EXPERIMENTAL ANALYSIS OF THE JUSTIFICATION OF USING A SPACE HEATING SYSTEM BASED ON PELTIER THERMOELECTRIC GENERATOR

Milan B. PUPČEVIĆ*,[1], Petar GVERO[1], Čedomir ZELJKOVIĆ[2], Milovan KOTUR[1], Predrag MRŠIĆ[2]

[1]Faculty of Mechanical Engineering, University of Banja Luka, Bosnia and Herzegovina
[2]Faculty of Electrical Engineering, University of Banja Luka, Bosnia and Herzegovina

Abstract: The Peltier or thermoelectric effect has been known for more than a century, but it found adequate commercial application only in the last decades. The goal of this paper is an experimental analysis of the possibility of using thermoelectric modules for heating the building. The concept of the system is to work without freon and without negative and harmful effects on the environment, and that is why a renewable energy source was conceived as the driver of the entire system. Solar heating using thermoelectric modules is not justified without solar cooling, for the reason that there are adequate and efficient solutions for solar heating and preparation of domestic hot water. Here, heating is being studied in order to combine it as a complete solution for thermal comfort in the space together with cooling in the future. The idea is to make a detailed mathematical model of heat transfer in order to analyze the dimensions of the heat exchanger, while a more detailed analysis of the shape of the exchanger itself and optimization of the number of modules is planned in the future. The system is designed with a thermoelectric module built into the wall of the building. Due to thermal comfort in the space, the heat exchange will be analyzed by natural convection. The experiment is designed so that the Peltier element is positioned on the heat exchangers and the input current and all necessary temperatures are measured. The heat exchanger, as well as the space that simulates the living room of a residential building, was scaled by dimensional analysis due to the cost of installation. The COP of a space heating system using a Peltier thermoelectric generator has a low value if the system operates with natural convection and heat exchangers without optimal fine spacing.

Keywords: Thermoelectric effect, Peltier module, Heat sink, Heating, Renewable energy sources

1. INTRODUCTION TO THERMOELECTRIC EFFECT

Physicist Thomas Johann Seebeck noticed that if two conductors, which are made of different materials, are connected at their ends so as to form two different nodes and if these nodes are exposed to different temperatures, placed near a compass, the needle will move. He initially believed that the magnetic field changed due to temperature changes, but later he realized that the current flowing through the conductors generated the magnetic field and moved the compass needle. The appearance of an electric voltage in an electric current circuit composed of two different conductors, when their junctions are at different temperatures, is called the Seebeck effect or the thermoelectric effect.

He discovered the phenomenon that enables the direct conversion of temperature differences into electric current in 1821, and the instrument for measuring temperature based on it is called a thermocouple. The ratio of the potential difference to the temperature difference at the ends is called the Seebeck coefficient. Seebeck discovered the thermoelectric effect with a closed loop, although in the literature it is always presented as an open loop (Figure 1).

A conductive or semi-conductive material is defined by curve **A** and its ends **a** and **b**. In those points **a** and **b**, which have temperatures $\mathbf{T_a}$ and $\mathbf{T_b}$ respectively, wires **A** and **B** are connected. It is assumed that the ends **c** and **d** are at the same temperature $\mathbf{T_0}$. If the metal wire begins to heat up at

---

*Corresponding author e-mail: milan.pupcevic@mf.unibl.org

one end, that is, if there is a temperature difference in the material, the thermodynamic balance is disturbed because the electrons on the hotter part of the wire have more energy than those on the colder part.

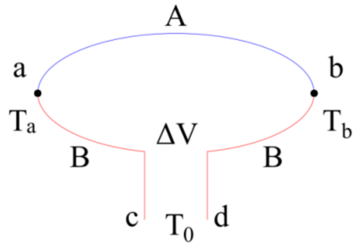


Figure 1. Seebeck effect-principle

The result is the diffusion of electrons from the hotter to the colder end of the wire, which leads to an electric field with a positive pole on the hotter part and a negative pole on the colder part of the wire. The appearance of an electric field leads to the establishment of thermodynamic equilibrium, and at the ends **c** and **d**, due to the potential difference, a voltage **ΔV** known as the Seebeck electromotive force is formed.

The Seebeck effect is one of the three thermoelectric phenomena, and together with the Peltier and Thomson effects, it explains how a voltage is created due to a temperature difference, that is, it represents a thermoelectric voltage generator [1,2].

After Seebeck's thermoelectric effect, in 1834, the French physicist Jean Charles Athanese Peltier had a similar discovery, using the same components but with the opposite direction of the cycle. He applied voltage to the ends **c** and **d** of the mentioned cycle from figure 1, where he observed that current flows in the loop. As a result of the flow of current, depending on the direction, at one end (**a** or **b**) of the junction of two metals there is a cooling effect and at the other a heating effect. By changing the polarity, there is a change in the flow of current, that is, if node **a** heated up and node **b** cooled down by changing the polarity, node **a** cools down and **b** heats up [3].

