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Modelling of an Improved Hybrid Cooler Used in Sustainable Buildings

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Abstract. Sustainable buildings are resource-efficient and environmentally friendly in terms of structure and energy consumption. It is not enough for a green building to have only greener structure and envelope; the meaning is extended to all its equipment and applications used, too. The purpose is to reduce the consumption of the conventional energy, to efficiently use energy resources and to reduce pollution and environmental degradation. Due to all these aspects, sustainable buildings use renewable and other different types of alternative energies. Among these are the photovoltaic (PV) and the thermoelectric (TE) energies. In most cases, a high-performance building uses the electric energy provided by PV panels included in a more complex system. In attempt to reduce the complexity of the photovoltaic system and its investment costs, modelling an improved photovoltaic-thermoelectric hybrid cooler was a proper option (a cooler can be found in almost every existing building, especially in houses). The choice of this combination was determined by the use of the direct (DC) current delivered by the PV system by the thermoelectric cooling (TEC) modules embedded on the cooler. An improved variant of the PV-TEC cooler was investigated. The modelling analysis comprises i) an appropriate volume for the day-to-day use, ii) new materials comparing to those already used in the structure of other hybrid coolers, iii) different numbers and positions of the TEC modules on the surface of the cooler's sides. All the results are discussed to establish the proper behaviour and variant of the photovoltaic-thermoelectric cooler and to further realize a prototype to see if the theoretical results confirm.

1. Introduction

Nowadays, both common people and scientists are preoccupied to improve their life conditions and to achieve a sustainable development. On these lines, it is very important to find a proper balance between all social, economic and environmental factors. A first step is to try to reduce the energy consumption from conventional energies and the pollution rate; this goal can be achieved by finding alternatives to conventional energies and developing newer or improved buildings and equipment.

Because the real estate sector is in a continuous growth and buildings are responsible for a great percent of global energy and water consumption, global CO₂ emissions, waste with negative effects on human life conditions, they must assure positive effects on environment, ecology, economy and life, according to the sustainable business management for buildings [1]. These criteria are referred both to building design and structure and to all its equipment and applications.

More and more buildings use the solar energy through the photovoltaic (PV) systems. The electric energy resulted can be directly used by other devices or equipment like the thermoelectric cooler



(TEC) modules. The PV system and the TEC modules can be coupled, giving birth to a new and more complex system – a hybrid cooler. This type of cooler can be used in sustainable buildings to ensure the refrigeration process needed for food preservations [2,3].

This issue represented a field of interest for many researchers [4,5,6] over the last decades. But with all these, there are still aspects that can be improved regarding the operation and the behaviour of such a cooling equipment. That is why, in this paper was considered an improved variant of a photovoltaic-thermoelectric cooler. This improved variant refers to an appropriate volume for the day-to-day use, new insulating material and different numbers and positions of the TEC modules. The investigation of the proposed variant focused on temperature behaviour of the hybrid cooler and on the inside air distribution according to convection phenomenon.

2. Methodology

The purpose of this work was to realize a model of the hybrid cooler by using new insulating material and to analyse the behaviour of the thermoelectric cooler from the temperature and inside natural convection perspectives. Furthermore, the materials, the chosen geometry and the modelling will be detailed in this section.

2.1. Materials

The materials taken into consideration can be divided in two categories: those used in the PV system and the ones of the thermoelectric cooler.

2.1.1. PV system. The photovoltaic system consists of a PV panel of 360 W coupled to a deep cycle battery of 90 Ah. The direct current (DC) provided by the panel and stored in the battery directly supplied the TEC modules mounted on the cooler.

2.1.2. TEC cooler. The interior of the thermoelectric cooler was considered to be made of a stainless steel plate of 0.8 mm, insulated with polyurethane foam and sheep wool insulation, respectively, of 50 mm thickness each and sealed with High Impact Polystyrene (HIPS) of 3 mm.

Thermoelectric cooling modules of 60 W nominal cooling capacity were used for the cooling process (figure 1). Due to the nominal value rated at the cold side of the module under a temperature difference $\Delta T = 0^\circ\text{C}$ [7], in simulation, was considered a smaller value of the TEC cooling capacity during operation.



