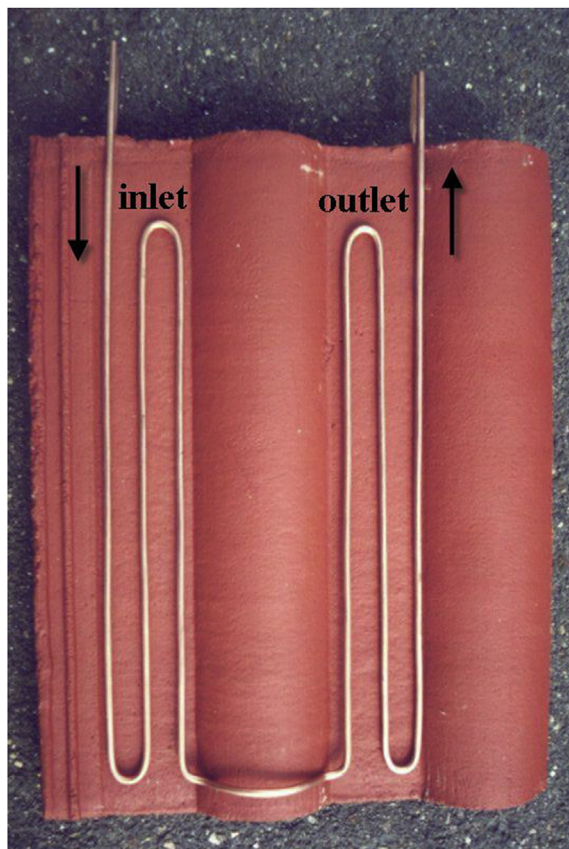


Fig. 14. The tile element design.

problems to be solved in the next future.

3.4. Temperature distribution measurement and evaluation

Measurement is to be achieved during processing large amounts of collected data and evaluation of computer-assisted methods that will be suitable for the preparation of subsequent analyses. We have prepared a data acquisition and analysis software that helps carry out the designated work. The applied unit is a commonly used data acquisition and storage software.

The collector surface temperature distribution is difficult to measure using conventional temperature measuring devices. Therefore, the calculated, modelled temperatures values were verified with infrared camera recordings. Software accuracy of infrared images was $\pm 0.1^\circ\text{C}$ and Fig. 17 shows the recording features in case of surface temperature distribution of a solar tile module.

For illustrating the influences of heat flow, in Fig. 18 the infrared camera recording shows the temperature distribution of the tile surface during a typical clear summer day's weather condition. 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 as indicated at position "D".

4. Determination method of solar collector efficiency

In order to determine the collector thermal efficiency (η) it is necessary to measure the warming of the fluid in the collector along with the intensity of solar radiation and in the volumetric/mass flow rate of the liquid as main variables. The amount of fluid flowing through the collector can be measured by a hot water volume meter. The measuring accuracy is $\pm 0.1\text{ L}$.



Fig. 15. Surface of the collector.

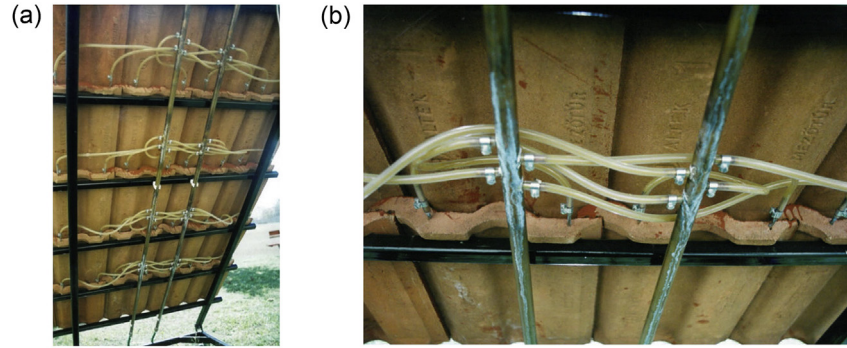


Fig. 16. Rear surface of the tile collector, a) pipe junction system b) fitting arrangements.

As a comparative study, a typical solar thermal collector has been examined and verified for calculating efficiency. The experiment has been performed with a Vitosol 100, 2 m² surface of Cu-based solar absorber for determining the efficiency along with 800 W/m² of solar radiation intensity, which is a normal value for summer period [19].

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

$$\eta = \eta_0 - k_1 \frac{\Delta T}{I_g} - k_2 \frac{\Delta T^2}{I_g}, \quad (13)$$

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

During the calculation the comparative factory data based values of the optical efficiency (η_0), the heat dissipation factors (thermal conductivity - k_1) and the heat loss coefficient (thermal radiation - k_2) in the case of Vitosol 100 were as follows: $\eta_0 = 81\%$, $k_1 = 3,78 \text{ W/m}^2\text{K}$ and $k_2 = 0,013 \text{ W/m}^2\text{K}^2$.

Orientation measurements were also carried out in advance. Expected amount of heat was resulting from solar radiation on this basis. The measurement-based results of the efficiency approximation curve is shown in Fig. 19.

The optical test efficiency parameters (η_0) cannot be measured directly, therefore the estimated value were determined using extrapolation from the measured data as: $\eta_0 = 0,776$. The parameters of the efficiency curve of Eq. (13) were identified as the first-degree heat loss (thermal conductivity) characteristic value as $k_1 = 4,24 \text{ W/m}^2\text{K}$ and the second-degree heat loss (thermal radiation) value as $k_2 = 0,008 \text{ W/m}^2\text{K}^2$.

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 (fabrication, 2011; [12,20]), the efficiency calculations were performed with several cases which shows that the values are within an appropriate band area as shown in Fig. 20 in comparing to traditional solar collectors.