In the middle of the 19th century, William Thomson, better known as Lord Kelvin, analyzed in detail and gave a comprehensive explanation of the Seebeck and Peltier effects and their connection. Based on the above, it is possible to create a thermoelectric generator of electricity that can be used as a heating or cooling device.

Over time, it has been concluded that for practical use, it is necessary to strengthen the effect of thermoelectrics, that is, it is necessary to multiply the basic assembly by connecting several thermoelectrics. A parallel connection is not the best solution because it does not multiply the voltage, and it requires a large current, which significantly reduces the cooling effect. A series connection has a higher resistance, which means a lower current, and metal wires that connect hot and cold ends of the thermoelectric reduce the cooling effect, because they themselves conduct heat well [1]. Essential progress in the study and exploitation of thermoelectric circuits is brought about by the use of semiconductors instead of metals.

2. EFFICIENCY OF THERMOELECTRIC ELEMENT

Peltier discovered the thermoelectric effect by the case of two wires whose ends are not connected, and an external source of electric voltage is not connected between them while one end is heated. This results in a temperature difference that disrupts the thermodynamic balance. In other words, free electrons from the hotter end of the wire have a higher energy than those on the colder part, which causes electrons to diffuse from the hotter to the colder part of the wire and thus an electric field is created. The amount of heat per unit of time from one joint to another is given by the equation (1):

$$Q = \pi \cdot I \tag{1}$$

where I is the electric current in the circuit and π is the Peltier coefficient (which is defined as $\pi = Q/I$ at : $\Delta T = 0$).

Output power and conversion efficiency are two key parameters for evaluating the performance of a thermoelectric generator. By applying the basic block a theoretical model was developed providing a basic framework for testing the performance and characteristics of thermoelectric generators [4].

Modern thermoelectric modules are manufactured using semiconductors, which offer higher conversion efficiency and higher power output than metal alloys. They consist of **n-type** and **p-type** semiconductor thermocouples connected in series with a conductive strip (usually copper or aluminium), Figure 2. The consumer shown is not part of the thermocouple structure, and the practical device is, as a matter of fact, a matrix constructed repeating these basic blocks.

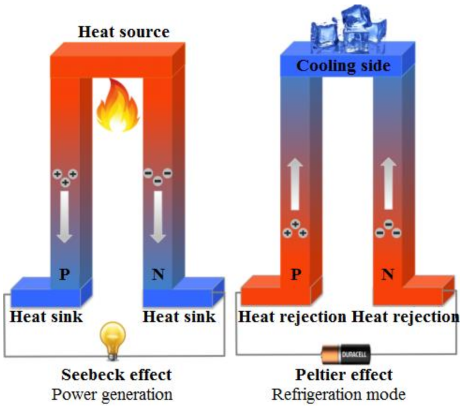


Figure 2. Peltier effect principle [5]

Compared to conventional systems, an adequately regulated system with thermo modules can provide temperature regulation more precise than ±0.01 °C.

The conversion efficiency of the thermoelectric generator is defined as the ratio of the power delivered to the consumer P and the absorbed heat at the hot junction Q_h, as:

$$\varphi = \frac{P}{Q_h} \tag{2}$$

The conversion efficiency depends on the thermoelectric quality factor or goodness factor Z, which is a measure of the suitability of the material for thermoelectric applications, and is defined by the relationship according to equation (3):

$$Z = \frac{S_s^{\,2} \cdot \sigma_e}{\lambda} \tag{3}$$

where S_S is the Seebeck coefficient, σ_e is the electrical conductivity and λ is the thermal conductivity coefficient.

Figure 3 shows the dependence of the conversion efficiency and the temperature of the hot side for different quality factors, where the temperature of the cold side is constant and equals 300 K.

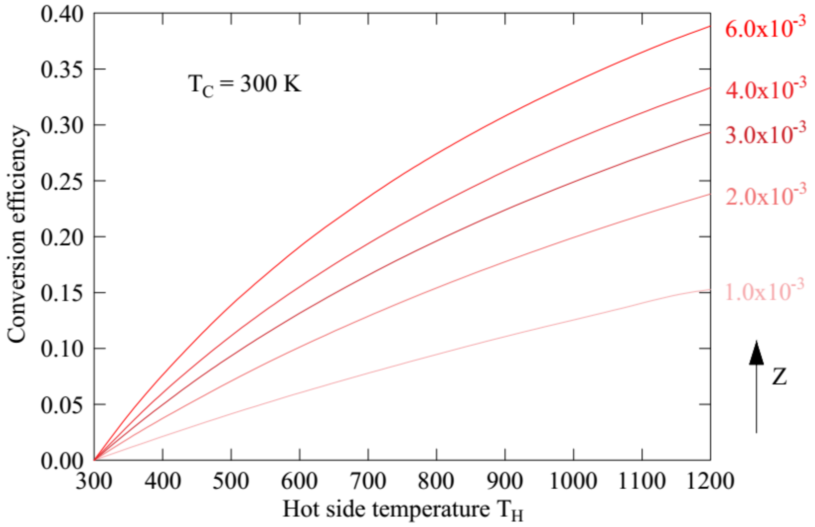


Figure 3. Conversion efficiency as a function of temperature and quality factor [4]

The thermoelectric goodness factor *Z* ranges predominantly from $2{\cdot}10^{-3}$ to $3{\cdot}10^{-3}$ K^{-1}, which implies that the conversion efficiency is approximately 5% for a temperature difference of 100 K, and ranges up to 20-25% for a temperature difference of around 800 K.