Figure 1. TEC module

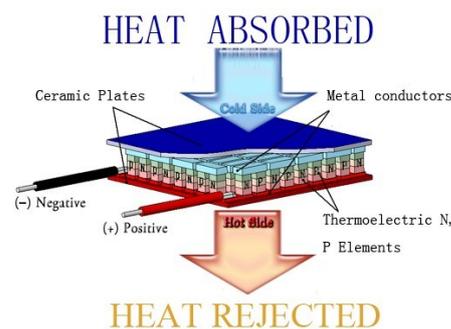


Figure 2. Scheme of a TEC module [8]

The operation principle of the thermoelectric refrigeration is relatively simple: the DC current applied to the device determine the movement of the electrons through the semiconductors, at the junction of the N and P elements; the current flows from electrons to holes (from N-type to P-type) and the heat flux is absorbed from the cooling space. In order to have a continuous heat flux flow, it is mandatory to cool the hot side of the thermoelectric modules.

Because of their reduced dimensions of 40 x 40 mm, different numbers and positions of them have been used in the modelling process. The goal was to determine the value of the achieved temperature and its distribution inside the cooler.

2.2. Modelling the thermoelectric cooler

The models were realized in Ansys Fluent. A series of factors were considered when modelling the thermoelectric cooler for the analysis of the temperature behaviour – variation and distribution.

Because the hybrid cooler is wanted to be used in the day-to-day life by people, a significant volume of 112 l was considered. The geometry of the thermoelectric cooler consists of a cuboid made of stainless steel and insulated in one case with polyurethane foam and with sheep wool in the second case. The aim was to determine to rate of temperature variation inside the TEC cooler due to the small difference of the thermal conductivity of the two insulation types: only 0.019 W/m·K [9].

Based on the principle that the cold air descends while the hot air rises, the thermoelectric cooling modules were mounted on the upper face of the cooler. The upper face of the cooler was considered one of the biggest surface of the refrigerator. Due to the greatest face surface of the cooler of 2800 cm² comparing to the extreme small surface of a TEC module of only 16 cm², two arrangement variants were made: with 4, respectively 10 thermoelectric cooling modules (figure 3 and figure 4).

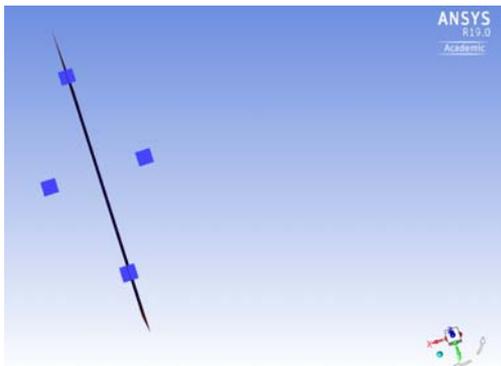


Figure 3. Variant 1 with 4 TEC modules

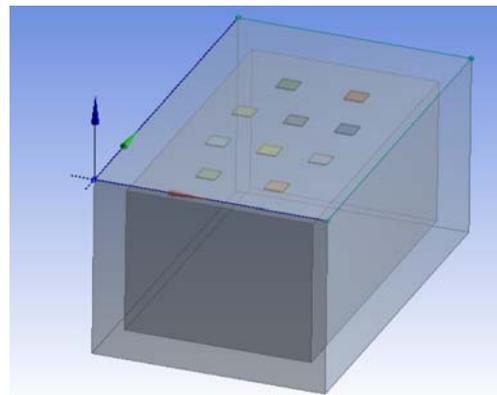


Figure 4. Variant 2 with 10 TEC modules

After realizing the geometry, the mesh part and a section in the longitudinal, respectively transversal plan has been made, like in figure 5. The purpose was to see the real effective structure and to obtain proper qualitative results.

