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# Life Cycle Assessment Of Cooling and Heating System Based on Peltier Module

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**Abstract**. Sustainability in the construction branch refers strongly to the service life of buildings. According to many literature studies, typical energy standard buildings are characterized by significant share of the operational phase on their life cycle, considering various environmental indicators. Thus, the kind of the energy source is very often the key factor influencing the results of building's Life Cycle Assessment.The innovative solution of cooling and heating system based on Peltier device is developed at Lublin University of Technology. The results obtained during laboratory tests (COP 0,767) as well as the results of Life Cycle Assessment procedure (GWP at the range of 0,22–0,9 $gCO_{2eq}$/Wh) show that the developed system, after specific modifications, may be treated as environmentally friendly source of cooling and heating energy.

## 1. Introduction

In thermoelectric cooling, the Peltier modules are used to induce the heat flux between both sides of the module. Although the principle of heat transport in a specific direction has been known for a long time, the application of this phenomenon was possible with the discovery of the semiconductors. The development of electronics caused a drop of prices of thermoelectric devices, causing the extension of Peltier module applications in many areas of life.

Nowadays, they are comparable with efficiency and performance of conventional refrigeration equipment in certain uses. The unique properties of the cells are suitable for special applications that were previously unattainable. They small dimensions, the ability to scale cooling elements, reliability, control options and independence from space position together with the quiet work make the use of Peltier modules possible for many areas.

In this work, the application of the Peltier module in the refrigeration chamber will be presented in order to reduce the temperature of internal air. The heat transported from the chamber will be then used for preparation of hot water. The system's performance will also allow the conceptual Life Cycle Assessment of the processes of heating and cooling energy generation.

## 2. Thermoelectric cooling in literature studies

Thermoelectric coolers use the Peltier phenomenon: the operation of electric current in an electric circuit built of two diverse substances causes the increase in temperature in one of the two wires and in the other – its decrease and absorption of heat [1]. According to the literature sources [2] designing of a thermoelectric cooler should be based both on the system cooling power output and cooling COP. That means there is a need to consider both the Peltier module operation and the heat sink design.

The enhancement of thermoelectric cooler operation may be obtained in three basic ways. The first method is based on the design and optimization of Peltier module, based on several geometrical parameters [3], [4], [5], [6], [7], [8], [9]. The second method relates to designing of the cooling system itself, with special attention paid to heat sinks [10], [11], [12]. The third method is based on the cooling system working parameters like electric current, flow rates of media, etc. [13], [14].

It is necessary to underline that the efficiency of the heat exchange processes at hot and cold side of Peltier module greatly influences the COP of system. Typical solutions include air cooled heat sinks, water cooled heat sinks and heat sinks integrated with heat pipes. What is more, the parameters of the heat sink at the hot side is more significant than at the cold side. This is caused by the higher heat flux density at hot side resulting from heat transfer and additional phenomena, like Seebeck and Thomson effects.

### *2.1. Applications of thermoelectric coolers*

Standard applications of thermoelectric cooling include electronic cooling, domestic refrigeration, scientific, medicine and automobile applications. Yet, the use of Peltier modules is not limited to the above mentioned categories. With the development of new production technologies and higher efficiency of modules, the new applications can be found.

One of the innovative technology is the development of the thermoelectric domestic air-conditioning systems. In the paper written by Riffat and Qiu [15], the comparison of thermoelectric and conventional vapour compression air-conditioner performance was presented. In spite of the fact that COP obtained for thermoelectric cooling system was lower than for the conventional air-conditioner, this solution has several advantageous features which may cause its application. Its quiet and multi-positional operation are especially suitable for domestic use.

In the another paper written by Cosnier et al. [16], a study of a thermoelectric air-cooling and air-heating system is presented. The COP between 1.5 and 2 for the 5 °C temperature difference between hot and cold side was obtained by supplying an electrical intensity of 4 A. Gillott et al. [17] developed thermoelectric cooling system for air conditioning application. The maximum COP was 0.46 while the electrical current 4.8 A was used for each module.

In the work of Liu et al. [18] theoretical and experimental study of a thermoelectric solar air conditioner with the possibility of heat recovery for hot water heating was presented. The test system was manufactured and tested in laboratory conditions in three operating modes: room cooling, room cooling and heat recovery for water heating, space heating. Results obtained in this study indicate that with adequate control of operating conditions, the tested system can be used to provide hot water without losing cooling power. The system operating in the internal air cooling and water heating mode has a relatively high COP, which values reached 4.51 (for water temperature in the tank 20 °C).

## 3. Materials and methods

The experimental setup developed at Faculty of Environmental Engineering, Lublin University of Technology consisted of the following elements:

- cooling chamber,
- water tank with pipes and water meter,
- Peltier module with finned heat sink and Alpine 11 fan (cold side) and water heat sink (hot side),
- two temperature sensors on the cold side of the module,
- two temperature sensors on the hot side of the module,
- two temperature sensors inside the cooling chamber,
- APEK AL 154 recorder,
- two digital PeakTech 3340 DMM voltage meters,
- PeakTech 2010 DMM digital current meter,
- Constanter Gergeltes Netzgerat 0-12 V regulating and control power supply,
- Korad KA3010D power supply.