The quality factor *Z* varies with temperature, and since its unit is K^{-1}, for practical reasons, a new quality factor is defined which is the product of factor *Z* and temperature (*ZT*), which has the same role. It is precisely the *ZT* factor that limits the conversion efficiency of thermoelectric devices, and therefore the main challenge in research is finding materials with high *ZT*. The maximum value of the *ZT* factor is for the Bismuth-Telluride alloy, which has the maximum value at temperatures around 300 K. Figure 4 shows the dimensionless thermoelectric quality factor *ZT* as a function of the absolute temperature *T* for various thermoelectric materials.

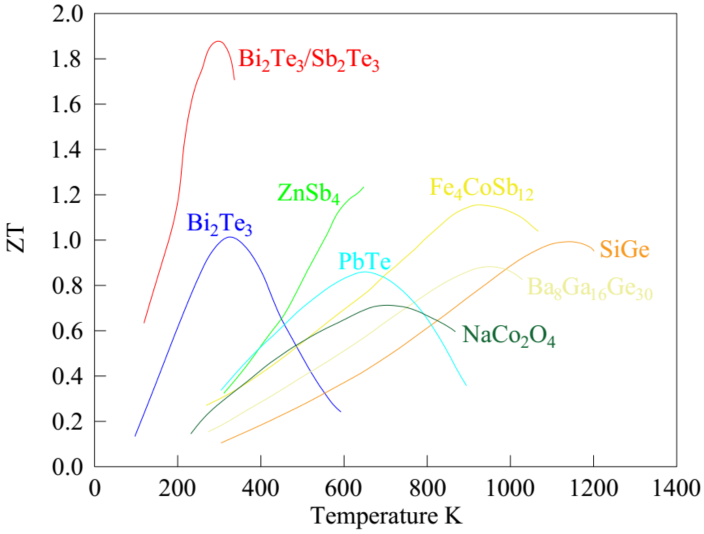


Figure 4. ZT as a function of material and temperature [4]

Recent research with the application of nanostructures for the production of thermomodules defines the value of the *ZT* factor even higher than 2 [4,6]. In addition to bismuth-telluride, there are other most commonly used alloys, such as lead-telluride, silicon-germanium and bismuth-antimony. Of course, the goal is to find better thermoelectrics which have lower price and a higher quality factor, and some of the newer ones are clathrates, quasicrystals, tetrahedrites and silicon nanowires.

3. ANALYSIS OF THE POSSIBILITY OF APPLYING THE THERMOELECTRIC MODULE FOR HEATING

It is known that thermoelectric elements found their initial important application in the space program, but subsequently also in the production of portable car freezers, for cooling computers, in the auto industry, as well as in industry for the utilization of waste heat at high temperatures.

Cheaper individual components, as well as entire thermoelectric modules (TEM), have led to the idea that they can also be used in HVAC systems [7,8]. Although they have low efficiency, these systems can be used for heating and cooling spaces if they get energy from solar photovoltaic modules, because solar cooling still does not have an adequate commercial solution. As a consequence of the combustion of fossil fuels to generate electricity used in HVAC systems the greenhouse effect is created, this continuous increase of global warming indirectly leads to a higher demand for air conditioning systems. In addition, the refrigerant of the traditional air conditioner, freon, leads to irreversible damage to the ozone sphere after leaking.

The position of these devices in the building itself is not limited due to their small dimensions, and they can be installed in the wall [9] or in the suspended ceiling of the room [10,11]. There is also the possibility of creating an air channel in which a heat exchanger with a Peltier element as a heat generator would be placed, whereby air circulation from the space would be provided through the module [12].

During the construction of new buildings, the heat source can be easily positioned in the wall or in the ceiling, but in existing buildings it is very difficult to reconstruct the ceiling and it would be financially unjustified. The idea of the work is to position the mentioned installation on the existing wall, while additionally installing an isolation panel that separates the system from the surrounding air. The mentioned external vertical wall can be made of photovoltaic panels, as shown in Figure 5.