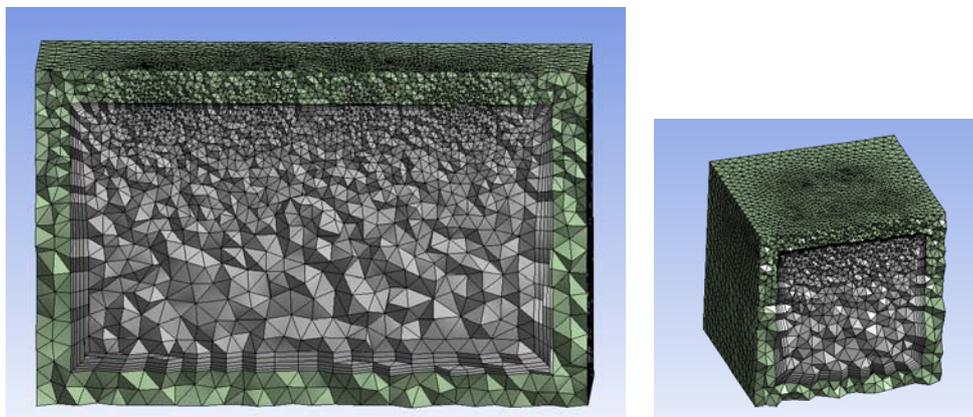


Figure 5. Sections of the thermoelectric cooler

3. Results and discussions

3.1. 4 TEC modules

The first case analysed was the one of the 4 TEC modules situated on the upper face of the hybrid cooler. The section plane is a longitudinal one through the 2 modules situated up to the front and back ends. From the temperature distribution emphasized below (figure 6 and figure 7), in the back side of the thermoelectric cooler, the temperature uniformly descends with lower values (0 to 8°C) up to the bottom of the cooling room. In front of the cooler, lowest values of temperature are being achieved only in a small area near the TEC module, while in rest, temperature grows significantly. The distribution curves describe rather a Gaussian function. This type of distribution is influenced in a great percent by the air velocity inside the cooler, as described later in this sub-section.

Reckless of the insulation type – polyurethane foam or sheep wool – temperature distribution inside the cooler in the section plane presents the same trend. The only difference is in the temperature value which in the case of the polyurethane foam is slightly lower (up to 1.5°C) because of a better thermal conductivity of 0.02 W/m·K.

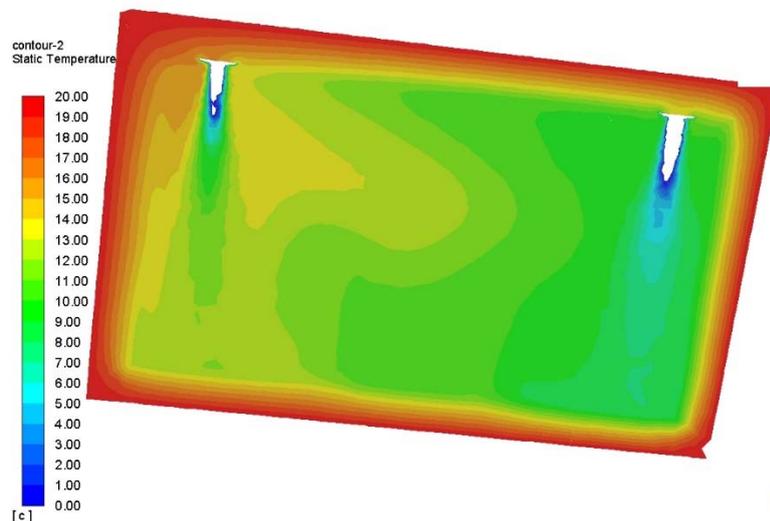


Figure 6. Temperature variation in the case of using polyurethane foam

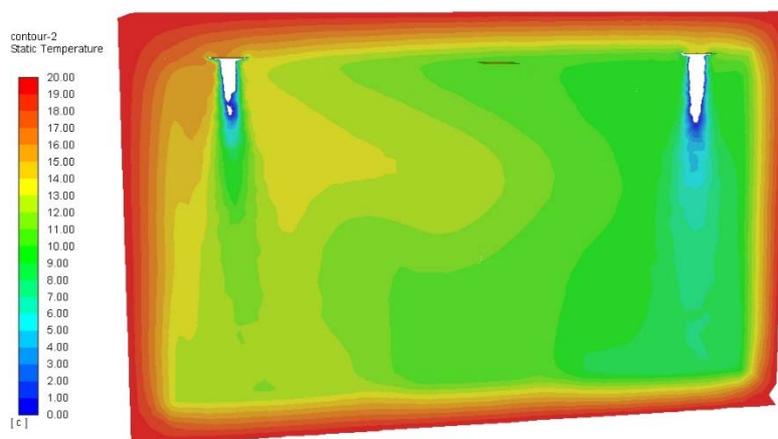


Figure 7. Temperature variation in the case of using sheep wool insulation

As regarding the natural convection inside the thermoelectric cooler, it is obvious from figure 8 a) and b) that the air velocity presents the same variation trend and values. Figure 9 certifies that the extremely low values of the inner air velocity – between 0.0003 and 0.276 m/s.

