THERMOELECTRIC AIR CONDITIONER

BY

ARCHSUEK MAMEEKUL

A Dissertation Submitted in Partial Fulfillment of the Requirements for

The Doctor of Philosophy in Physics Program

at Sakon Nakhon Rajabhat University

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DISSERTATION APPROVAL

SAKON NAKHON RAJABHAT UNIVERSITY

DOCTOR OF PHILOSOPHY

PROGRAM IN PHYSICS

Dissertation Title: Thermoelectric Air Conditioner

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ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my thesis advisor, Prof. Dr. Tossawat Seetawan for he invaluable help and constant encouragement throughout the course of this research. I am most grateful for he teaching and advice, not only the research methodologies but also many other methodologies in life. I would not have achieved this far and this thesis would not have been completed without all the support that I have always received from he.

In addition, I am grateful for the teachers of physics: Assoc. Prof Dr. Athorn Vora-ud, Assoc. Prof. Dr. Wilawan Kumharn, Asst. Prof. Dr. Hussakorn Wattanasarn, Artith Machinery Co., Ltd and others person for suggestions and all their help. Finally, I most gratefully acknowledge my parents and my friends for all their support throughout the period of this research.

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บทคัดย่อ

ในการศึกษาครั้งนี้ ได้ออกแบบและประดิษฐ์เครื่องปรับอากาศแบบโมอิเล็กทริก (TESSAC) ที่มีขนาด 400 บีทียูต่อชั่วโมง โดยใช้โมดูลเทอร์โมอิเล็กทริก (TEC) (รุ่น: TEC1-12710) จำนวน 3 โมดูลต่อแบบขนาน ปริมาตรการทำความเย็น 1 ลูกบาศก์เมตร การจัดการความร้อนดำเนินการโดยใช้ระบบหม้อน้ำอลูมิเนียมที่ส่งน้ำผ่านสารหล่อเย็นโมลิบดีนัมเหลวเพื่อควบคุมอุณหภูมิที่ด้านร้อนของโมดูลเทอร์โมอิเล็กทริก ประสิทธิภาพการทำความเย็นและกำลังไฟฟ้า เป็นเวลา 3 ชั่วโมง ตามผลการทดลองโมดูลเทอร์โมอิเล็กทริกสามารถทำความเย็นลดลงเหลือ -8.5°C หลังจากการสร้างเครื่องปรับอากาศเทอร์โมอิเล็กทริก จำนวน 3 โมดูลตามที่ออกแบบ TESSAC แล้ว สามารถทำความเย็นที่ด้านเย็นได้ 9.3°C จากนั้นอุณหภูมิที่ห้องจำลองจะอยู่ที่ประมาณ 27.5°C ภายในอุณหภูมิแวดล้อมที่ 33.5°C ค่าสัมประสิทธิ์ประสิทธิภาพ (COP) ของ TESSAC 5.5 โดยใช้พลังงานไฟฟ้ากระแสสลับ 202.31 วัตต์

คำสำคัญ: การทำความเย็น เทอร์โมอิเล็กทริกคูลเลอร์ น้ำยาหล่อเย็นหม้อน้ำ เครื่องปรับอากาศแบบเทอร์โมอิเล็กทริก

TITLE	Thermoelectric Air Conditioner
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DEGREE	Ph.D. (Physics)
INSTITUTION	Sakon Nakhon Rajabhat University
YEAR	2024

ABSTRACT

In this study, I designed and fabricated a thermoelectric solid-state air conditioner (TESSAC) within 400 BTU/hour by using three thermoelectric cooling (TEC) modules (model: TEC1-12710). Thermal management was carried out with the aluminum water-to-radiator system through the liquid moly coolant to control the temperature on the hot side of the TEC module. The cooling performance and electrical power were measured during the operating system in 1 m^3 for 3 hr. According to the experimental results, the TEC1-12710 of one module could be generated cooling by decreasing the temperature to -8.5°C. After the useful TEC of 3 modules as functional TESSAC fabrication, TESSAC could be cooled at the cold side around 9.3°C. Then, the temperature at the center simulation room is around 27.5°C within the ambient temperature of 33.5 °C. The coefficient of performance (COP) of TESSAC was calculated to be obtained at around 5.5, with the AC power used at 202.31 W.

Keywords: Refrigeration, Thermoelectric Cooling, Refrigerants, Thermoelectric Air Conditioner

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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Air conditioners were first made in the 1900s by using the process of dehumidification, which involves condensing the water vapor in the air to form water droplets, then sending cold air with low humidity instead. The air conditioners available on the market today by use refrigerant, which has been continuously developed (Saini, Watzman, & Bahk, 2021). These results are increased energy consumption, emissions of greenhouse gases, and noise from the operation of the system. For example, in the USA electricity was accounted for more than 76% of total consumption, also more than 40% of all types of energy consumption and related greenhouse gas emissions occur in the building sector. Furthermore, heating, ventilation and heat pump air conditioning are account for 35% of both residential and commercial energy under use which energy consumption was increased. Hence, share of annual electricity consumption is rose from 25% in the 1950s to 40% in the early 1970s and to 76% in 2012 (Gao, Sun, Ma, & Ren, 2021). However, the conversion of primary energy sources into electricity is not always efficient (typically 35–50% for heat engines, 20% for solar thermal plants, 15–40% for solar cells), and thus a substantial amount of energy is lost as waste heat. (Massetti, et al., 2021)

Thermoelectricity is a promising technique to overcome the issues in recovering waste heat to electricity without using moving parts. Thermoelectric (TE) effect is defined as the conversion of a temperature gradient directly into electricity and vice versa. Thermoelectric generators have several advantages, they are particularly reliable, maintenance free, durable with long operating life under extreme conditions, (Rowe, 1995; Alam & Ramakrishna, 2013; Sinnarasa, Thimont, Presmanes, Barnabé, & Tailhades, 2017) non-toxic components (mostly, oxide materials) for human health or the environment, compactness, and a flexible shape. (Hoang, et al, 2022) Unlike solid-state refrigeration systems, current compression cooling technology does not use refrigerants or compressors. It has significant advantages in terms of zero emissions and noise (He, Li, Fan, Zheng, & Chen, 2021; Ma, Zhang, Tong, Huber, Kornbluh, Ju, & Pei, 2017). The thermoelectric also has service life of more than 100,000 hours (Charilaou, Kyratsi, & Louca, 2021). It is a solid-state cooling system that uses the Peltier effect to obtain cooling from thermoelectric source. Therefore, the thermoelectric cooling technology is one of the most promising, it is an alternative technology of the 21st century because thermoelectric refrigeration systems were developed and application in the air conditioning field ventilation, heating. This is an important strategic trend for the future. (Zuazua-Ros, Martín-Gómez, Ibañez-Puy, Vidaurre-Arbizu, & Gelbstein, 2019).

Adeyanju & Manohar (2020) reported prototype thermoelectric air conditioner with a cooling capacity of 286 W using three Peltier TEC1-12730 modules with an installation of the heat sink on the cold side of the thermoelectric. The experiment was conducted in a foam box and measuring at 1.6414 m^2. It was found that, thermoelectric it took air conditioner 4 minutes to reach the desired temperature of 22 °C, while a standard air conditioner system (the refrigeration cycle) also took 20 minutes to cool down to room temperature. The experiment was determined the cooling efficiency by using thermoelectric (TEC1-12708, China). Besides, the performed was installing by the heat sink to both cold and hot sides, it was using the hot side cooling fan. In addition, the air conditioner spreading the coolness on the cold side and optimum current of 1 A. The cooling capacity is 29 W with COP 0.34 under the cold air temperature at 28 °C and air velocity at 0.9 m/s (Maneewan, Tipsaenprom, & Lertsatitthanakorn, 2010).
In addition, The thermoelectric analysis method was based on thermoelectric mathematical modeling to study the effect of the thermoelectric properties for materials based on power on four thermoelectric air-cooling systems following that, 1) Scenario 1: σ, σ and κ changing in equal proportions 2) Scenario

2: α, σ and κ changing for equal ZT values 3) Scenario 3: α, σ and κ changing for maximum COP and 4) Scenario 4: Relationship of the maximum COP with the ZT value and a constant voltage of 4 volts. Meanwhile, for the experiment water was circulated from the water tank with equipped also was fixed frequency by pump measured under two high precision power meters and a T-type thermocouple sensor. The temperature of the TEM critical points was measured by using this device and four sensors were evenly placed on the surface of the heat pipe. The study were measured the temperature of the sensor facing the center of the module for thermoelectric material applications. The cooling efficiency of the thermoelectric air-cooled system has been significantly increased when the temperature difference between hot and cold is reduced for applications with small temperature differences. Thus, the modules with higher α values were offered better performance with thermoelectric materials of the same virtue (Duan, Sun, Lin, & Wu, 2021).