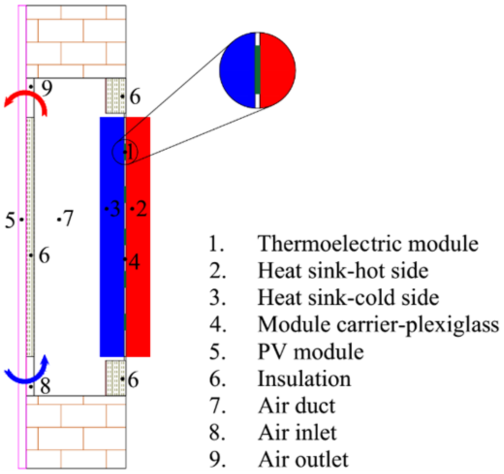


Figure 5. Heating system with TEM positioned in the wall

The idea of this paper is that thermoelectric modules are used for heating, and some further research would consider cooling of buildings, optimizing the number of modules and heat exchangers and room temperature, such as [13].

Based on the analysis of previous research [14-16], the installation, shown in Figure 6, is designed so that one side of the Peltier element is maintained at a constant temperature using a laboratory cooling device. The accuracy of air temperature adjustment inside the cooling device is ±0.1 °C, which simulates temperature in the environment. The cold (summer) or warm (winter) side of the

Peltier element has a variable temperature depending on the demands in the room, and a heat exchanger is mounted on the device itself, in order to increase the surface area for transferring heat to the ambient air. The temperature of the surrounding rooms, that is the temperature of the air in the laboratory where the installation is located, is maintained at a fixed desired temperature using a heat pump.

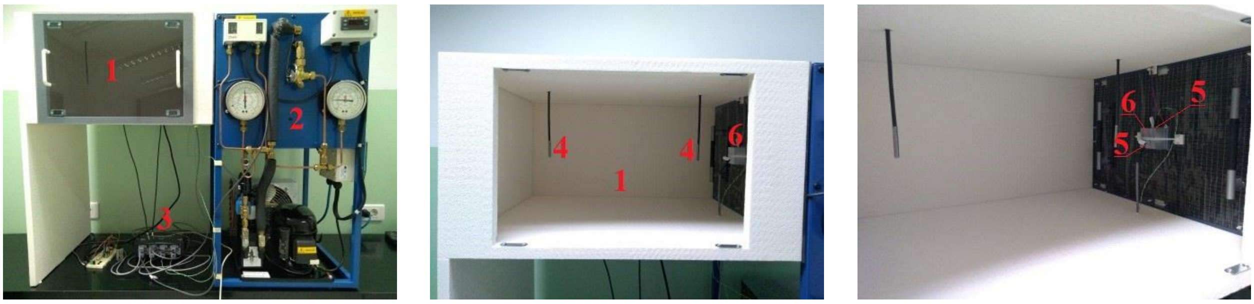


Figure 6. Experimental installation for thermoelectric module analysis; 1 - heated room; 2 - cooling device that simulates outside air; 3 - data acquisition; 4 - air temperature sensors in the room; 5 - heat exchanger surface temperature sensors; 6 - heat exchanger on the warm side;

The basic component of the installation with a thermoelectric generator (TEG) is certainly the Peltier element shown in Figure 7, whose characteristics are shown in Table 1.

Figure 7. Peltier element used during measurement HP-127120

The thermomodule is powered by a 24 V power supply with the ability to regulate voltage from 0 to 14.5 V and current from 0 to 12 A. Temperature sensors are PT100 probes, with a resolution of ±0.1 °C. The acquisition to which the sensors are connected is manufactured by “QuantumX”, model “MX840B”. The acquisition is moderated with calibrated devices and measures voltage and current at the ends of the Peltier element and temperature at several points.

Table 1. Technical characteristics of the used TEG

Product type	HP 127 120
Product dimension, height	2.8 mm
Product dimension, width	40 mm
Product dimensions, length	40 mm
Nominal Voltage	14.5 V/DC
Temperature difference (max.)	68 °C
Heating power (max.)	106 W
Current (Max)	12 A

The contact of the thermomodule with the heat exchanger was made using thermal paste, and the contact resistance to heat transfer itself was not considered in this paper. The existing heat sink are identical on both sides and are made of aluminium alloy, as shown in Figure 8. The space between hot and cold air is separated by 4 mm thick plexiglass. Plexiglass plays the role of the thermomodule support along with the rest of the installation.

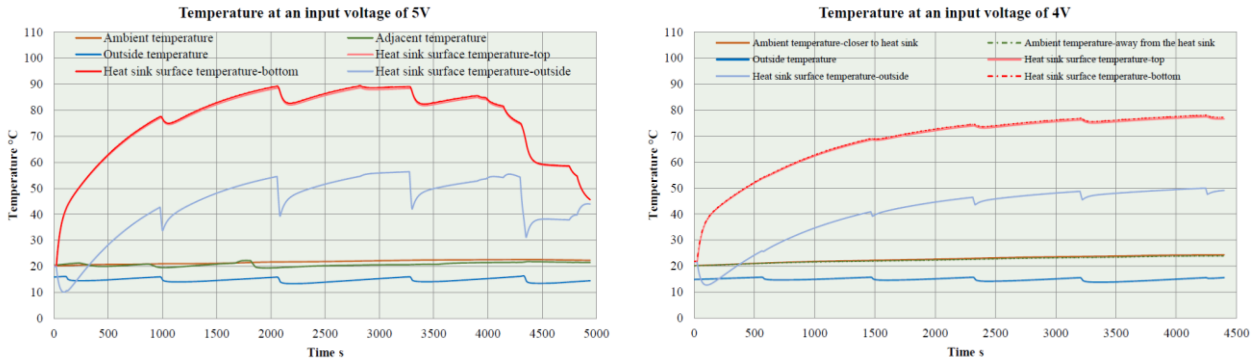
Figure 8. Aluminium heat exchanger

The existing heat sink (Figure 8) that was used during the experimental analysis was prepared in the machining center so that it has identical dimensions as the Peltier element, to cover its entire surface.