The described setup allowed the measurement of temperatures, flows and power consumption of the designed system, presented in Figure 1.

**Figure 1.** Experimental setup: cooling chamber, water tank and measurement system.

Temperature sensors were placed in six measuring points. The most important two are located inside the cooling chamber, another two on the cold side of the module. The last pair of sensors was located on the hot side of the module. Before each measurement series, the air temperature inside the test chamber was equalized with the air temperature inside the laboratory. During the experiment, the temperature inside the laboratory varied within ± 0.1 ° C.

The temperature at the set points of the cooling and heating system was measured by means of calibrated measurement-recording system, and the measurement results were archived with the APEK AL.154 recorder with a time step equal 60 seconds. A heat source supplied from the power grid was placed in the test chamber. Heat source power control was carried out remotely using a regulator. Based on the preliminary tests, the source power setting at the regulator was determined to be 5 W.

In the experiment, two different heat exchangers (specified above) were used. The minimization of the heat transfer problems was based on preliminary tests, where the input parameters for the supply of the fan radiator as well as for the Peltier module were stated. The aim of the preliminary tests was to ensure the optimal heat distribution and to avoid the problems of cooling capacity loss caused by Joule's effect. The preliminary test showed that application of the electric current of 7A to the TE module causes significant heat gains on the hot side of the TE module (due to Joule's effect), thus this excess heat is conducted to the cold side of the TE module affecting the cooling process negatively.

In the water exchanger circuit, the distilled water was used in order to protect the devices against scaling. The temperature of water at the beginning of experiment was 10.5 °C. The volume flow of water was determined on the basis of preliminary tests and was equal 3 $dm^3$/min. The flow was constant for each measurement series in which the air and water heat sinks were used.

To determine the integral COP for the entire system, the authors used the following formula [18]:

$$COP = (Q_c + (Q_h - Q_{loss})) \cdot (P_{TE} + P_{fan} + P_{pump})^{-1} \quad (1)$$

where:
$Q_c$ – cooling power of the TE, W,
$Q_h$ – thermal power of the hot TE, W,
$Q_{loss}$ – heat losses between the tank and the atmosphere, W,
$P_{TE}$ – power supplying thermoelectric cell, W,
$P_{fan}$ – fan power, W,
$P_{pump}$ – pump power, W.

After conducting the experiment, as a part of the research project, Life Cycle Assessment procedure was conducted in order to provide information about the environmental burdens connected with the designed thermoelectric cooling system operation. LCA allows the comparison between the typical solution of cooling and heating system and the developed thermoelectric cooling and heating system in terms of environmental indicators. For Life Cycle Impact Assessment, Global Warming Potential 100a method was used in order to examine the greenhouse gas emissions throughout the designed system life cycle.

## 4. Results and discussion

### *4.1. Results of laboratory tests*

The results presented in this study were obtained with the use of electric current 6 A. The preliminary dimensioning of the system was based on the cooling and heating capacities of Peltier module. The aim of the experiment was to achieve the hot water temperature 55 °C, which happened after 232 minutes of system operation. The lack of constant water consumption, which would cause the temperature drop in the tank, resulted in its rise to the desired level. However, it has to be mentioned, that the examined situation corresponds to the typical case of water heater operation, and the consumption of water leading to the steady state would possibly result in the increase of system performance. The temperature distribution at the measuring points is presented in Figure 2.

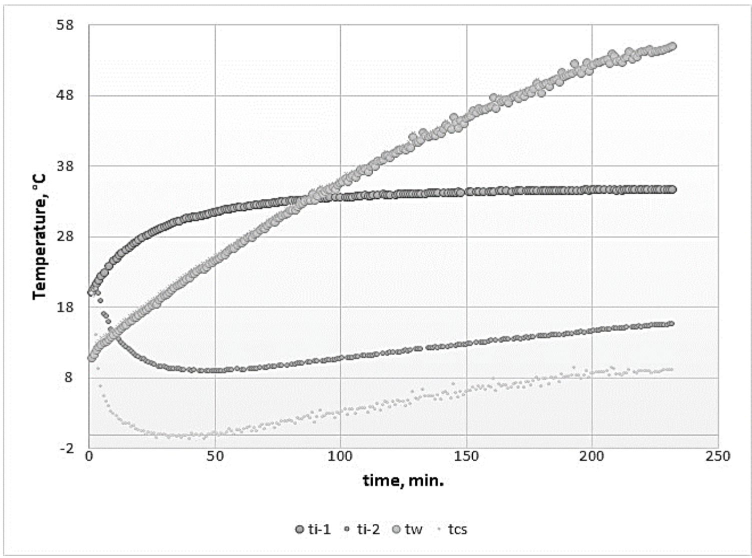


**Figure 2.** Temperature measured inside the cooling chamber without the use of cooling system (ti-1), inside the cooling chamber within the operation of the cooling system (ti-2), inside the water tank (tw) and on the cold side of Peltier module (tcs).