In research operations, the researchers was studied and guidelines for the methods designing thermoelectric air conditioner. There is an experiment to find out the suitability of the construction. Therefore, in this work we have objective for design and fabrication mobile capacity of 400 BTU/hr thermoelectric Solid-State Air Conditioner consisting with temperature control. The method for creating thermoelectric air conditioner is obtained the cooling system and the hot side cooled by using heat sink combined with water through a circulating radiator in the system. At least, we expected in this generation and next generation our work can be benefit for data information of thermoelectric solid-state air conditioner and also can adaption toward other electronics artificial intelligence devices capable.

1.2 RESEARCH OBJECTIVES

1.2.1 Thermoelectric Solid-State Air Conditioner Design and fabrication.

1.2.2 Find out the efficiency of Thermoelectric Solid-State Air Conditioner.

1.3 SCOPE AND LIMITATION OF THE THESIS

1.3.1 Design and fabrication of 400 BTU/hr thermoelectric Solid-State Air Conditioner consisting with thermoelectric air conditioner temperature control and adjustment the system.

1.3.2 Test the operating power and performance of the thermoelectric air conditioner fabricated with commercial applications.

1.4 ANTICIPATED OUTCOMES OF THE THESIS

1.4.1 Thermoelectric Solid-State Air Conditioner.

1.4.2 National and International journal article publications.

CHAPTER 2

THEORY AND LITERATURE REVIEWS

In chapter 2 we were review the theories and research involved in our work, the dissertation is Design and construction of Thermoelectric Solid-State Air Conditioner (TESSAC). Also, the researcher has studied various concepts, theories, experiment and researches related. Then, the researcher has presented the following topics as follow:

2.1 Thermoelectric Effect.

2.1.1 Seebeck Effect.

2.1.2 Peltier Effect.

2.1.3 Thomson Effect.

2.2 Solid-State Thermoelectric Cooling.

2.2.1 The Benefits of Solid-State Thermoelectric Cooling.

2.2.2 Solid-State Thermoelectric Coolers Work.

2.3 Refrigerants.

2.3.1 Classification of Refrigeration.

2.3.2 Effects of Refrigerants.

2.3.3 Refrigeration System Components.

2.4 Thermoelectric Air Conditioners.

2.4.1 Integration of the thermoelectric air conditioning system into building structure.

2.4.2 The Advantages of Thermoelectric Air Conditioners.

2.4.3 Commercial TEC Air Conditioner (TEAC).

2.5 Researches related.

2.1 Thermoelectric Effect

Thermoelectric (TE) effects and the existence of an intrinsic connection between charge and heat transport phenomena in materials have been well known since the discoveries of Thomas Seebeck in the early 19th century. When a material is subject to a temperature gradient, high-energy carriers residing in hot regions tend to diffuse to the cold ones, producing a charge build-up and an electrostatic potential difference and make charge carrier diffuse from hot side to cold side. TE effects provide a very interesting way to convert waste heat into useful energy using a solid-state converter: this possibility has been widely explored since the 1950s, but in practice TE devices have been relegated so far to a small group of niches scientific, medical, or military applications. (Rossella, Pennelli, & Roddaro, 2018) However, this effect can be used to generate electricity, measure temperature or change the temperature of objects because the direction of heating and cooling is determined by the polarity of the applied voltage, then thermoelectric devices can be used as temperature controllers.

The performance of thermoelectric devices is determined by a dimensionless unit, namely the figure of merit (ZT). The combination of TE materials parameters is represented defined by Eq. 1. (Burton, et al., 2018; Singh, Anwar, Dubey, & Mishra, 2023)

$$ZT = \frac{S^2 T}{\rho\kappa} = \frac{(PF)T}{\kappa} \tag{1}$$

Which is obtained from parameters consist with: S is Seebeck coefficient, ρ is electrical conductivity, T is absolute temperature and κ is thermal conductivity. Furthermore, the parameters power factor (PF), indicating that the material has good power efficiency, and also show high performance of TE materials requested high power factor within low thermal conductivity, the PF was defined by Eq. 2.

$$PF = \frac{S^2}{\rho} \tag{2}$$

The power factor focuses on the electrons in the material when the thermal conductivity at the ends of the material is excluded (Twaha, 2016). For the term of thermoelectric effect are encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect (Deen Dayal Upadhyaya College, 2024).

2.1.1 Seebeck Effect.

In 1821 Thomas Seebeck, a German physicist discovered that when two dissimilar metal (Seebeck used copper (Cu) and bismuth (Bi)) wires are joined at two ends to form a loop, a voltage is developed in the circuit if the two junctions are kept at different temperatures. The pair of metals forming the circuit is called a thermocouple. The effect is due to conversion of thermal energy to electrical energy. The Seebeck effect (Figure 1) is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit direct to DC current flows through that circuit. Then, the voltages produced by Seebeck effect are small, usually only a few microvolts (millionths of a volt) per kelvin of temperature difference at the junction. If the temperature difference is large enough, some Seebeck-effect devices can produce a few millivolts (thousandths of a volt). Numerous such devices can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current and the large arrays of Seebeck-effect devices can provide useful, small-scale electrical power if a large temperature difference is maintained across the junctions.

In addition, the valence electrons in the warmer part of metal are solely responsible for that and the reason behind this is thermal energy because of the kinetic energy of these electrons, these valence electrons migrate more rapidly towards the other (colder) end as compare to the colder part electrons migrate towards warmer part. Besides, in the hot side Fermi distribution is soft and the higher concentration of electrons above the Fermi energy but on cold side the Fermi distribution is sharp we have fewer electrons above Fermi energy. In Seebeck Effect electrons is transmittal where the energy is lower. Therefore, it will move from warmer end to the colder end which leads to the transporting energy and thus equilibrating temperature eventually (Deen Dayal Upadhyaya College, 2024).

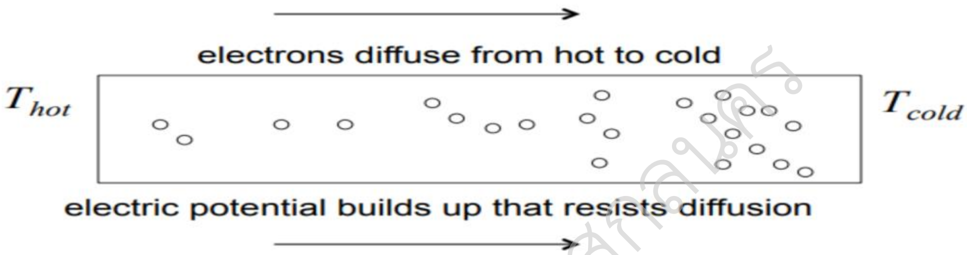


Figure 1 Shown the Seebeck Effect (Deen Dayal Upadhyaya College, 2024).

In simple words we can come to conclusion that the electrons on a warmer end have a high average momentum as compared to the colder one. Then, they will take energy with them (more in no.) as compared to the other one. This movement results in the more negative charge at colder part than warmer part, which Leads to the generation of electrical potential. If this connected through an electrical circuit. It results in the generation of a DC. However the voltage produced is few microvolt (10-6) per Kelvin temperature difference. Now we all are aware of the fact that the voltage increase in series and also has current increase in parallel. Then, for keeping this fact in mind if we can connect many such devices to increase the voltage (in case of series connection) or to increase the maximum deliverable current (in parallel). Keeping care of only one thing that a large temperature difference is required for this purpose. Additionally, one thing must keep in mind that we have to maintain constant but different temperature. Therefore, the energy distribution at both the end will be different and hence it leads to the successful mentioned process.

However, when open circuit the potential will be difference in the circuit whose junctions are maintained at temperatures T_h and $T_c\left(<T_h\right)$ is given by Eq. 3 and support information in Figure 2.

$$\Delta V = S_{AB}\left(T_h - T_c\right) \quad (3)$$

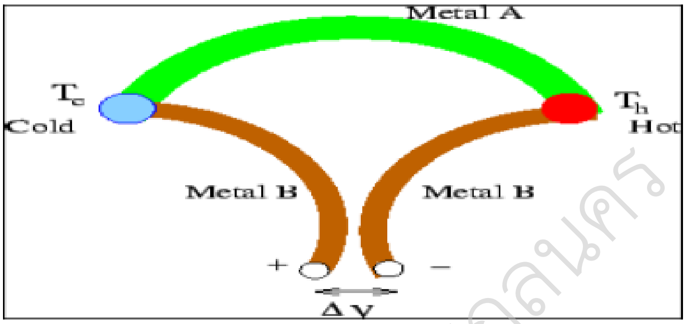


Figure 2 The diagram of Seebeck effect in open circuit with the different type of material (Deen Dayal Upadhyaya College, 2024).