Earlier in the paper, the efficiency of the Peltier element was defined, and a large number of works analyze the efficiency of the Peltier as an independent component, but for the specific application of the Peltier element in HVAC systems, it is necessary to have more detailed results of the complete system with heat exchangers. Some authors [9,17,18] considered an entire TEG system, but the goal of this paper is to create a detailed mathematical model, and then on a smaller scale, experimentally confirm the results obtained with the mathematical model.

To define the limits of the mathematical model, it is necessary to perform measurements first, in order to establish whether the system that includes the Peltier element and the aluminium heat exchanger on both sides is stable for natural convection. Also, the idea is to test how the system reacts to a change in parameters, for example the external temperature in the event of a cold wind, which is shown in figure 9. Figure 9.a shows the characteristic temperatures for a voltage of 5 V and a current of 2 A, while figures 9.b shows the characteristic for 4 V and 2 A.

It is observed that the system at low voltages and currents, which can be provided by solar photovoltaic systems, easily reaches 90 °C. This temperature has just been adopted as the limit according to recommendations and rules in heating systems. The heat sink surface temperature at the top and bottom are uniform and the deviations are a maximum of 1.1 °C, while the average is 0.5 °C. The adopted ambient temperature is 20 °C. The experiment was started with a room temperature of 20.0 °C, and during the measurement it reached 22.7 °C. The external temperature is adopted in the amount of 15±1.5 °C. It is observed that the system is not stable, that is, the temperature of the exchanger in the environment changes rapidly, and therefore the temperature of the hot exchanger in the room. Regardless of this subcooling, the system warms back up to the set value very quickly. The temperature of the exchanger in the environment is initially cooled below the air temperature and then heated up to a maximum temperature of 56.4 °C. The temperature difference between the heat exchangers on the hot and cold sides is on average 31.4 °C, while the minimum and maximum temperature differences are 0.1 and 47.8 °C, respectively. The temperature of the adjacent rooms for the room where the measurements are performed, that is the temperature of the laboratory where the system is located during the measurement, is adopted as a heated space and ranges within 20±1 °C.



a. 5 V i 2 A

b. 4 V i 2 A

Figure 9. Experimental results of measurements of an aluminium heater with a Peltier element as a heat generator

4. MATHEMATICAL MODEL OF A HEAT EXCHANGER WITH A PELTIER ELEMENT AS A HEAT GENERATOR

Heat transfer is very specific depending on the process, and the model becomes even more complicated with a heat sink with narrow ribs measuring around 1 mm. In order to highlight the influence of the exchanger, even when it comes to natural convection, the heat transfer from a flat aluminium plate is primarily analyzed.

Surface temperature T_s of 90 °C was adopted as in the experiment, and Ambient temperature T_∞ at a value of 20 °C. The average temperature T_{avg} for which the fluid characteristics are adopted is 55 °C. The dimensions of the heat exchanger that was used in the experiment itself are 40x40 mm, which is the starting value for the mathematical model, and the limit value of the dimensions of the square exchanger that would be used in the space is 1x1 m.

Determining the transferred amount of heat from a flat plate during natural convection begins by defining the Rayleigh number according to equation (4), where β is the volume expansivity, ν kinematic viscosity, Pr Prandtl number and characteristic length is the height L.

$$Ra_L = \frac{g \cdot \beta \cdot (T_s - T_\infty) \cdot L^3}{\nu^2} \cdot \mathrm{Pr} \tag{4}$$

Based on the obtained values, the Nusselt number is adopted according to equation (5) [19], in order to be able to define the heat transfer coefficient from the warm aluminium surface to the ambient air.

$$Nu = \left\{ 0.825 \cdot \frac{0.387 \cdot Ra_L^{1/6}}{\left[1 + (0.492/\mathrm{Pr})^{9/16}\right]^{8/27}} \right\}^2 \tag{5}$$

Convection heat transfer coefficient in that case amounts to:

$$\alpha = \frac{\lambda}{L} \cdot Nu \tag{6}$$

based on which the required natural convection heat transfer rate can be expressed:

$$Q_{conv} = \alpha \cdot A_s \cdot (T_s - T_\infty) \tag{7}$$

where A_s is the area of the square plate [19].

