Preliminary study of TEC application in cooling system

A C Sulaiman¹, N A M Amin¹, M S Saidon², M S A Majid¹, M T A Rahman¹ and M N F M Kazim¹

¹School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia.
²Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Malaysia Perlis, Kampus UniCITI Alam, Sungai Chuchuh 02100 Padang Besar, Perlis, Malaysia.

nasrulamri.mohdamin@unimap.edu.my

Abstract. Integration of thermoelectric cooling (TEC) within a space cooling system in the lecturer room is studied. The studied area (air conditioned surrounding) is encapsulated with wall, floor, roof, and glass window. TEC module is placed on the glass window. The prototype of the studied compartment is designed using cabin container. The type and number of TEC module are studied and the effects on the cooling performance are analyzed as it is assumed to be tested within an air conditioned lecturer room. The experimental and mathematical modeling of the cooling system developed. It is expected that the mathematical modeling derived from this study will be used to estimate the use of the number of TEC module to be integrated with air conditioner unit where possible.

1. Introduction
In the last two decades, the world has witnessed severe energy crises in developing countries, especially during summer primarily due to cooling load requirements of buildings. About 40% of the energy has been consumed and this is expected to further increase due to the standards of living improvement and the increase of the world population. The use of air conditioner has increasingly penetrated the market during the last few years and greatly contributed in the upsurge of absolute energy consumption [1-3]. There are two types of system that are used for cooling and heating system in the building namely as passive and active types. Passive cooling involves the use of natural processes for heating or cooling to achieve balanced interior conditions. The flow of energy in passive design is by natural means: radiation, conduction, or convection without using any electrical devices, for example, ambient air is transferring the heat by convection, sky (upper atmosphere) transfers heat by long-wave radiation, water transfers heat by evaporation and ground transfers heat by conduction. An example of the active refrigeration systems classification is shown in figure 1.
As for the research project in hand, the thermoelectric module (TEM) as shown in figure 2 is expected to be used for refrigeration, air conditioning system or power generation application. TEM is an alternative device used for cooling and heating via Peltier effect. J.C.A Peltier discovered this in 1834. TEM is a phenomenon of cooling and heating when two junctions of thermoelectric material which are bismuth and Telluride are passed through by current.

During operation, the current flow will causes heat to be transferred from one side to another to create hot and cold sides. If the direction of the current is reversed, the cold and hot sides are changed. Besides, the cooling power for TEM can be varied by adjusting its operating current. On the other hand, thermoelectric cooling (TEC) system can absorbs and dissipates heat depending on the current polarity so that TEM is not required in any moving parts or production compared to conventional cooling system and generator. TEM cooling system also has numerous advantages such as no noise produce due to any vibrational impact, use no coolant, high reliability and environmental-friendly. The single stage cooler of TEC consists of two ceramic plates with p and n-type semiconductor materials (bismuth, telluride) between the ceramic plates. The elements of semiconductor material are connected electrically in series and thermally in parallel. Usually, the thermoelectric couples are electrical in series and thermal in parallel. The module can contain such several hundreds of thermoelectric couples.

Recently, the demand for thermal comfort of the cooling system makes the consumption of energy becomes higher. TEC is an alternative method to reduce electrical consumption for air conditioned room. In addition, the performance of current air conditioning is not very efficient in the long term as it may causes higher energy consumption. Research on TEC module, as in figure 3, has been carried out extensively for some application such as for electronic cooling, medical technology, commercial product
and military instrument. In last decade, many researchers have expressed concerns about the potential growth of the thermoelectric system and it may give bigger impact to solve our energy challenge.

Figure 3. Thermoelectric cooling [6].

2. Thermoelectric Cooling (TEC) Application in Building
The research project reported elsewhere has studied the TEC system as shown in figure 4, for 2.8m x 2.7m x 2.7m building space with a variation pulse current ratio, cooling load, pulse width and dissimilar pulse shapes. From that variation, the TEC system provides the average cooling power of 600W with the COP of 1.01 by changing the pulse operation of the thermoelectric cooling system from normal mode operating condition [7].

Figure 4. Schematic diagram of the thermoelectric cooler for building space cooling application [7].

In this configuration of thermoelectric radiant air conditioning (TE-RAC) system, the researcher has studied by consuming critical temperature, the design data, and thermal characteristic of thermoelectric radiant panel. They presented that the complex relations between different parameter by considering the temperature decreasing in difference surface from the TEM. Figure 5 shows the novelty of the thermoelectric module adopted in radiant air conditioning to remove the heat load of the room by thermal convection and radiation. The optimal value used of TEM set as 16 per square meter with 4mm thickness of thermoelectric radiant panel that fit for cooling this building. The COP of TE-RAC is larger than the
COP of conventional TE air-conditioning system, which illustrates that the TE-RAC system is a promising approach to enlarge the market of TE technology in the large cooling field [8].

![Diagram of the scheme of thermoelectric radiant air-conditioning system](image)

**Figure 5.** The scheme of thermoelectric radiant air-conditioning system [8].

From the literature review conducted, the research on the performance of the TEC module is particularly involved in the cooling or heating system of various applications. Previous researchers have investigated the TEC system placed on one side of the room wall which is the atmospheric air that is supplied to TEC system and the cold air supplied to the room while the hot air will directly out from the room [7]. The thermoelectric module is placed electrically and thermally in parallel and is sandwiched between heat radiator and aluminum panel to substitute the radiant air conditioning system and the thermoelectric radiant panel exchanges heat with another surface in the room by radiation and exchange heat with the room air by convection [8].