Figure 2 shown the diagram of Seebeck effect in open circuit with the different type of material consider as metal A dan B in giving desirable hot or higher temperature T_h and cold or lower temperature T_c. The potential difference V (ΔV) are generated across the circuit junctions held at different temperatures proportional to the temperature difference between junction (T_h - T_c). This ratio will resulting coefficient of proportionality called Seebeck coefficient. This will be given by Eq. 4.

$$-\frac{\Delta V}{\Delta T} = S \quad (4)$$

Where S is Seebeck coefficient or thermopower, ΔV is voltage gradient, and ΔT temperature difference. Seebeck coefficient also a symbol of potential of cold side respected to the hot side of metal in open loop. The negative sign is representation of charge across the material mainly electron and the convention of current flow (Hofmann, Kroon, & Müller, 2019).

Where the coefficient of proportionality is known as the thermoelectric power or the Seebeck coefficient. Then, the term of thermoelectric power is a misnomer because it does not measure any power and is measured in $\mathrm{V} / {}^{\circ}\mathrm{K}$. By convention, Seebeck coefficient sign is the sign of the potential of the cold end with respect to the hot end. Thus, if S_{AB} is positive conventional current flows from A to B at the hot junction. Seebeck coefficient is not a constant but is dependent on temperature. The temperature dependence of a commercial thermocouple is usually expressed as a polynomial expansion in powers of temperature T. For instance, the thermocouple with Platinum as one of the metals and an alloy of Pt-Rh (90:10) then the open circuit voltage is given approximately by Eq. 5.

$$V = c + aT + vT^2 \tag{5}$$

So, the thermoelectric power is given by Eq. 6.

$$\frac{dV}{dT} = a + 2bT \tag{6}$$

The relationship between V and T is a parabola. The temp. $T_n = -a/2b$ at which the thermoelectric power is maximum is called the neutral temperature. The temperatures $T_i = T_0$ and $T_i = T_0 - a/b$ at which a small change in the difference of the junction temperatures leads to a change in the sign of Thermo emf is called the inversion temperature as shown in Figure 3.

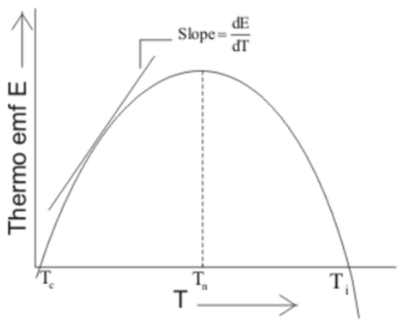


Figure 3 Viriation of Thermo emf with temperature hot junction.
(Physics Catalyst, 2024).

A complete understanding of Seebeck effect requires knowledge of behaviour of electron in a metal which is rather complicated. The Seebeck coefficient depends on factors like work functions of the two metals, electron densities of the two components, scattering mechanism within each solid.

Moreover, the Seebeck effect is a manifestation of the fact that two points in a conductor (or a semiconductor) are maintained at different temperatures, the charged carriers (electrons or holes) in the hotter region, being more energetic will diffuse towards region of lower temperature. The diffusion stops when the electric field generated because of movement of charges has established a strong enough field to stop further movement of charges. For a metal, carriers being negatively charged electrons, the colder end would become negative so that Seebeck cofficient is negative. In part of a p-type semiconductor holes diffuse towards the lower temperature resulting in a positive Seebeck coefficient.

Finally, the performance of thermocouple is determined by the Seebeck coefficient of the pair of metals forming the thermocouple are show in Table 1. As it is impracticable to list the coefficient of all possible pairs, the Seebeck coefficients of metals are usually given with respect to Platinum as standard whose Seebeck coefficient is taken as zero. The following table gives the Seebeck coefficient ($^{mV}\!/_{K}$) of some standard thermocouple material at 0 °C.

Table 1 Seebeck coefficient in various material.
(Deen Dayal Upadhyaya College, 2024; Duraisamy, et al., 2019).

Material	S ($\mu V/K$)	**Material**	S ($\mu V/K$)	**Material**	S ($\mu V/K$)
Bismuth	-72	Lead	4	Iron	19
Constantan[1]	-35	Tantalum	4.5	Nichrome	25
Nickel	-15	Rhodium	6	Antimony	47
Potassium	-9	Gold	6.5	Germanium	300
Sodium	-2	Silver	6.5	Silicon	440
Mercury	0.6	Copper	6.5	Tellurium	500
Carbon	3	Cadmium	7.5	Tin selenide	580
Aluminium	3.5	Tungsten	7.5	Selenium	900

2.1.2 Peltier Effect

In 1834 Jean Peltier, a french watch maker, discovered a second thermoelectric effect. If a current flows through a circuit containing junction of two dis-similar metals, it leads to an absorption or liberation of heat at the junctions. Heat is given out or absorbed depending on the pairs of metals and the direction of the current. The phenomenon of heat evolution is different from the Joule heat as Peltier effect is a reversible process while Joule loss is irreversible.

In addition, the direction of the current at the junction is same as the direction of the Seebeck current, heat is liberated if the Seebeck junction is a hot junction or is absorbed if the junction is cold. Thus for a copper constantan thermocouple if the current flow at the junction is from copper (+) to constantan (-), heat is absorbed on changing to the direction of the current, heat will be liberated at the same junction, showing that the phenomenon is reversible as shown in Figure 4 (Deen Dayal Upadhyaya College, 2024).

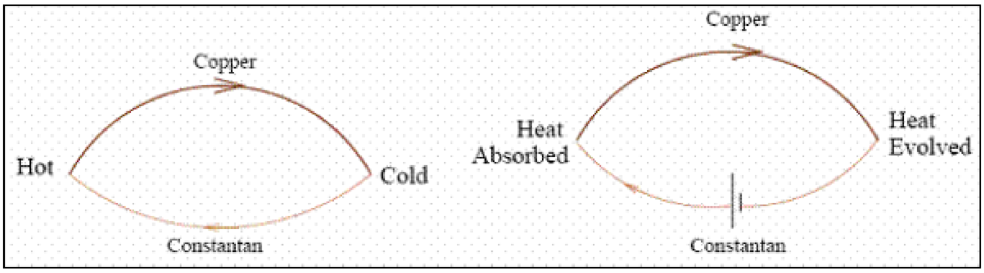


Figure 4 Shown the copper constantan (Deen Dayal Upadhyaya College, 2024).

The amount of heat Q liberated to the surroundings in order that the junction may be kept at the same temperature is proportional to the current I passing through the junction was calculate by Eq. 7.

$$Q = \Pi_{AB} I \tag{7}$$

Where the constant Π_{AB} is thermal current density to electrical current density that called the Peltier coefficient. Peltier coefficient represent amount of heat current is carried per charge thorough material. The Peltier coefficient depends on the pair of materials A and B of the junction and also on the junction temperature. To search for charge was use Eq. 7 and 8 as follow:

$$q = \Pi j \tag{7}$$

$$q = \Pi \sigma \left(-\Delta T \right) \tag{8}$$

Besides, the heat is difficult to measured precisely than thermal difference, this phenomenon connected Seebeck coefficient since it is capable to measurement. Where the both equation may related to Seebeck as Eq. 9 (Terasaki, 2011).

$$\Pi = ST \tag{9}$$

2.1.3 Thomson Effect.

William Thomson (later well known as Lord Kelvin) discovered a third thermoelectric effect which provides a link between Seebeck effect and Peltier effect. Thomson found that when a current is passed through a wire of single homogeneous material along which a temperature gradient exists, heat must be exchanged with the surrounding in order that the original temperature gradient may be maintained along the wire. (The exchange of heat is required at all places of the circuit where a temperature gradient exists. Thomson effect may be understood by a simple picture. A conductor has free charge carriers, which are, electrons in metals, electrons and holes in semiconductors and ions in case of ionic conductors. As the same time, when consider a section of such a conductor whose one end is hotter than the other end. The charge will carriers at the hot end, and being more energetic, diffuse towards the colder end.

Moreover, the charge separation sets up an electric field ($\vec{E}$). After that, the diffusion of carriers would stop when the attractive force on the carriers due to this electric field is strong enough to retard the motion of the carriers due to thermal effect as shown in Figure 5 (Deen Dayal Upadhyaya College, 2024).