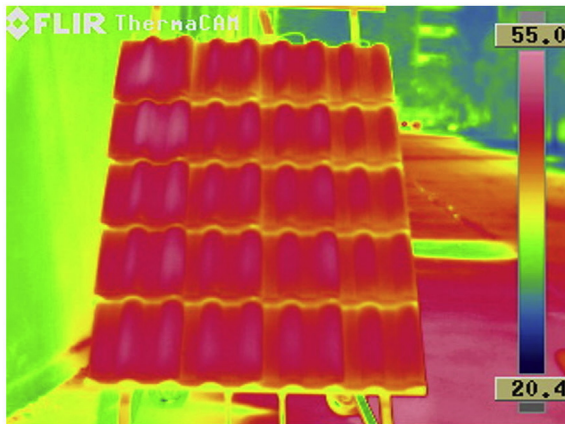


Fig. 17. Measured surface temperature distribution of solar tiles.

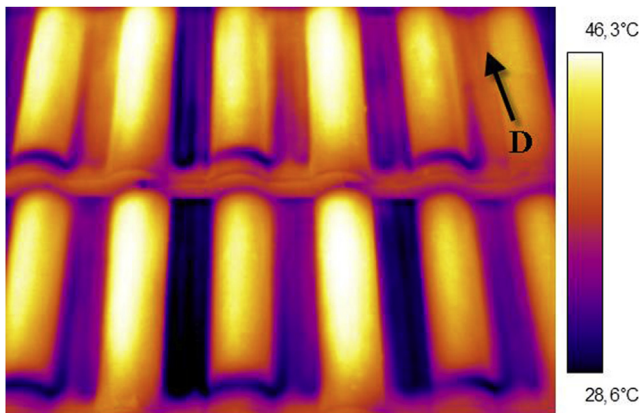


Fig. 18. Visualization the temperature distribution of the tile collector.

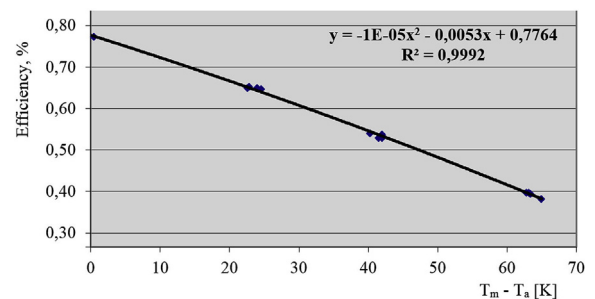


Fig. 19. Solar collector efficiency curve ($I_g = 800 \text{ W/m}^2$).

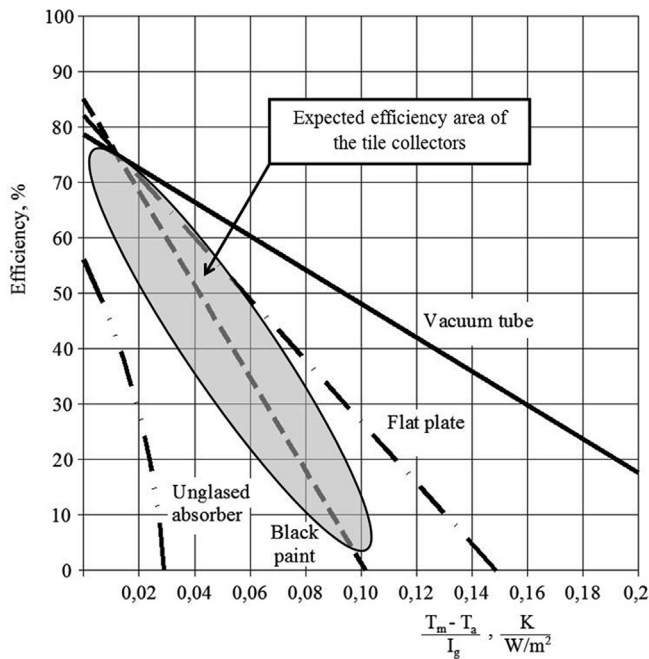


Fig. 20. Efficiency range of solar tile collectors system.

5. Economic issues

There are several approaches to estimate the economics of solar thermal systems, for instance the multiple calculation method [21].

The preliminary financial analysis of the solar system, adverse, longer-term returns indicated 15–17 years in Hungary. 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 8–10 years [12].

In the recent case, 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 [22]. In 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.

6. Conclusions

Nowadays, high-rising pollution problems associated with sustaining economic growth. The renewables including solar energy available to all, decentralized exploitation could reduce it significantly. The idea is to design simple equipment that are suitable for capturing solar radiation, and some structural parts of buildings can be formed by solar collector items.

Based on the theoretical calculations some experiments with the roof integrated solar tile collector were carried out. Besides the complex structure, especially the temperature distribution of the tile element was tested by thermal imaging method, and used for evaluation. Based on the measurements it can be stated that in the case of tile collectors with concrete absorber, near surface tile temperature (ΔT_t) of 30 °C can be reached as compared to the ambient temperature. In the case of the simplest structural design

(no thermal insulation, no surface covering) the working fluid ($\Delta T_{w,out}$) can warm up to 20–25 °C. It was estimated that the expected efficiency range of the solar tile system was comparable to the traditional one.

Concerning to the structural design the built-in pipe diameter cannot be increased over the half of the concrete tile thickness without reducing the roof load capacity. In energy point of view, it is not suggested to increase the pipe length beyond 3 m.

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 recommended 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.

The results of the performed studies imply certain modification on the equipment in order to improve the heat transfer of the collector body. The further aim is to develop an easy-to-install equipment, which are expected to be effective especially in the summer period. A further study is also required to test the durability of the designed tile collectors.

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