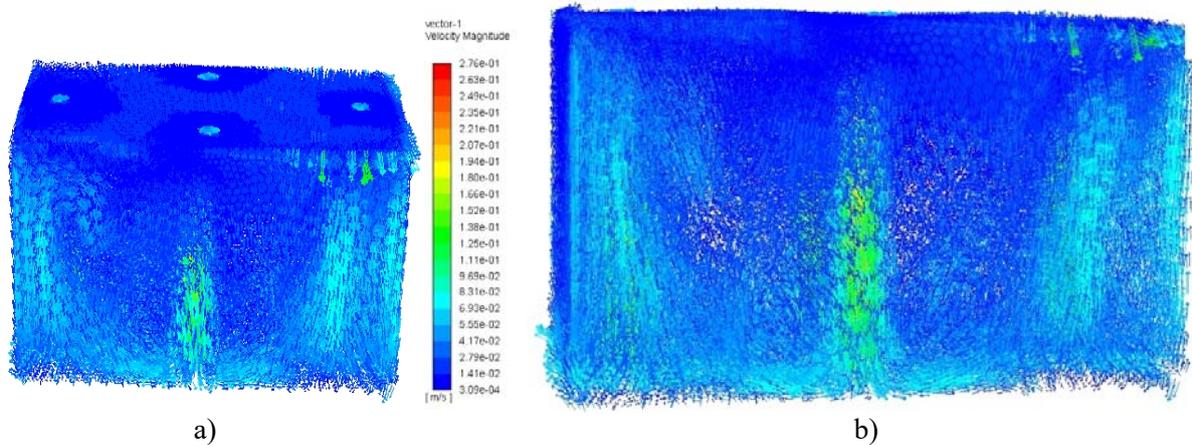


Figure 8. Natural convection inside the TEC cooler: a) polyurethane foam insulation, b) sheep wool insulation

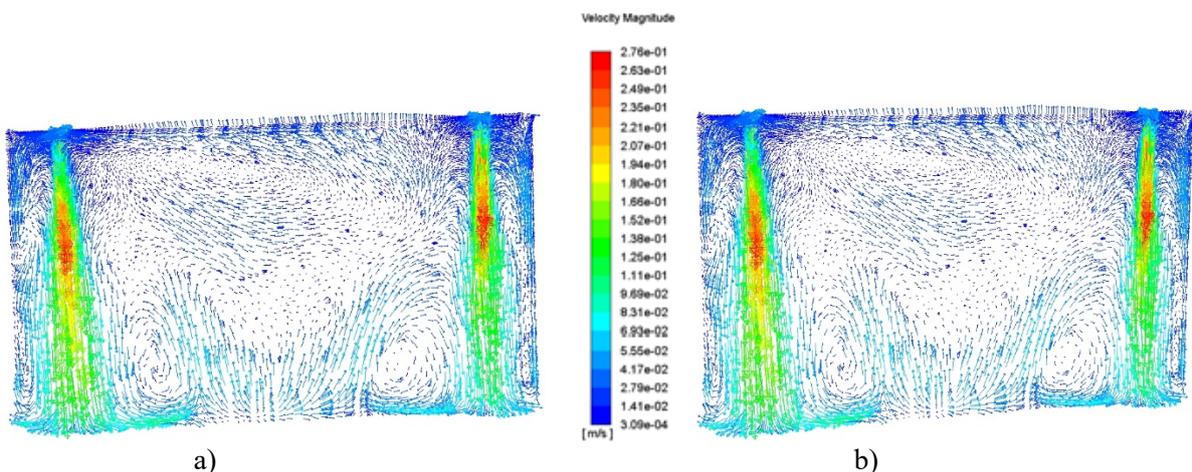


Figure 9. Velocity magnitude in the section plane for: a) polyurethane foam insulation, b) sheep wool insulation