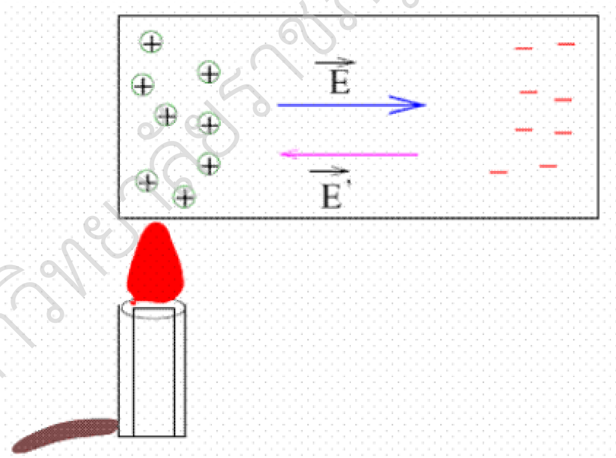


Figure 5 thermal effect (Deen Dayal Upadhyaya College, 2024).

We can represent the effect of the thermal gradient responsible for the diffusive motion of the carriers by an effective field ($\vec{E'}$). This effective field is proportional to the thermal gradient and can be written as Eq. 10.

$$E' = \sigma \frac{dT}{dx} \tag{10}$$

Where σ is Thomson coefficient for the material of the conductor. The Thomson electromotive force (emf) is ε_{th} given by Eq. 11.

$$\varepsilon_{th} = \int E^{'} dx = \int_{T1}^{T2} \sigma dT \tag{11}$$

Where T_1 and T_2 are the temperatures at the two end of the rod. Thomson effect is a manifestation of the Thomson emf described above. Clearly, one cannot demonstrate the existence of the emf by using it to drive a current in a close circuit. This is because one uses a single metal with a temperature gradient, the integral σdT around a close loop is zero. For dis-similar metals, Peltier effect dominates over Thomson effect (Bilotti, Fenwick, Schroeder, Baxendale, Taroni-Junior, Degousée, & Liu, 2018).

When a current is passed through a homogeneous conductor with a temperature gradient, the rate of heat production per unit volume is given by Eq. 12.

$$\dot{Q} = \rho I^2 - \rho I \frac{dT}{dx} \tag{12}$$

Where ρ is resistivity. The first term is the irreversible Joule heat. The second term is due to Thomson emf.

In metals such as copper and zinc, the hotter end is at a higher potential (as shown in the figure above). In such a situation if the current due to an external supply is in the same direction as the direction of decreasing potential, there is additional evolution of heat due to Thomson effect and the net heat produced is more than the Joule heat. If the direction of the current is reversed, heat energy is converted to electrical energy due to Thomson effect and the rate production of heat is reduced. This is known as positive Thomson effect.

An anomalous situation occurs in metals such as cobalt and iron. In these metals the hotter end is at a lower potential so that charge carriers move against the thermal gradient. The effect is opposite of what happens in case of positive Thomson effect. Such anomalous effect is known as negative Thomson effect. Lead shows zero Thomson effect. The simple physical picture given above cannot explain the strange behavior (Deen Dayal Upadhyaya College, 2024).

2.1.3.1 Commercial Peltier devices.

A single Peltier element can be used to produce electrical power (via the Seebeck effect) or to pump heat (via the Peltier effect). In either application, the power output of a single Peltier element is generally not sufficient for realistic situations. To increase their power, commercial Peltier devices are composed of many n-type and p-type semiconductor Peltier elements. The individual elements are connected in series using metallic junctions. As a result of this, the junctions between the semiconductors do not form a barrier potential, as they would do in a p-n diode, and charge carriers flow freely in both directions. In a Peltier device, the individual elements are arranged so that the n- and p-type heat flow in the same direction (Figure 6). A complete Peltier device architecture is shown in Figure 7. It consists of two electrically insulating ceramic plates sandwiching a series of p-n pairs joined by copper. This design provides a large surface area improving heat pumping for cooling and heating applications. Waste heat absorption and electrical power production (via the Seebeck effect) also benefit from the increased surface area.

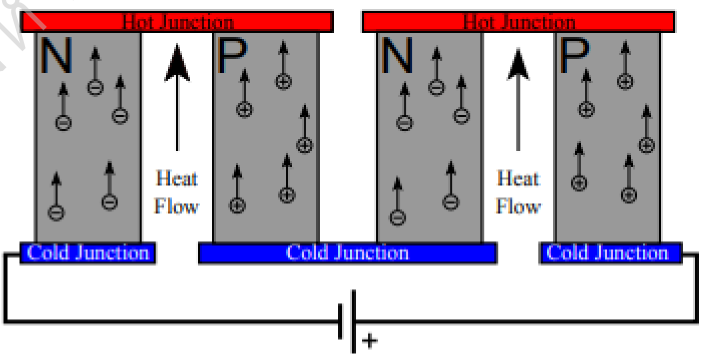


Figure 6 A series of alternating n- and p-type semiconductor elements, which pump heat from bottom to top when a voltage is applied.

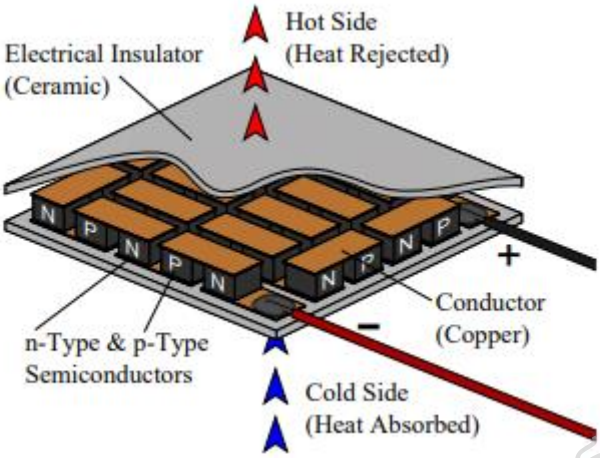


Figure 7 Shown the design of a commercial Peltier device.

Figure 7 shown the design of a commercial Peltier device, the sharp look like a sandwiched consist between two ceramic insulators, alternating n- and p-type semiconductors elements are arranged across a plain and are connected in series electrically with copper junctions. When the current is supplied to the Peltier device and heat is pumped from one surface to the other.

Summary: In this generation, thermoelectric devices have recently attracted considerable interest owing to their unique ability of converting heat to electrical energy in an environmentally efficient manner. These devices are promising as alternative power generators for harvesting electrical energy compared to conventional batteries. Inorganic crystalline semiconductors have dominated the thermoelectric material fields. Nevertheless, their application has been restricted by their intrinsic high toxicity, fragility, and high cost. In contrast, organic thermoelectric materials with low cost, low thermal conductivity, easy processing, and good flexibility are more suitable for fabricating thermoelectric devices (Zhang, Heo, Park, & Park, 2019). Thermoelectric materials based on Seebeck and Peltier effect. This leads to utilize hardly usable or almost lost thermal energy into productive applications as efficient as possible. Therefore, the efficiency of thermoelectric conversion of heat is characterized by the figure of merit ZT which is related to the Seebeck coefficient S, thermal conductivity

κ , electrical conductivity σ and absolute temperature T , respectively (Rademann, Raghuwanshi, & Hoell, 2016).

2.2 Solid-State Thermoelectric Cooling.

Solid-State Thermoelectric Cooling or Thermoelectric Cooling (TEC) (Figure 8) is a new technology that has the potential to revolutionize the way things are kept cold, whether it is food, wine, beer or cigars. In fact, it is a completely different approach to refrigeration from standard compressors (Energy Saver, 2024).

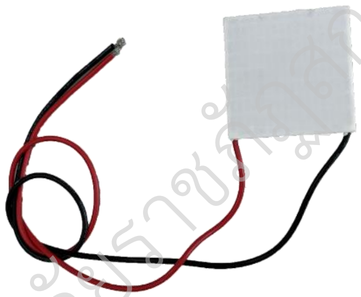


Figure 8 Shown the Solid-State Thermoelectric Cooling (TEC).

A thermoelectric cooling, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump by applying a low voltage DC power source to a thermoelectric module and heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (plus and minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications (Ferrotec, 2024).

