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To cite this article: Karel Raz and Zdenek Chval 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **904** 012002

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Development of the solar roof tile with internal cooling

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Abstract. This paper deals with the development of the roof tile with the integrated solar panel. This panel is cooled down with respect to maximizing of the efficiency. Dimensions of the tile are according generally used roof tile. Plastic solar tile can replace the regular one. The design of the tile was validated by usage of thermal simulations and flow simulations in NX Nastran software. These FEM solutions were validated by the measurement on the prototype. The output of this research is prototype from plastic material. This material was selected because of the fast and cheap production.

1. Introduction
Main aim of this paper is design of the roof tile, which is equipped by the cooled solar panel. This panel will be placed on the top side of the tile. Efficiency of the energy conversion from solar to electrical is highly temperature-dependent [1]. Lower temperature leads to the higher electrical output. Designed solar tile has to fully replace regularly used roof tile Tegalit Star [2]. Used cooling medium can be used as source of heat (heating, warming up the water, etc.) in the heat exchanger. The efficiency of solar panels is highly temperature-dependent and it is generally about 13-25%. This efficiency is measured for temperature 25°C and solar loading 1000W/m^2 (according STC standard). The decreasing of output with respect to the temperature is obvious from the following figure (Fig.1). The output (in terms of voltage) around twice lower when temperature of panel is by 100°C higher.
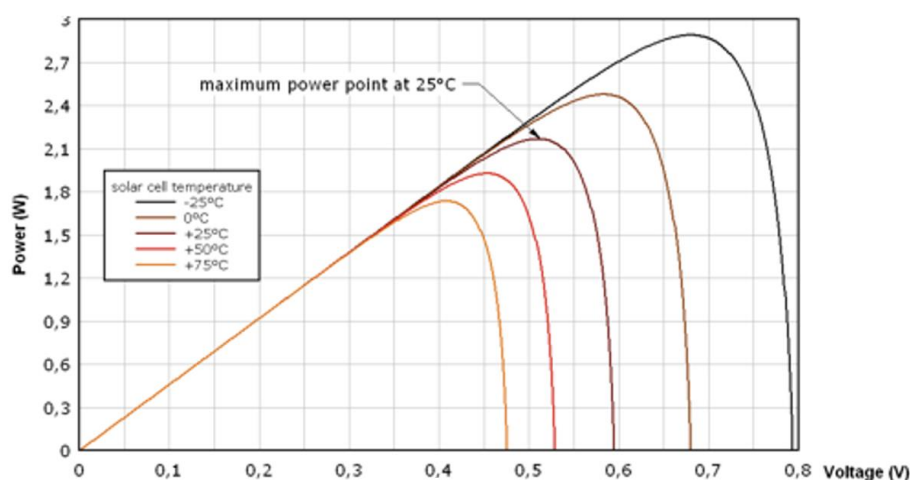

Figure 1. Dependency between power, voltage and temperature of solar panel [3]

Different producers are focused on this area nowadays. Most often is the cooling procedure performed by the water spray focused on the top surface of the solar panel [4,5]. Disadvantage of this solution is in heat losses of cooling water, which is not used further. [6,7,8]

2. Design of the solar roof tile

The design is obvious from the following figure (Fig.2). The tile was created as a plastic part produced by injection molding. The tile has integrated three straight longitudinal cooling channels. Straight design of channels is selected because of minimization of pressure loss. On the top surface of tile is solar panel. This panel is connected by gluing with thermal material as a glue. The flexible hose from PVC performs connection between panels [9,10].
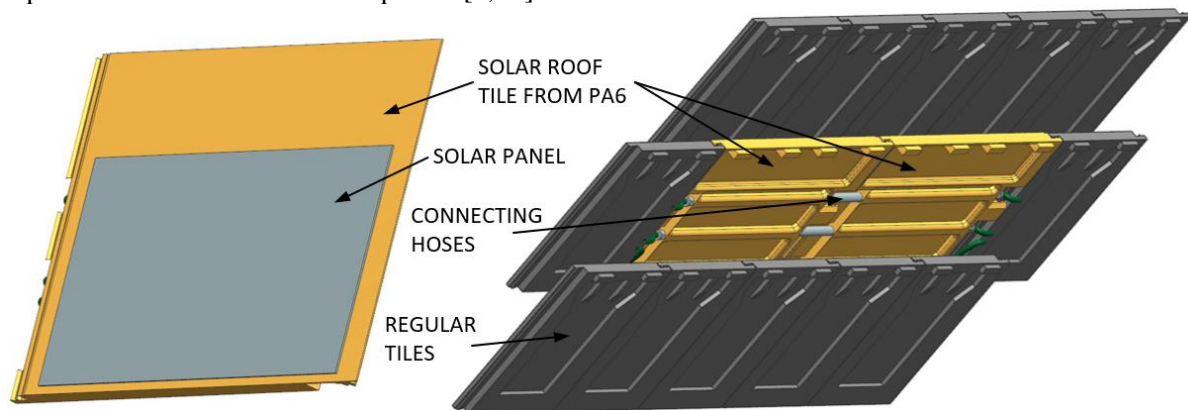
Figure 2. Individual solar tile (left) and array of tiles (right)

3. Pressure loss

The pressure loss is necessary to determine with respect to correct selection of the hydraulic pump and optimal circulation of the cooling liquid. The suitable pump will be used in the experimental device.