As mentioned before, the temperature distribution depends on the air velocity inside the cooling room. The air velocity is higher in the line of the modules, reason why the temperature in that area, descending to the bottom of the cooler surface is lower than in the rest. That Gaussian curves described in the temperature distribution diagrams, are been caused by the extreme low air velocity in the middle-upper part of the cold room. This is a consequence of the presence of the other 2 TEC modules situated in the middle of the upper surface, but towards margins.

3.2. 10 TEC modules

In the case of 10 thermoelectric modules set on the upper face of the cooler, the considered heat flux was of 700 W/m^2 . Now, the heat transfer during the cooling process was analysed from both conductivity and radiation aspects, comparing to the first variant with 4 modules when only conductivity was considered. According to figure 10, the temperature achieved inside the cooler was between 2.5°C and 3°C , normal value in the refrigeration range [10,11]. As we approach to the TEC modules, the temperature drops in an exponential way, reaching the minimum value of -5°C . But this

aspect does not influence the temperature refrigeration domain because of its thin film and extremely small section.

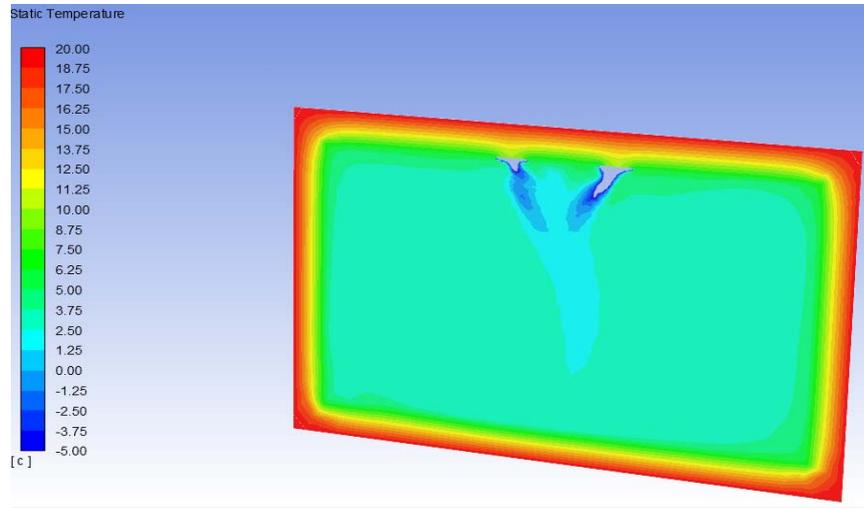


Figure 10. The inner temperature of the thermoelectric cooler

The distribution of the temperature inside the thermoelectric cooler can be observed and 12, too, as iso-surfaces at 1.95°C in figure 11 and at 1.04°C in figure 12.