Therefore, the TEC Cooling Performance were report by various researchers has obtain the cooling performance from TEC by optimizing the size, material, cooling capacity and the temperature different for improving the COP of TEC. Additionally, the cooling COP of TEC depends on the current through the module and the temperature difference between two side of TEM. The COP of TEC is consider the temperature of cold side T_c and temperature of hot side, T_h given by Eq. 13.

$$COP_c = \frac{1}{(T_h - T_c) - 1} = \frac{T_c}{(T_h - T_c)} \tag{13}$$

2.2.1 The Benefits of Solid-State Thermoelectric Cooling.

Energy Saver (2024) mentioned about the Benefits of thermoelectric cooling as follow: In general, TEC works best in small spaces, particularly for electronic device where there simply is not enough space to put a compressor-based cooler. In a small size cooler, these systems are also quite efficient and may use less electricity than a compressor-based unit of the same size. Thermoelectric cooling also allows for very fine temperature control, to within 0.1 degree under certain conditions. Furthermore, solid state cooling units have no moving parts, so they are far less likely to break than a traditional compressor, which requires several fans and lengthy coils through which refrigerant must pass. However, TEC use no refrigerant, which are known to damage the ozone layer if they leak from a faulty machine. These refrigerants also make proper disposal difficult. TEC is also silent, unlike a compressor which vibrates when running and can be quite loud when it cycles on. Then, the simple electric current required to run a TEC makes no sound at all, unless a fan is present to improve air circulation

2.2.1.1 Products Which typically Use thermoelectric power and Applications. (Energy Saver, 2024; Applied Thermoelectric Solutions, 2024; Ramachandra & Kumar, 2020)

Thermoelectric device is considered as successfully commercialized due to high reliability, low weight and less maintenance. Moreover, thermoelectric offers two primary applications, one is for renewable energy utilization and second is for generating electricity with waste energy during heating or cooling process. This module can operate as a cooler or electricity generator. Cooler mode allows the module to transform the current flow to temperature difference direct current to temperature gradient. Meanwhile, electricity generator mode allows the module to produce electricity caused by the temperature gradient.

The TEC modules are devices of the future. The applications of TEC modules have so far been employed in many devices where the size of the device is small. In applications where the temperature needs to be stabilized, a cooling effect needs to be produced or heat up the device using a reverse current, thermoelectric cooling modules have been used. Some of the other potential and current uses of TEC are:

(1) Small refrigerators and wine coolers.

(2) Electric portable picnic, beverage, and car coolers.

(3) Portable and personal air conditioning and other small cooling appliances.

(4) Cooled seating.

(5) Cooled coverings such as blankets.

(6) Solid-State refrigerators.

(7) Heated and cooled mattresses.

(8) Wine bottle coolers.

(9) Telecom devices.

(10) Thermal therapy devices.

(11) Electronics and Peltier CPU cooling.

(12) Thermoelectric battery thermal management.

(13) Electronics kiosk cooling.

(14) Zonal thermoelectric climate control.

(15) Heated and cooled vehicle seats.

(16) Thermoelectric Office chairs.

(17) Mini In-vehicle Peltier refrigerators.

2.2.1.2 The advantage of Solid-State Thermoelectric Cooling. (Applied Thermoelectric Solutions, 2024)

(1) There are no moving parts. This means solid-state thermoelectric technology has higher reliability which leads to happier customers and increased profits.

(2) No Greenhouse Gases Required: Unlike compressor based conventional cooling systems, solid-state thermoelectric heating and cooling does not require expensive refrigerants.

(3) Scalability: 1) Systems can be scaled from less than one watt of cooling power up to kilowatts. 2) The ability to scale thermoelectric thermal management systems offers a much wider range of market share opportunities compared with systems that are not scalable and 3) Common components can be used for large and small scale systems. This results in reduced manufacturing and design costs.

(4) Efficiency: 1) Solid-state systems have the potential to operate at high efficiency (COP), depending on the application and design and Customers want efficient products. Additionally, efficiency gains can be obtained by using the devices for spot or distributed cooling rather than cooling an entire enclosure which is common with conventional technology.

(5) Cooling and Heating in One Device: Unlike compressor based systems, solid-state devices can heat and cool from the same device with a simple switch in the direction of electrical current.

(6) Precise Temperature Control: Solid-state thermoelectric devices excel at precise temperature control. This makes possible products that are out of reach with conventional compressor based systems that are more difficult to control.

(7) Below Ambient Cooling: The ability to control temperature to below ambient allows food to last longer, drinks to feel colder, batteries to last longer, CPU's to run cooler and at higher performance, better human thermal comfort, longer life electronics and safer medicine storage. All of these result in benefits customers need and want.

(8) Silent Operation: With solid-state technology, there will be no noise complaints as there are with conventional vibrating compressor technology.

(9) Mountable in Any Orientation: Since there is no refrigerant or moving parts, solid-state thermoelectric devices can be mounted in any orientation.

2.2.2 Solid-State Thermoelectric Coolers Work.

Thermoelectric cooling systems rely on electricity flowing through two different types of conductors – such as different types of metal like copper or zinc. When DC voltage is applied and direct current runs from one conductor to the other, there is a change in temperature where the two conductors join. When this small thermoelectric effect is multiplied by creating junctions between two ceramic plates, a cooling effect strong enough to keep appliances and computers cool is created. Besides, one plate is the "cool side" while the other is the "hot side". The cold side goes inside an ice-free cooler or wine refrigerator, while the hot side is connected to metal fins that act as a heat sink to help dissipate excess heat on the outside of the appliance. However, TEC is also known as solid-state cooling, because there is no liquid refrigerant running through the machine. Instead, solid metal is used to transfer thermal energy (Energy Saver (2024). Consequently, thermoelectric assemblies became practical for real-world applications and are now found in everything from consumer goods to spacecraft (EIC SOLUTIONS, 2024).

2.2.2.1 Challenges of solid-state thermoelectric coolers system for building applications.

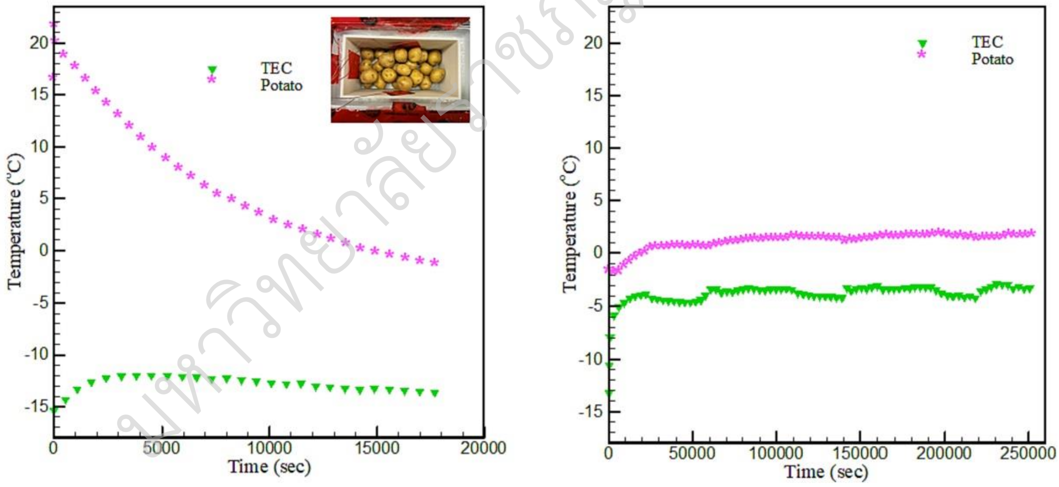
Working fluids that are commonly used as the refrigerant in the conventional Vapor Compression Air Conditioning (VCAC) system have high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP), as a result of leakage during the manufacturing, operation, servicing and disposal at the end-of-life. Table 2 shows summarizes the effort of researchers on the study of thermoelectric cooling system under building scale application. The major challenge in the real buildings study was handling the huge changes by the ambient condition such as ambient temperature, RH, and solar radiation (Baheta, Looi, Oumer, & Habib, 2019).

Table 2 Shows the Solid-State Thermoelectric Cooling system integrated with building cooling application.

Type Number	Source of power	Scale	Results	Ref.
TEC1-12706 (Varies)	-	Real weather condition	Under cooling mode, TE-RAC provided 5670 W of cooling capacity coupled with 1.77 COP when the applied current is 1.2 A.	(Shen, Xiao, Chen, & Wang, 2013)
TEC1-12708 (36)	Electric grid	Real weather condition	This experiment was done in an enclosed test chamber with 4.5 m^3 volume. The thermoelectric radiant panel able provide 201.6 W cooling capacity and has 0.82 COP	(Lertsatitthanakorn, Wiset, & Atthajariyakul, 2009)
TEC1-12708 (3)	Electric grid	Controlled environment	A counter-flow TE-AD system that provided 29 W cooling capacity, coupled with 0.34 COP	(Maneewan, Tipsaenprom, & Lertsatitthanakorn, 2010)
TEC1-12730 (24)	Electric grid	Real weather condition	This experiment was done in a test chamber with a total volume of 4.7 m3. At 6 A current level, the system provided 498.6 W of cooling capacity and 0.679 COP	(Irshad, Habib, Thirumalaiswamy, & Saha, 2015)
TEC1-12730 (15)	Solar	Real weather condition	This is the extension study of Ref. 14. By reducing the number of TEM and integrated with PV wall, COP of the system enhanced to 1.15 at 6 current level.	(Irshad, Habib, Basrawi, & Saha, 2017)

2.2.2.2 Solid-state thermoelectric coolers for food refrigeration and storage applications.

Refrigerated storage and transport are now critical in the food supply chain. On the one hand, refrigeration is required at all stages of the food supply chain (Tassou, Lewis, & Ge, 2010; Coulomb, 2008) Literature shows that several cooling technologies have been used in the food refrigeration system to overcome the disadvantages (i.e., reducing electricity consumption and carbon footprint) of the typical vapor compression cycle, as shown in Figure 9 (Tassou, Lewis, & Ge, 2010). Such refrigeration technologies are sorption refrigeration-adsorption system and thermoelectric (TE) refrigeration (Ziegler, 2002; Siddique, Venkateshwar, Mahmud, & Van Heyst, 2020; Siddique, Bozorgi, Venkateshwar, Tasnim, & Mahmud, 2023).