3.1. Analytical determination of the pressure loss

Pressure loss of the straight tube is defined as (1): [11,12]

$$\Delta p = \lambda \cdot \frac{l}{d} \cdot \frac{w^2}{2} \cdot \rho \tag{1}$$

Where:
λ – Friction coefficient
w – Average speed of the flow
ρ – Density of the liquid
d – Diameter of the tube

Cylindrical area of the channel is D14x 454 mm. The pressure loss is 0.005 bar.
Hose coupling (two- input and output) has dimensions D8 x 30 mm. The pressure loss is 0.0065 bar.
Analytical solution showed total pressure loss 0.018 bar.

3.2. Virtual simulation of the pressure loss

Determination of the pressure loss was performed also by the virtual simulation by usage of the finite element method. The difference of pressure at input and output was validated (Fig.3). The pressure loss is 0.05 bar. It is about twice higher value comparing to the analytical solution. The difference is caused by more accurate virtual simulation, which is respecting complex shape [13] of cooling and influence of internal friction [14,15].
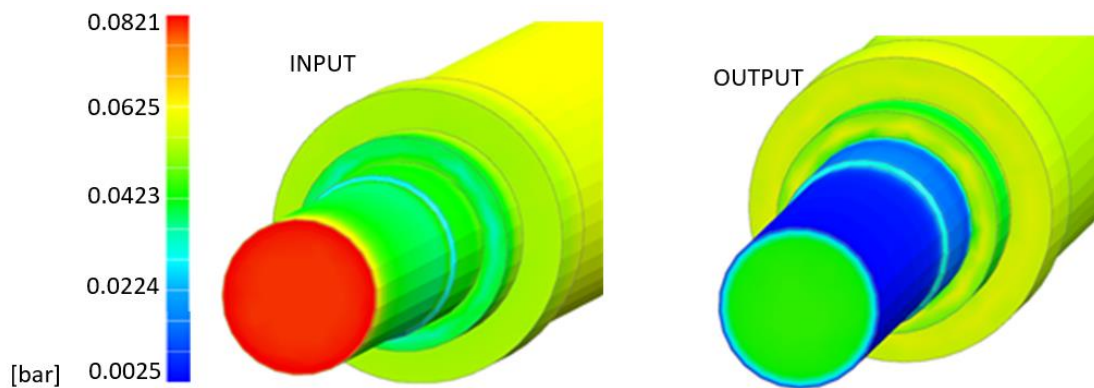
Figure 3. Pressure distribution in fluid at input and output [bar]

4. Validation of the cooling effect

The efficiency of the solar panel was determined for average input values. These values are changed with respect to the period of the year. The simulation was evaluating the average temperature on to top surface of the solar panel. The ambient temperature was selected according the period of year. The loading was constant $800W/m^2$. This load was applied on the surface of solar panel and surface of the tile. The influence of clouds and non-uniform sunlight is neglected. The input temperature of cooling water is $20°C$, the volume flow is $0.5m^3/h$. The material of the tile is PA6 with coefficient of the thermal conductance 0.3 $[W·m^{-1}·K^{-1}]$ [16]. It is obvious that usage of materials with higher thermal conductance is beneficial, but economical reason is more significant [17]. Simulation was performed as transient and steady- state analysis with considering of the dynamics of the fluid. During the simulation was considered the emissivity to the environment. The software NX Nastran was used for the simulation.

4.1. Temperature distribution with cooling- steady state
Average ambient temperature is $16°C$. Thermal loading is $800W/m^2$ (maximal possible value in Czech Republic).
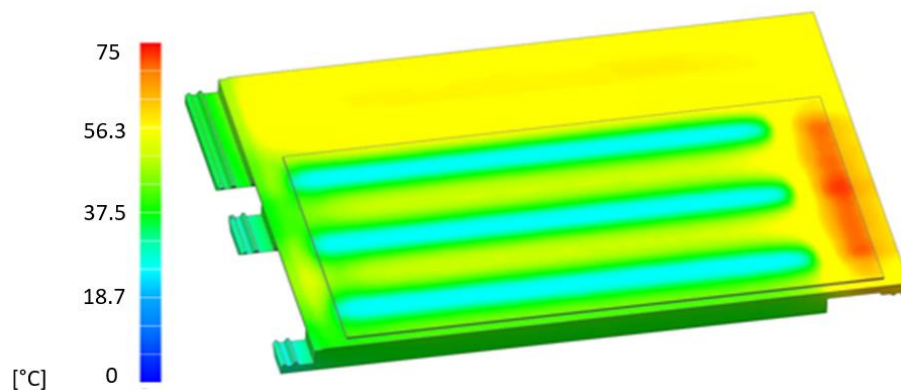
Figure 4. Steady state temperature in summer with cooling in Czech Republic [℃]