In addition to convection, heat transfer must also include radiation if a complete and detailed mathematical model is desired, which is done according to equation (8), where ε is the emissivity of the aluminium surface, A_s is the surface area, and $\sigma = 5.67 \cdot 10^{-8}$ W/m^{2}K^4 is the Stefan-Boltzmann constant.

$$Q_{rad} = \varepsilon \cdot \sigma \cdot A_s \cdot \left(T_s^{\,4} - T_\infty^{\,4} \right) \tag{8}$$

Based on the presented mathematical model, Figure 10 shows the heat transfer diagram for different dimensions of a square plate heated by Peltier elements to 90 °C.

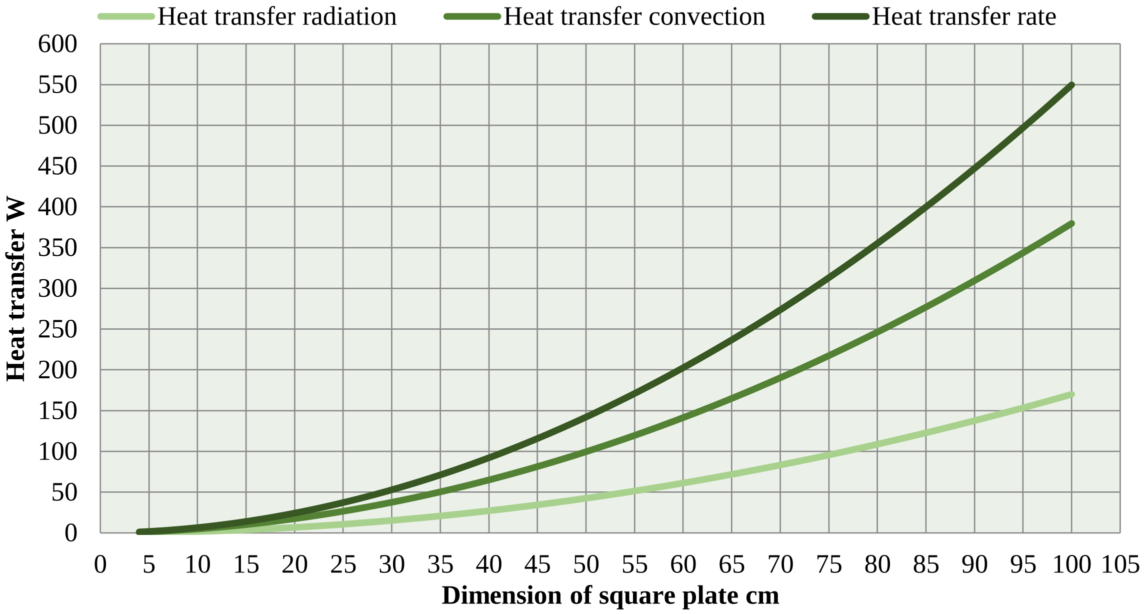


Figure 10. Heat transfer for different plate dimensions

It is observed that the Peltier elements installed on the heat exchanger in the form of a flat aluminium plate, which would have the dimensions of commercial heating bodies - radiators, can ensure thermal comfort in residential areas, but these values are very small and unjustified. The efficiency of that system would be very low because the specified heat flux values are defined with an aluminium plate completely covered with thermoelectric elements, and if these values were to be achieved, the system would be unprofitable.

Natural convection from a vertical finned surface of rectangular shape has been the subject of numerous studies, mostly experimental. Bar-Cohen and Rohsenow [20] have compiled the available data under various boundary conditions and developed correlations for the Nusselt number and optimum spacing. The heat sink model used during the experimental analysis has a very small fin spacing S, and therefore does not have an optimum fin spacing for the given dimensions.

Characteristic length is the height L and is 40 mm, heat sink width $W = 40$ mm, and height from the base $H = 25.1$ mm. As shown in Figure 11, the fin spacing is $S = 1.5$ and fin thickness $t = 1.2$ mm. In order to define the heat sink surface A_s, the number of fins $n = 15$ is necessary.

The calculation was first performed for the existing heat sink and the resulting values were analyzed with the values obtained experimentally, which is shown below.

Then, a preliminary mathematical model for the same heat sink with optimum fin spacing was made in order to consider the possibility of greater efficiency of this system, which is not shown in detail.

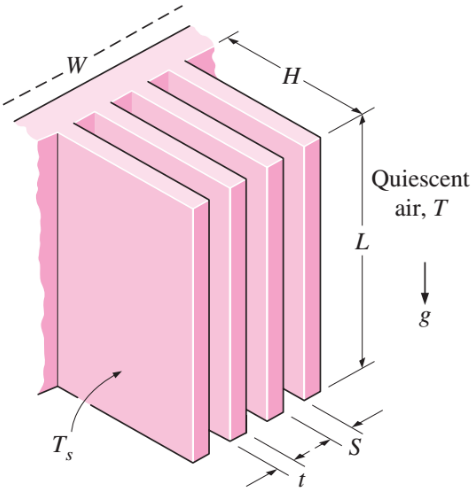


Figure 11. Various dimensions of a finned surface oriented vertically [19]