(a) (b)

Figure 9 Shown the Cooling temperature behavior of potato and TEC wall when (a) TEC was turned on at 52 W (12 V and 4.4A) and (b) TEC was fixed at 11.4 W (6 V and 1.9A). (Bozorgi, Venkateshwar, Tasnim, & Mahmud, 2023).

A commercially available thermoelectric module (model: CP-031; supplier: TE technology) was used as the main driving cooling agent for the proposed system. The TEC module consists of with the thermoelectric Peltier device, heat sink, aluminum heat spreader plate, and a cooling fan, as shown in Figure 10. The maximum power input to the TEC module is 12 VDC and 6A whereas the power input to the fan is 12 VDC and 0.18A. The overall weight of the TEC module is 0.9 kg with a volume of 10.2 × 8 × 9.1 cm^3. This TEC module was directly attached in the middle of one of the long walls of the aluminum with screws and thermal conductive paste (heat transfer coefficient 2.31 W/mK) to minimize the air gap (Bozorgi, Venkateshwar, Tasnim, & Mahmud, 2023).

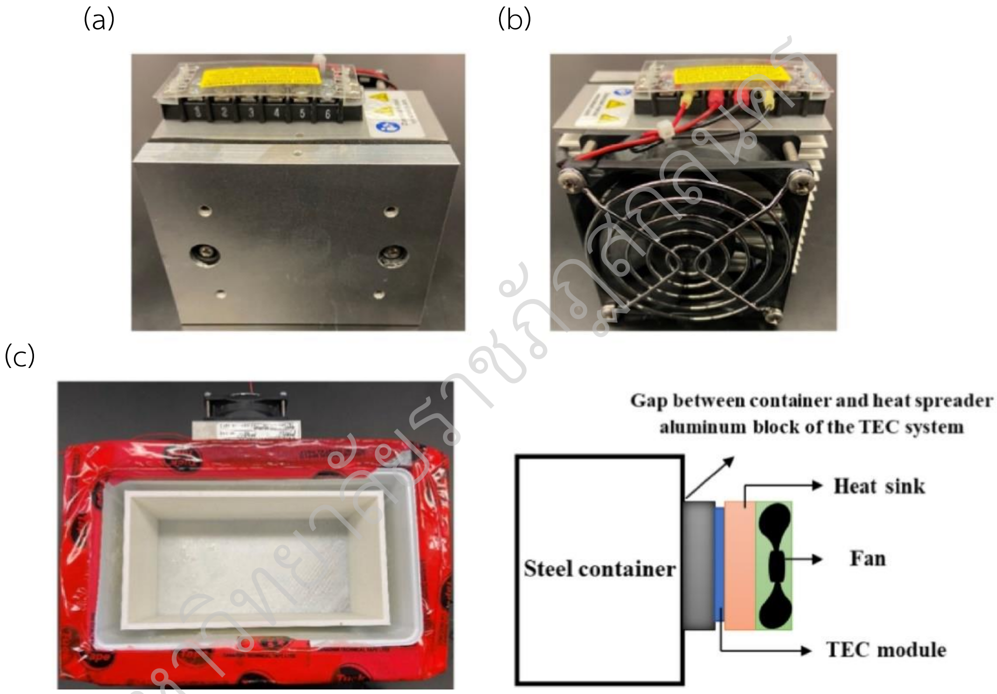


Figure 10 Shows the Commercial thermoelectric module CP-031 (a) front view; (b) back view; (c) TEC module attached to the container (Bozorgi, Venkateshwar, Tasnim, & Mahmud, 2023)

Then, solid-state thermoelectric cooler has been used in a wide range of food sectors that include portable coolers (Riffat & Ma, 2003). However, there is a limitation to the thermoelectric cooler for food storage that too low COP even less than one (Mirmanto, Syahrul, & Wirdam, 2019; Biswas & Kandasamy, 2021) In addition, there is solid-state thermoelectric cooler box that made of three-layer wall, six TEC modules (TEC1-12706), six inner heat sinks with fan, six outer heat sinks with fan, six top fans, two-power supply, connect with contactor, switch, and a thermostat as shown in Figure 11 (Lawal & Chang, 2021).

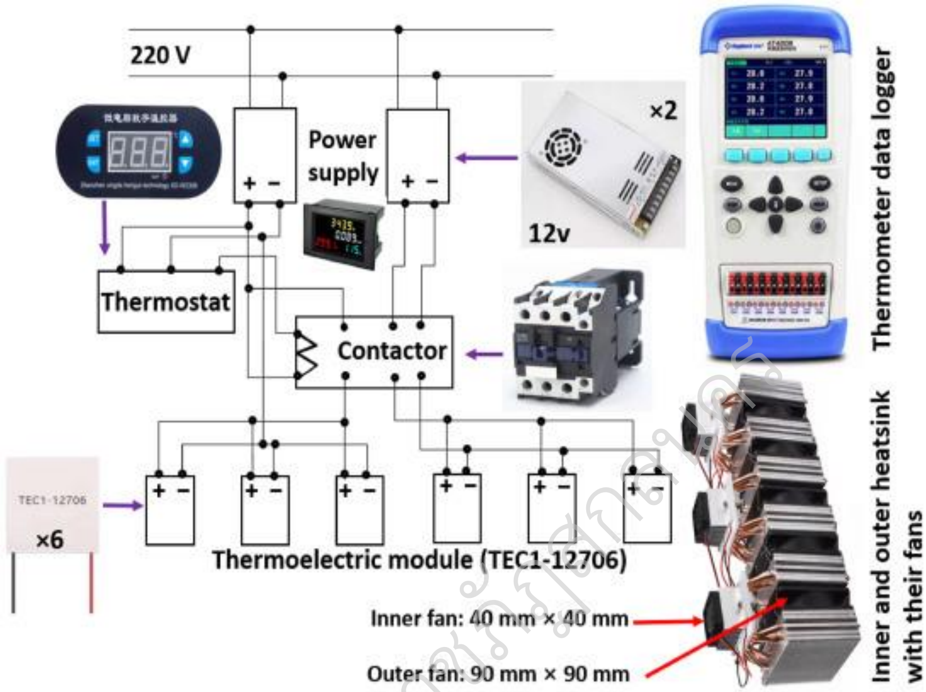


Figure 11 Shown the Electric circuit of cooler box and installation materials. (Lawal & Chang, 2021).

2.3 Refrigerants.

The first designers of refrigeration machines, Jacob Perkins in 1834, and others later in the 19^{th}, used ethyl ether (R-610) as the first commercial refrigerant. The reason is easy to understand if one has ever spilt this liquid on the hand and felt the effect. It was not particularly suitable to the purpose. However, being dangerous as well as requiring an excessive compressor volume. In the other hand, more appropriate refrigerants, for example, ammonia (R-717), carbon dioxide (R-744), ethyl chloride (R-160), isobutane (R-600a), methyl chloride (R-40), methylene chloride (R-30), and sulfur dioxide (R-764), were soon introduced, including air (R-729). Three of these refrigerants became very popular, that is, ammonia and sulfur dioxide for refrigerators and other small units and carbon dioxide preferably for ships refrigeration. A large number of substances were tried over the following years, with varying success.

In the early 1930s, the introduction of chlorofluorocarbons (CFCs) was revolutionary as compared with the natural substances. In addition to their use as refrigerants in refrigeration and air-conditioning systems, CFCs were utilized as foam-blowing agents, aerosol propellants, and cleaning solvents since 1950. The main arguments put forward in their favor were complete safety and harmlessness to the environment. Both these claims were proved wrong. Many accidents have occurred because of suffocation in the heavy gas, without warning, in below threshold spaces. It was evident that CFCs and related compounds contribute tremendously to the destruction of the stratospheric ozone layer and to the greenhouse effect (i.e., global climate change), which are considered among the most significant environmental problems. In fact, CFCs are greenhouse gases that give a combined contribution to incremental global warming of the same magnitude. The most abundant greenhouse gas is CO_2 and the others are CH_4, N_2O, CFCs, and so on. The effect of CFCs on global climate change was assumed to vary considerably, roughly contributing in the range 15–20% as compared to 50% for CO_2. The interesting point is that in order to minimize global climate change, making reductions in CFC utilization seemed to be easier than reducing fossil fuel use. Therefore, a full ban on these substances was essential.