Average temperature of the solar panel is $43.1°C$ (Fig.4). The efficiency of solar panels is 0.4% lower by each degree Celsius. The efficiency is therefore 92.7% comparing to the standardised STC test ($25°C$ and $1000 W/m^2$).

4.2. Temperature distribution without cooling- steady state
Average ambient temperature is $16°C$. Thermal loading is $800W/m^2$ (maximal possible value in Czech Republic).
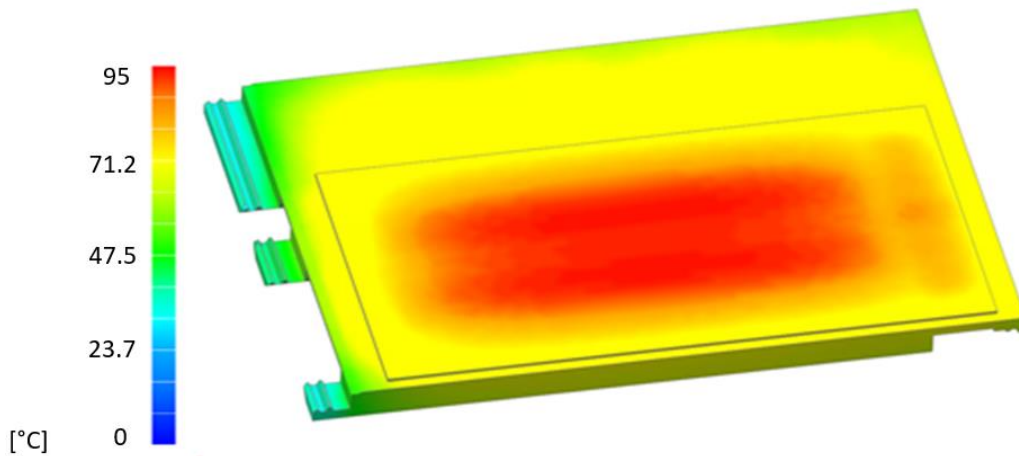
Figure 5. Steady state temperature in summer without cooling in Czech Republic [℃]

The average temperature of the solar panel is 83.2 °C (Fig.5). The efficiency is 76.7% comparing to standardized STC test. The difference between design with cooling and without cooling is about 15%.

## 5. Measurement of the prototype

Parameters of the testing device are as follows:

Two independent circuit are used, each with 4 panels. One circuit is cooled down by internal circulation of water. Material of roof tiles is PA6. Temperature of each panel and cooling water is measured. The water pump is connected to the battery, so therefore is the prototype independent on the electricity. Electrical load are two bulbs 50W. Angle of device is 30°C (optimal value for Czech Republic). Orientation is to the southwest. The water tank was 40 liters- size. The following figure (Fig.6) shows real prototype and the diagram of connection.
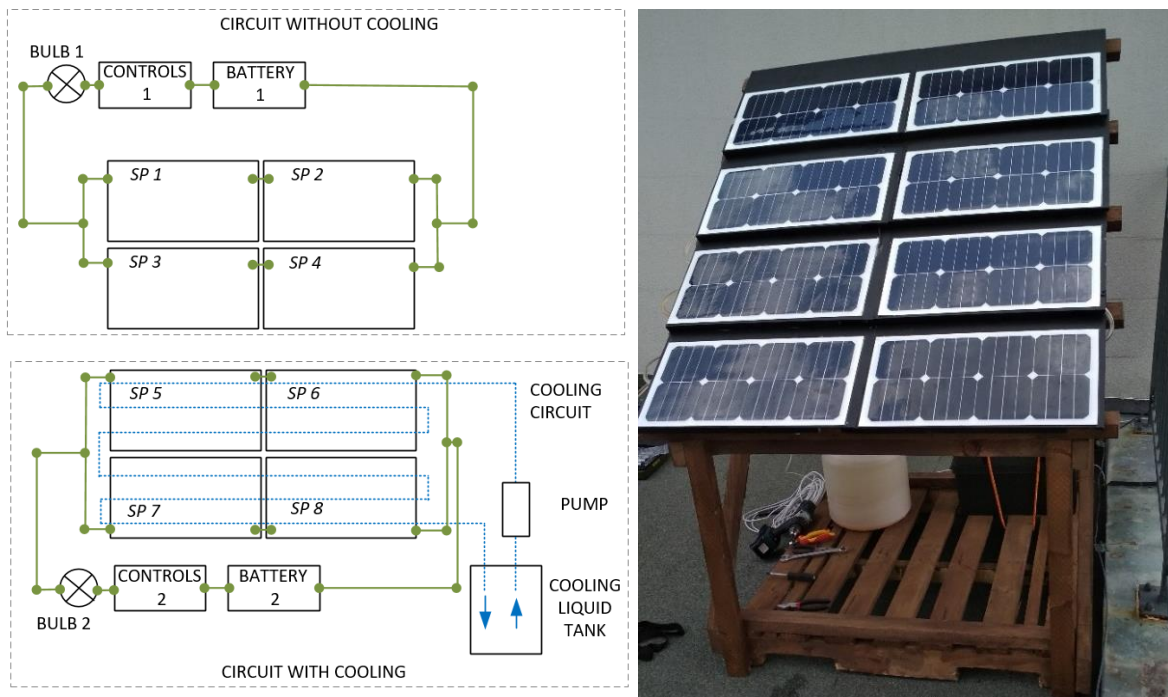
Figure 6. Diagram of the prototype connection (left) and real prototype (right)