The characteristic length for vertical parallel plates used as fins is usually taken to be the spacing between adjacent fins *S*, where the Rayleigh number is expressed as:

$$Ra_S = \frac{g \cdot \beta \cdot (T_s - T_\infty) \cdot S^3}{\nu^2} \cdot \Pr \tag{9}$$

Although the fin height *L* could also be used for characteristic length, as defined for a flat plate by equation 4, where the ratio of these two Rayleigh numbers is defined by equation 10.

$$Ra_L = Ra_S \cdot \frac{L^3}{S^3} \tag{10}$$

During the experimental analysis, it was observed that the temperature distribution along the length of the exchanger is uniform, that is, it has very small deviations, which is shown in Figure 9. With that assumption, the recommended relation for the average Nusselt number for vertical isothermal parallel plates [20] was adopted, that is T_s = const.

$$Nu = \left[\frac{576}{(Ra_S \cdot S/L)^2} + \frac{2.873}{(Ra_S \cdot S/L)^{0.5}} \right]^{-0.5} \tag{11}$$

Fin spacing problem will be shown below, where for the specified real exchanger with the Rayleigh and Nusselt number defined, the convection heat transfer coefficient has a small value:

$$\alpha = \frac{\lambda}{S} \cdot Nu = 0.431 \left[W/m^2K \right] \tag{12}$$

which implies a very small heat transfer rate, defined by equation (13).

$$Q_{conv} = \alpha \cdot A_s \cdot (T_s - T_\infty) = \alpha \cdot (n \cdot 2 \cdot L \cdot H) \cdot (T_s - T_\infty) = 0.905 \left[W \right] \tag{13}$$

This shortcoming is due to narrow fin spacing and the impossibility of ideal air flow between two fins, and therefore optimum heat transfer. To overcome this shortcoming, the exchanger with natural convection must be defined with optimum fin spacing, which is planned as a continuation of this work. A preliminary assessment is that with optimum fin spacing, up to 10 times higher heat quantities can be ensured.

Heat transfer radiation obtained from a heat sink with a constant surface temperature T_s can be divided into radiation from exposed surfaces and radiation in the channel. Channel radiation has an effective channel emittance ε_{ch} [21], unlike exposed surfaces that have an emissivity ε.

$$Q_{rad} = \left[\varepsilon_{ch} \cdot S \cdot L + \varepsilon \cdot \left(A_s - A_{ch}\right)\right] \cdot \sigma \cdot \left(T_s^{\,4} - T_\infty^{\,4}\right) \tag{14}$$

The amount of heat obtained by radiation from the heat sink is 1.664 W, which generates a total heat from the exchanger in the amount of 2.569 W. If the input electrical power and the amount of heat obtained are considered, the heating coefficient of performance *COP* is obtained in the amount:

$$COP = \frac{Q}{P} = 0.31 \tag{15}$$

It is observed that the *COP* coefficient has a very small value, and the reason is the heat exchanger that does not have optimal fin spacing and is not able to deliver the maximum amount of heat for that surface of the Peltier element. In addition, a system was considered in which the Peltier element and the heat exchanger are of the same surface, which is not rational. It is necessary to reduce the number of TEM and therefore the input electric power, and to increase the area of the exchanger, that is, to optimize the number of modules on the exchanger of a certain area.

5. CONCLUSION

This paper presents experimental analysis of the justification of using a space heating system based on Peltier thermoelectric generator. For this purpose, the measurement and simulation of the heat generator was carried out. This generator could be positioned in the wall of the building, with solar photovoltaic panels as a source of electricity.

Measurement acquisition collected data on input voltage, input current, internal and external air temperatures, and surface temperatures of the heat exchanger on the hot and cold side. Aluminium heat exchangers were used, which together with the Peltier element make up the heating body.

On the thermoelectric module with the heat exchanger, the maximum surface temperature of 90 °C was reached, at the input electric power of 8.31 W and the temperature of the cold side in the range from 10 to 15 °C. Given that the system delivered only 2.569 W of heat energy into the space, it is concluded that the coefficient of performance *COP* is small - 0.31.

Considering the value of the input electricity, the value of the heat released into the room is very small, which leads us to the conclusion that without optimizing the heat exchanger this system is not justified to use. A preliminary assessment is that heat energy values from the exchanger optimized on the same system can be obtained up to 10 W, which makes the system competitive because a *COP* greater than 1 would be reached. Forced air circulation would further increase and ensure the stability of the system.

Further research aims, in addition to defining the air cooling system in the room, to optimize the heat exchanger and the number of modules per exchanger surface.

REFERENCES

[1] T.H. Cheng, *et al*. “An effective Seebeck coefficient obtained by experimental results of a thermoelectric generator module.” *Applied Energy*, vol. 88, issue 11, pp. 5173–5179, 2011. doi:10.1016/j.apenergy.2011.07.033

[2] I. Šumiga, *et al*. “Application of Thermoelectric Modules as Renewable Energy Sources.” *Technical journal*, Vol. 3, pp. 151-158, 2018. doi:10.31803/tg-20180301181527

[3] M. Vinko. “Primjena Peltierovih elemenata.” završni rad, Sveučilište sjever, Varaždin, Hrvatska, 2017.