Refrigerant is a chemical substance or mixture, usually a fluid or gas that is used in a refrigeration cycle to transfer heat from one part of a system to another. It is what makes air conditioners work and refrigerators keep food cold (Refrigerant finders, 2024). A refrigerant is a working fluid used in the refrigeration cycle of air conditioning systems (Figure 12) and heat pumps where in most cases they undergo a repeated phase transition from a liquid to a gas and back again. Refrigerants are heavily regulated due to their toxicity, flammability and the contribution of CFC and HCFC refrigerants to ozone depletion and that of HFC refrigerants to climate change (Refrigerant, 2024). For the physical state of substance composed three phase: gas, liquid, and solid. Refrigerant work as shifting of three physical state of substance and while changing the state of substance by thermal energy. By adding the thermal energy to three states will increase the temperature because to convert the substance phase need a larger thermal energy (Wang, 2001).

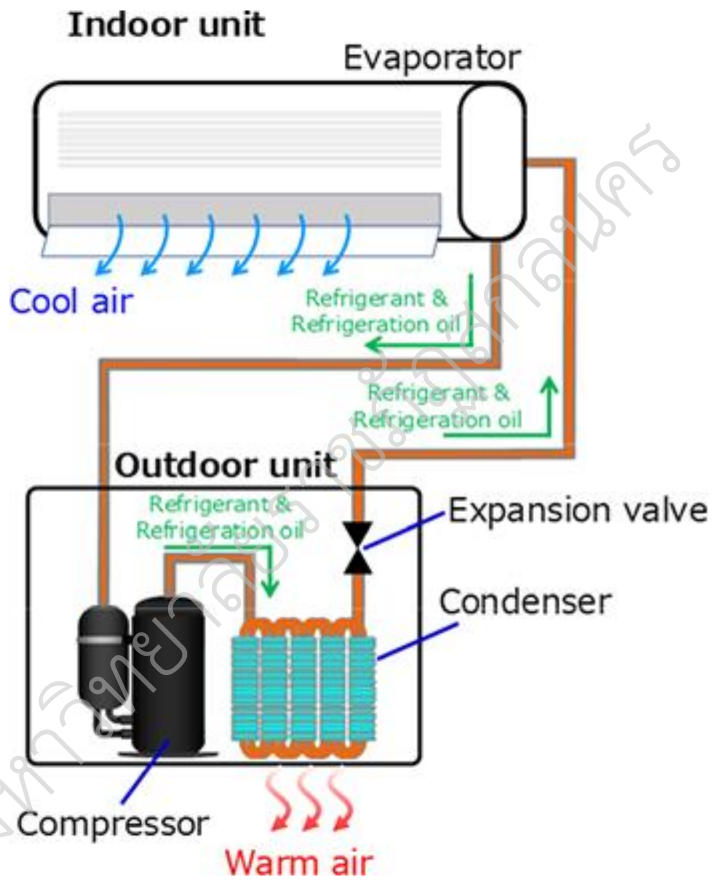


Figure 12 Shown the Refrigeration cycle: Room air conditioner (ENEOS, 2024).

Almost a decade ago, CFCs were banned worldwide as a result of their alleged effect on the stratospheric ozone layer and global climate change, despite the fact that CFCs were among the most useful chemical substances ever developed. During the past decade, research activities have been expanded tremendously to conduct ozone level measurements using various types of ground-based or airborne equipment. Additionally, more recently satellite technology has become a prominent technique providing more accurate findings about the ozone levels in different locations. It is well known that the stratospheric ozone layer acts as a shield against harmful ultraviolet (UV) solar radiation. More than two decades ago, researchers discovered that chlorine released from synthetic CFCs migrates to the stratosphere and destroys ozone molecules and hence the ozone layer, which was recognized as ozone layer depletion, known as one of the biggest environmental problems. In 1987, 24 nations and the European Economic Community signed the Montreal Protocol to regulate the production and trade of ozone-depleting substances. This was considered as a landmark in refrigeration history.

Therefore, this is by no means a unique experience. Similar predicaments have occurred following release to the environment of many other new chemicals. The extensive use of more new compounds is one of the big problems of our time. In this situation, it does not seem very sensible to replace the CFC/hydrochlorofluorocarbons (HCFCs) with a new family of related halocarbons, equally foreign to nature, to be used in quantities of hundreds of thousands of tons every year.

2.3.1 Classification of Refrigeration.

This section is focused on the primary refrigerants, which can be classified into the following five main groups; Halocarbons, Hydrocarbons. (HCs), Inorganic compounds, Azeotropic mixtures and Nonazeotropic mixtures. (Dincer & Kanoglu, 2003). Classification of refrigerant can be distinguish by primary and secondary. Primary refrigerant are substances in main interaction of heat cycle such as Ammonia, Carbon dioxide, etc. However, a secondary refrigerant are substances that required after primary heat interaction such as cooling purposes example Ice, Brine, and Solid Carbon dioxide.

The initial developers of refrigeration machines, such as Jacob Perkins in 1834, and others in the 19th century, initially utilized ethyl ether (R-610) as the first commercially available refrigerant. This choice was understandable if one had ever experienced the effects of spilling this liquid on the skin. However, ethyl ether was not ideal for refrigeration due to its dangerous nature and the need for excessive compressor volumes (Wang, 2001). Nowadays, there are dozens of refrigerants that are used throughout the world. The most common are called halocarbons. Halocarbons include CFCs, HCFCs, and HFCs – which are often known by their specific numbers, such as R12, R22, or R134a, and at times, by the single brand name Freon. The Chlorofluorocarbons of refrigerant are shows in Table 3 (Refrigerant finders, 2024).

Table 3 Shows the Chlorofluorocarbons (CFCs) of refrigerant.
(Refrigerant finders, 2024).

CFC Type	Chemical Name	Chemical Formula	Common Uses
R12	Dichlorodifluoromethane	CCl_2F_2	Automobile and refrigerator air conditioning, industrial chillers.
R11	Trichlorotrifluoromethane	CCl_3F	Commercial equipment, solvent, foam blowing.
R113	Trichlorotrifluoroethane	$CClF_2CClF_2$	Cooling systems, foam-blowing agents, cleanser for electrical equipment.
R114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$	Chillers for air conditioning, industrial process cooling.
R500	Dichlorodifluoromethane and Difluoroethane.	$C_3H_4Cl_2F_4$	Heating, chilling, air conditioning, ventilation applications, dehumidifiers.

Benhadid-Dib & Benzaoui (2012) distinguish among the refrigerants, different categories:

2.3.1.1 Fluorinated refrigerants.

Fluorinated refrigerants are largely responsible for the destruction of the ozone layer and contribute to the increase of the greenhouse effect. The interactions between the two phenomena are real but highly complex. We distinguish several types:

(1) Chlorofluorocarbon (CFC) refrigerants are compounds made up of chlorine, fluorine, and carbon. CFCs like R12 are commonly used as refrigerants, while R11 is also commonly used as a solvent or in foam blowing agents. They were invented in the 1920s and used extensively until their phase out in the early 1990s. These are the most common CFCs. Besides, they are stable and allowing them to reach the stratosphere without too many problems. At this stage, by transforming it contributes to the destruction of the ozone layer.

(2) Hydrochlorofluorocarbon (HCFC), they are molecules composed of hydrogen, chlorine, fluorine, and carbon. The most common HCFC is R22, but there are other types, such as R123 and R142b. HCFCs replaced CFCs in many applications but are now phased out in the United States and cannot be produced anymore. They are less stable than CFCs destroy ozone and to a lesser extent. These are called transitional substances.

(3) Hydrofluorocarbon (HFC) refrigerants are compounds consisting of hydrogen, fluorine, and carbon. They do not contain chlorine. Therefore, do not participate in the destruction of the ozone layer. This is known as substitution substance. Restrictions on this family of gas are currently limited. Within the European Union, the HFC will be banned from air conditioners for cars from 2011. Nevertheless, the most common HFCs are R134a, R404a, and R410a. HFCs are newer than CFCs and HCFCs, and are often used in replacement systems, but they too are being phased out over the next few years in the United States.

(4) Hydrocarbon refrigerants include other chemical compounds, such as propane and isobutane, which can be used in certain systems just like R12 and other refrigerants. Unlike CFCs, however, these refrigerants can be toxic or flammable, posing unique problems for their use.