The calculated COP for the thermoelectric cooling and heating system equals 0,767, which is higher than the typical values of literature COP for thermoelectric coolers, presented in Table 1. The differences result from the fact that the use of water heat exchanger on the hot side of the Peltier module in the presented study contributes to the rise of heat transfer efficiency, as well as from the various supply parameters and the TE module sizes. Moreover, it is worth to underline that there is possibility to obtain higher values of COP by keeping the temperature difference between the cold and hot side of modules as low as possible. However, this would not correspond to the practical aim of the presented study.

**Table 1.** Literature values of COP for selected thermoelectric coolers.

| Volume of cooling chamber ($m^3$) | COP | Type of the heat sink | Reference |
|---|---|---|---|
| 0.013 | 0.16 | Hot side: finned heat sink and fan | [19] |
| 0.115 | 0.3–0.5 | Cold side: finned heat sink and fan<br>Hot side: liquid heat exchanger | [20] |
| 0.055 | 0.56–0.64 | Hot side and cold side:<br>finned heat sink and fan | [21] |
| 0.056 | ~0.2 | Hot side and cold side:<br>finned heat sink and fan | [22] |

### *4.2. Results of LCA study*

Conceptual LCA procedure was carried out according to ISO 14040 guidelines and included detailed inventory of system production and operation during the assumed lifespan equal 10 years in this study. The assumed time of system usage included 3 working series (the same as in the experiment) per 2 days. Two various sources of supply energy were considered: EU-27 low voltage grid and small scale photovoltaic installation. For electricity generation processes characterization, Ecoinvent 3.0 database was used.

Results of the comparison of systems with two sources of electricity are presented in Figure 3.

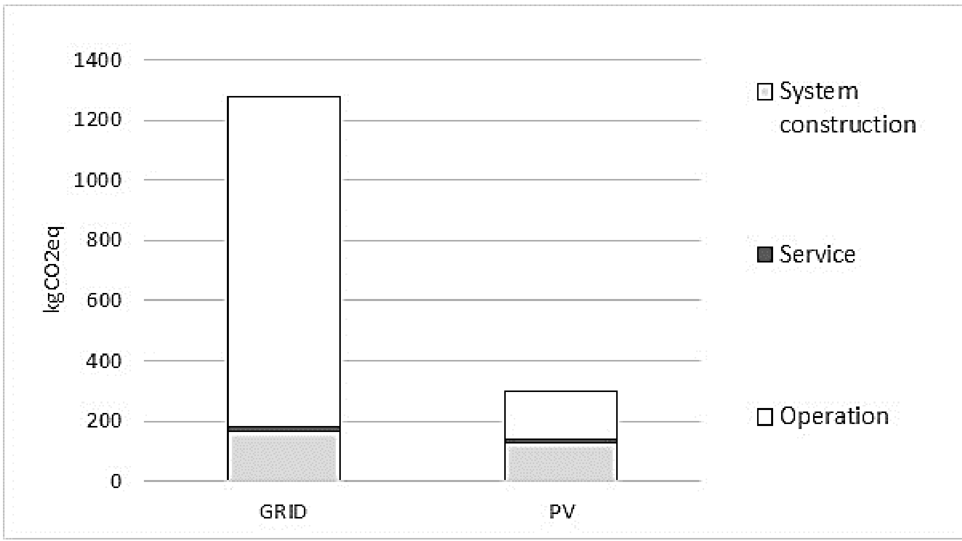


**Figure 3.** Greenhouse gas emission [$kgCO_{2eq}$] for thermoelectric cooling and heating systems supplied by photovoltaic panel (PV) and low voltage grid (GRID).

In both analysed cases, operation of the thermoelectric cooling and heating system is the most important issue, constituting 86% of total greenhouse gas emission for GRID option and 53% for PV supplied system. For the system powered by conventional energy, system construction constitutes 13% of the indicator, while for PV supplied system it is 43%. The emission of greenhouse gases calculated per functional unit was equal:

- 0,90 $gCO_{2eq}$/Wh for GRID heating and cooling system powered by conventional energy.
- 0,22 $gCO_{2eq}$/Wh for PV heating and cooling system powered by photovoltaic installation.

## 5. Conclusion

The results presented in this study seem promising while compared to the examined systems without the heat recovery on the hot side of the Peltier module. COP at the level of 0,767 and the possibility of 76% reduction of greenhouse gas emission is a base for further studies on the developed system. However, the improvement of system performance by addition of control devices, as well as serial connection of modules in the developed system are now issues of the highest importance. The mentioned improvements will be provided to rise the efficiency of thermoelectric cooling and heating system in order to develop the solution that could be an interesting alternative to the typical domestic air conditioning devices.

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