[4] R. Đurić. *Autonomni izvori termalne energije*, Beograd, Srbija, Elektrotehnički fakultet, 2020.

[5] Howthingswork.org,Science and Technologies Explained for Everyone. “Physics/Electronics-Thermoelectric effect and its applications”, http://howthingswork.org/physics-thermoelectric-effect-physics-and-applications/2/, April 20, 2017 [May 4, 2022].

[6] D.V.K. KHANH, *et al*. “Optimization of thermo-electric coolers using hybrid genetic algorithm and simulated annealing.” *Archives of Control Sciences*, vol. 24, issue 2, pp. 155–176, 2014.

[7] X. Ma, *et al*. “Building Integrated Thermoelectric Air Conditioners-A Potentially Fully Environmentally Friendly Solution in Building Services.” *Future Cities and Environment*, vol. 5, pp. 12, 2019. doi: https://doi.org/10.5334/fce.76

[8] I.A. Gondal. “Design and experimental analysis of a solar thermoelectric heating, ventilation, and air conditioning system as an integral element of a building envelope.” *Building Services Engineering Research and Technology*, vol. 40, issue 2, pp. 220-236, 2018.
doi: 10.1177/0143624418814067

[9] Y. Luo, *et al*. “Dynamical simulation of building integrated photovoltaic thermoelectric wall system: Balancing calculation speed and accuracy.“ *Applied Energy*, vol. 3, 2017.
doi: http://dx.doi.org/10.1016/j.apenergy.2017.03.024

[10] Z. Liu, *et al*. ”Experimental evaluation of a solar thermoelectric cooled ceiling combined with displacement ventilation system.” *Energy Conversion and Management*, vol. 87, issue 1, pp. 559–565, 2014.

[11] K. Irshad, *et al*. “Study of thermoelectric and photovoltaic facade system for energy efficient building development: A review.” *Journal of Cleaner Production*, vol. 209, pp. 1376-1395, 2019.
doi: https://doi.org/10.1016/j.jclepro.2018.09.245

[12] K. Irshad, *et al*. “Thermal comfort study of a building equipped with thermoelectric air duct system for tropical climate.” *Applied Thermal Engineering*, vol. 91, pp. 1141-1155, 2015.
doi: 10.1016/j.applthermaleng.2015.08.077

[13] L.G. Chen, *et al*. “Performance optimization of a class of combined thermoelectric heating devices.” *Science China Technological Sciences*, vol. 63, pp. 2640-2648, 2020.
doi: https://doi.org/10.1007/s11431-019-1518-x

[14] M.R. Fairuz, *et al*. “Experimental study of a mini cooler by using Peltier thermoelectric cell.” *IOP Conference Series: Materials Science and Engineering*, vol. 788, issue 5, 2020.
doi:10.1088/1757-899X/788/1/012076

[15] V. Giaretto, and E. Campagnoli. “The Elusive Thomson Effect in Thermoelectric Devices. Experimental Investigation from 363 K to 213 K on Various Peltier Modules.” *Metals*, vol. 10, issue 2, 2020. doi: https://doi.org/10.3390/met10020291

[16] Z. Abbas, *et al*. “Performance evaluation of novel solar-powered domestic air cooler with Peltier modules.” *Journal of Mechanical Science and Technology*, vol. 34, issue 11, pp. 4797-4807, 2020. doi: http://doi.org/10.1007/s12206-020-1036-0

[17] M. Trancossi, *et al*. “Thermoelectric and solar heat pump use toward self sufcient buildings: The case of a container house.” *Thermal Science and Engineering Progress*, vol. 18, 2020.
doi: https://doi.org/10.1016/j.tsep.2020.100509

[18] F. Afshari. “Experimental and numerical investigation on thermoelectric coolers for comparing air-to-water to air-to-air refrigerators.” *Journal of Thermal Analysis and Calorimetry*, vol. 144, 2020.
doi: https://doi.org/10.1007/s10973-020-09500-6

[19] Y.A. Cengel, and A.J. Ghajar. *Heat and Mass Transfer-Fundamentals and Applications*. New York, USA: McGraw-Hill, 2011.

[20] A. Bar-Cohen, and W.M. Rohsenow. “Thermally Optimum Spacing of Vertical, Natural Convection Cooled, Parallel Plates.” *Journal of Heat Transfer*, vol. 106, issue 1, pp. 116-123, 1984.
doi:10.1115/1.3246622

[21] K.K. Yong, *et al*. “On the role of radiation view factor in thermal performance of straight-fin heat sinks.” *International Communications in Heat and Mass Transfer*, vol. 37, issue 8, pp. 1087-1095, 2010. https://doi.org/10.1016/j.icheatmasstransfer.2010.06.012