The temperature on the upper surface of the solar panel is obvious from the following graph (Fig.7). Thermal cells are located on the plastic material of the roof tile. It is obvious, that is necessary to use the material with better thermal properties (it means with higher thermal conductivity). The difference between both circuits is not so significant. Difference between the virtual simulation and the measurement is caused by lower sunshine and therefore warming up of the panel was much lower during testing.
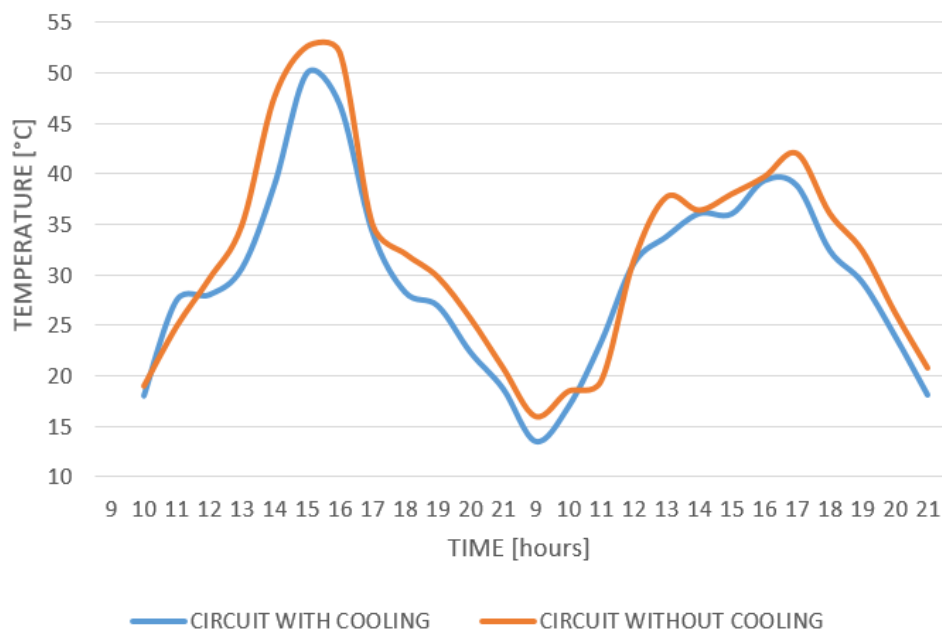
Figure 7. Temperature on the top surface of panels with and without cooling during time period of 11:00-21:00 (in two days)

6. Conclusion

This paper deals with the design of cooled solar tile. The designed solar tile is changeable with the regular tile Tegalit Star. It is possible to produce this solar tile with technology of injection molding. This is suitable because of the economical and time-depended point of view. The roof tile has solar panel on the top surface. Inside the tile are integrated three straight cooling channels. They are improving efficiency of energy conversion.

Mechanical connection between tiles is done by lockers. Hydraulic connection is done by flexible hose. Whole device was tested and temperature was measured on the top surface of tile. The pressure loss is negligible, because is around 0.05 bar. Velocity of cooling water during testing was around 3 m/s. This area of industry is significant, because solar energy is taking key role nowadays. The efficiency of solar panel (depends on individual type) is 0.4% lower by each degree Celsius. Future research will be focused on improving design with respect to better heat transfer. It will be beneficial to use plastic material with thermal additives. The conductivity is then 10times higher.

7. Acknowledgments

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