In this paper, the cooling system integrated with TEC module placed at the area of the glass window of an air conditioned room will be studied and the effects on air conditioner compression work will be analyzed. This study looks at the possibility of integrating the TEC within a cooling system to minimize the air conditioner compression work at air conditioned room. The principal aim of the study is to derive a mathematical model that is able to correlate the use of TEC and the effects on the air conditioner compression work. The proposed temperature of the studied area is at 25.5°C inside the air conditioned room and the cooling system at the area of the glass window or its surrounding.

3. **Experimental set up**

A 60Watt TEC module in an air conditioned room is utilized and cooled by a 1 HP AC unit (split unit type). The air conditioned room volumetric space is limited to 3m x 4m x 2m (length x width x height) and the area of glass window attached to the wall is 1.12m x 0.85m (length x width). The cooling system construction and configuration was studied. For future work, the derivation of the mathematical model system will be implemented based on the first and second order. The step response experiment will be implemented using MATLAB software. The step response experiment and the mathematical model will be verified with the real system. Data collection from the experiment can be described using general structure known as ARMAX and ARX model. These models will be used to obtain the experiment data and to evaluate whether the selected model will serve its purpose by determining the best model.
The general structure for ARMAX model:

\[ A(q^{-1})y(t) = B(q^{-1})u(t) + C(q^{-1})e(t) \]  
\[ \text{where} \]
\[ A(q^{-1}) = 1 + a_1 q^{-1} + \ldots + a_{na} q^{-na} \]
\[ B(q^{-1}) = b_1 q^{-1} + \ldots + b_{nb} q^{-nb} \]
\[ C(q^{-1}) = 1 + c_1 q^{-1} + \ldots + c_{nc} q^{-nc} \]

Equation (1) can be written as the difference equation:

\[ y(t) + a_1 y(t-1) + \ldots + a_{na} y(t-na) = b_1 u(t-1) + \ldots + b_{nb} u(t-nb) \]
\[ + e(t) + c_1 e(t-1) + \ldots + c_{nc} e(t-nc) \]  

The general structure for ARX model:

\[ y(t) + a_1 y(t-1) + \ldots + a_{na} y(t-na) = b_1 u(t-1) + \ldots + b_{nb} u(t-nb) + e(t) \]  

Meanwhile, the steady state simulation is done using Ansys CFX software to study the effects of TEC to cooling space area. To evaluate the optimal number of TEC module used in the cooling system, a simulation has been constructed in Ansys CFX (Figure 6). The tests were operated under transient and steady state analysis. Transient analysis is involving time function load while steady state is for determine the effect of steady thermal loads on a system. The steady state analysis also can determine the temperature, heat flow rates, thermal gradient and heat fluxes.

4. Simulation model run in the Ansys-CFX
The steady state simulation is conducted to investigate the effects of heat exchange from the area of the TEC region by assuming adiabatic walls. In this preliminary study, a TEC module has been set with 20°C in an air conditioned room. By considering the uniformity of surface temperature, the simulation is conducted. The changes of air flow from a TEC module in the air conditioned room wall with a certain period of time was depicted in Figure 6. Figure 6 (a) shows the air flow from a TEC module after 30 minutes is not affect the air surrounding of the air conditioned room. But after a certain timestep show in figure 6 (b) and figure 6 (c), the cold air from TEC module slightly cooling the surface of the room. When the steady state condition occurred, the room is covered of cold air that shows in figure 6 (d). From the results, the TEC module successfully affects the cooling of the room with steady state mode. Later, the simulations will be conducted for real mode of air conditioning room including heat losses from wall, floor, and roof. Therefore, more literature review will be done to set data of these losses.
Figure 6. The thermal changes from certain period of time inside the prototype modeling.

5. Conclusion
A preliminary testing on a TEC module effects in an air conditioned room has been studied. The optimum numbers of TEC module might be put into consideration, when it is expected to help the cooling system performance in air conditioned room. The temperature versus ampere data using the number of TEC and different types of TEC will be done on the future. The correlation between the number of TEC and the different types of TEC to the compression of air conditioner unit will be presented in the numerical form/mathematical model. Lastly, the mathematical model of this research work may be used for a better design of an air conditioned room consists of an air conditioner unit and glass windows.

6. Acknowledgements
The authors would like to acknowledge the Ministry of Higher Education of Malaysia and the Universiti Malaysia Perlis, Perlis, Malaysia for financial support under FRGS (9003-00564).

7. References
[1] Mattia D R, Vincenzo B, Federico S and Luca A. T 2014 Applied Energy 128 p 217-29
[2] Xiangfei K, Shilei L, Yiran L, Jingyu H and Shangbao L 2014 Energy and Buildings 81 p 404-15
[3] Adeel W and Zia U D 2013 Renewable and Sustainable Energy Reviews 18 p 607-5
[4] Clito F A A 2006 Applied Thermal Engineering 26 p 1961-71
[5] Einebinsenweisheit.com 2016 Available: http://www.einebinsenweisheit.com/p-peltier-element.html
[6] Artofcircuits.com 2016 Available: http://artofcircuits.com/product/tec1-12706-12v-6a-60-watt-thermo-electric-cooler-assembled-kit
[7] Manikandan S, Kaushik S C and Ronggui Y *Energy Conversion and Management* 2017 **140** p 145-56

[8] Limei S, Zhilong T, Qiang H, Cheng T and Huanxin C 2017 *Applied Thermal Engineering* **112** p 688-97