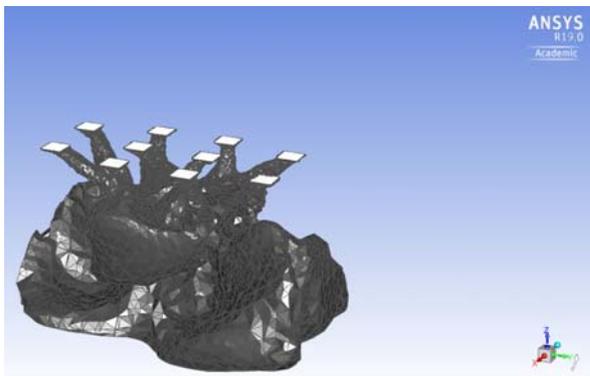


Figure 11. Iso-surface at 1.95°C

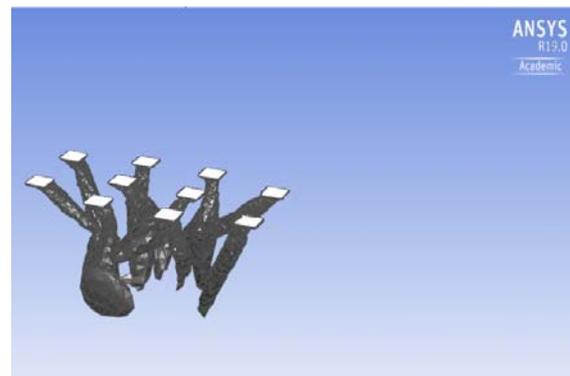


Figure 12. Iso-surface at 1.04°C

To have a better view of the air distribution inside the refrigerator and of the convection phenomenon, figure 13 emphasizes the velocity magnitude on the section plan, considering all 10 cooling modules, too. It was expected a concentration of the cold air in the middle of the cooler related to the 2-3-3-2 distribution of the thermoelectric modules on the surface of the refrigerator. This is the reason why in the two areas similar with vortices the air velocity is near to 0 m/s. Overall, the inside air velocity varies in an extremely reduced domain from 0.2 m/s to 0 m/s. This is translated in a very low convection phenomenon.

By analysing this case of 10 TEC modules with the one of 4 TEC modules, we can see that overall, the velocity magnitude is higher inside the entire cooling room. Excepting the margins and the inner of the two vortices, the air velocity is higher than 0 m/s. So, the natural convection phenomenon is pronounced when using a greater number of thermoelectric cooling modules for refrigeration, disposed in a more compact way.

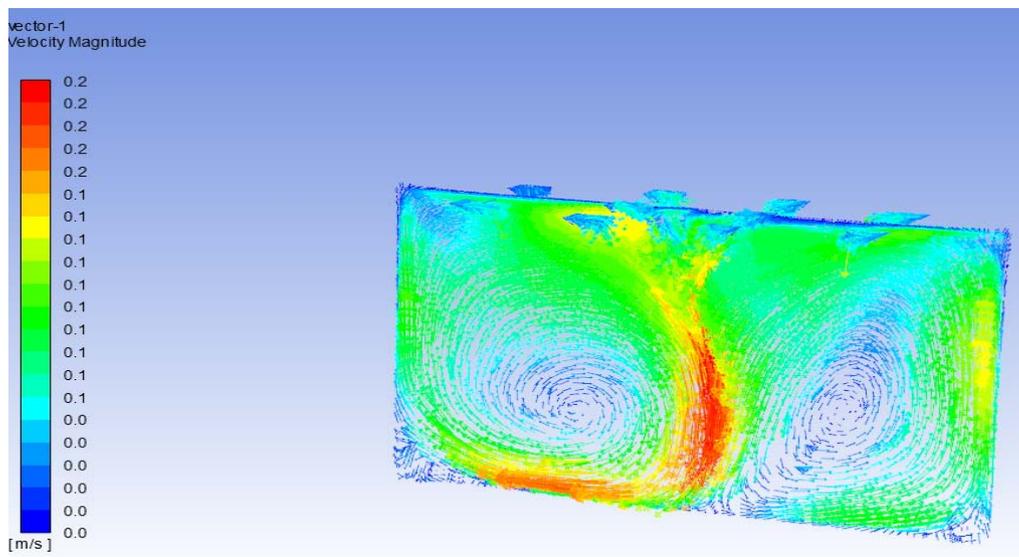


Figure 13. Velocity magnitude inside the thermoelectric cooler

4. Conclusions

The analyses made on the three presented models show that the number of the thermoelectric cooling modules grows once with the growth of cooler volume and its heat flux surface. In the detailed cases, a number of 10 TEC modules are needed to achieve a temperature value in the refrigeration range of 3°C. This aspect is important because the hybrid PV-TEC cooler is aimed to be used in sustainable buildings for food or other materials preservations.

The thermal conductivity of 0.039 W/m·K of the sheep wool insulation determined a raise of the inner temperature of the cooler with up 1.5°C comparing to the thermal conductivity of 0.02 W/m·K of the polyurethane foam.

The natural convection inside the hybrid cooler is extremely low; the greatest air velocity is of only 0.2 m/s.

It is interesting to further realize a prototype of the hybrid photovoltaic-thermoelectric cooler starting from these analyses and see if the theoretical obtained results are confirmed by the empirical work.

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