2.3.1.2 Mixture of refrigerants.

They can be classified according to the type of fluorinated components they contain. They are also distinguished by the fact that some mixtures are:

(1) Zeotropic: in a state change (condensation, evaporation), the temperature varies.

(2) Azeotropes: they behave like pure, with no change in temperature during the change of state.

2.3.1.3 Fluids down greenhouse effect.

They are considered less disturbing to the environment, because at once with no effect on stratospheric ozone and a low impact on the greenhouse effect. They all have disadvantages, either in security, or in thermodynamics.

(1) Ammonia (NH_3) or R-717 Fluid inorganic thermodynamically is an excellent refrigerant for evaporation temperatures between -35 °C + 2 °C. But it is a fluid dangerous toxic and flammable. Despite these shortcomings, its qualities are such that it is used in industrial refrigeration.

(2) Hydrocarbons (HC) as R-290 R-600a This is primarily propane (R-290), butane (R-600) and isobutene (R-600a). These body fluids have good thermodynamic properties, but are dangerous because of their flammability. The world of the cold has always been wary of these fluids, even if they have reappeared recently in refrigerators and insulating foams. Their future use in air conditioning seems unlikely, given the cost of setting both mechanical and electrical safety.

(3) Carbon dioxide (CO_2) or R-744 Fluid inorganic, non-toxic, non-flammable, but inefficient in thermodynamics. Its use would involve high pressure and special compressors. Currently, specialists in air conditioning and refrigeration are interested again by:

- Its low environmental impact (ODP = 0, GWP = 1)
- The low specific volume resulting in facilities with low volume (small leak)

(4) Water (H_2O) Fluid inorganic, of course, without toxicity. Although it high enthalpy of vaporization is interesting, It does not lend itself to the production of cold below 0°C. It is not suitable for compression cycle and applications are rare.

Furthermore, there are also refrigerant blends that combine these refrigerant types. For example, R500 is a blend of R12 (a CFC) and R152a (an HFC) that is used in commercial air conditioning and some dehumidifiers. Similarly, R502 is a blend of R22 (an HCFC) and R115 (a CFC), that is often used in refrigerated transportation systems (Refrigerant finders, 2024). Subsequently, more suitable refrigerants were introduced, including ethyl chloride (R-160), methyl chloride (R-40), methylene chloride (R-30), and sulfur dioxide (R-764), as well as air (R-729). Among them, ammonia and sulfur dioxide became popular for refrigeration units, while carbon dioxide was preferred for ship refrigeration. Over the years, many substances were experimented with varying degrees of success (Wang, 2001).

2.3.2 Effects of Refrigerants.

In the early 1930s, the advent of chlorofluorocarbons (CFCs) revolutionized refrigeration compared to natural substances. Besides their use as refrigerants, CFCs were used as foam-blowing agents, aerosol propellants, and cleaning solvents from 1950 onwards. They were touted for their safety and environmental friendliness, claims that were later proven false. CFCs contributed significantly to the destruction of the stratospheric ozone layer and the greenhouse effect, making them major environmental concerns. Despite being effective and versatile CFCs were globally banned almost a decade ago due to theirs impact on the ozone layer and climate change. Moreover, the refrigerants that escape from refrigeration equipment either during regular operations such filling and emptying or due to accidents were accumulate in large quantities in the upper atmosphere (stratosphere). In this region, they undergo catalytic decomposition, which leads to the depletion of the ozone layer. This phenomenon lead damage to radiation. Radiation that poses a threat to life on earth, including plants and animals, has been associated with the depletion of stratospheric ozone. This depletion is linked to the presence of chlorine and bromine in the stratosphere. Additionally, refrigerants contribute to global warming by acting as greenhouse gases in the atmosphere.

The Montreal Protocol of 1987 was a landmark agreement signed by 24 nations and the European Economic Community to regulate the production and trade of ozone-depleting substances, marking a significant moment in refrigeration history. The phase-out of CFCs led to extensive research on ozone levels using ground-based, airborne, and satellite technologies. This highlighted the crucial role of the stratospheric ozone layer in shielding against harmful UV radiation. This experience with CFCs is not unique, as similar issues have arisen with the release of other new chemicals into the environment. The widespread use of new compounds poses a significant challenge in modern times. Therefore, replacing CFCs and hydrochlorofluorocarbons (HCFCs) with a new family of halocarbons, which are also unnatural and used in large quantities annually, may not be the most sensible solution.

Another way refrigerants impact the environment is leading to a new classification based on their effect on atmospheric warming. Even R11, known for its harmful impact on the ozone layer, is compared in terms of its contribution to the greenhouse effect with CO_2. Freons, ranked third (14%) among gases with a greenhouse effect, owe their position to their high capacity for absorbing infrared radiation. In refrigeration and heat pump systems to their direct impact on the greenhouse effect through refrigerant leakage, there is an indirect impact on global warming due to the release of CO_2 during the transportation of energy produced by the system. This indirect impact is obviously greater than the associated direct impact. As the amount of refrigerant in the system increases direct impact also increases.

As a result, a new orientation has emerged regarding the utilization of working fluids. Consequently, CFC refrigerants such as R11 and R12 were replaced by simple compound refrigerants like R123 (HCFC) and R134 (HFC), which have a reduced or zero impact on the depletion of the ozone layer. This alternative is attractive because the substitutes have similar properties (temperature, pressure) to the ones they replace, and changes that were made directly to the existing installations can be achieved with minimal investments (Sarbu, Valea, & Ostafe, 2014).

2.3.3 Refrigeration System Components.

There are several mechanical components required in a refrigeration system. In this part, we discuss the four major components of a system and some auxiliary equipment associated with these major components. These components include condensers, evaporators, compressors, refrigerant lines and piping, refrigerant capacity controls, receivers, and accumulators. Major components of a vapor-compression refrigeration system are as follows: (1) compressor (2) condenser (3) evaporator and (4) throttling device are shown in Figure 13. In the selection of any component for a refrigeration system, there are a number of factors that need to be considered carefully, including:

- Maintaining total refrigeration availability while the load varies from 0 to 100%
- Frost control for continuous performance applications.
- Variations in the affinity of oil for refrigerant caused by large temperature changes, and oil migration outside the compressor crankcase.
- Selection of cooling medium: 1) direct expansion refrigerant, 2) gravity or pump recirculated or flooded refrigerant, or 3) secondary coolant (brines, e.g., salt and glycol).
- System efficiency and maintainability.

- Type of condenser: air, water, or evaporative cooled.

- Compressor design (open, hermetic, semi hermetic motor drive, reciprocating, screw, or rotary).

- System type (single stage, single economized, compound or cascade arrangement).

- Selection of refrigerant (note that the type of refrigerant is basically chosen based on operating temperature and pressures).

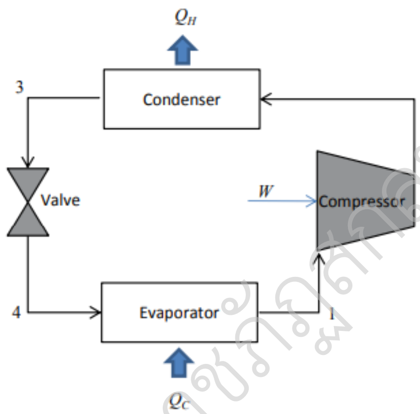


Figure 13 components of a vapor-compression refrigeration system.

A refrigeration system is mechanism the movement of heat by removing heat of surrounding and transferred the heat onto places that have higher temperatures. Refrigeration require both two state or phase of refrigerant on liquid and gas state in different cycle. Often in refrigeration system, refrigerant happen in both phase to do absorption and mechanical vapor compression system depending on the temperature. Refrigeration system will removed heat as refrigerant adsorption heat when shifting phase from liquid to gas state. However, when absorbed heat is removed from refrigeration system, the refrigerant will change back from gas to liquid state. Further, the phenomenon of refrigerating and heating are opposite of process. Basic of refrigeration including step of heating, ventilation, and air conditioning. Air conditioning in refrigeration system refers to circulation of air to control temperature, moisture, odor of product or environment. Refrigeration often to serve as a food preservation essential, medical application, factory and industrial system because refrigeration possess a system that can controlled and remaining specific temperature (Fenton, 2019).

Refrigeration system requires several mechanical components and auxiliary equipment related to these major components. These include condensers, evaporators, compressors, refrigerant lines and piping, refrigerant capacity controls, receivers, and accumulators. The key components of a vapor-compression refrigeration system are the compressor, condenser, evaporator, and throttling device. This configuration run on basic refrigeration cycle that contain of evaporator, compressor, condenser or receiver, and expansion device (He, Li, Fan, Zheng, & Chen, 2021). The cycle of refrigeration had same with vapor compression cycle. Condenser or condensing system work to discharges heat into surrounding by adding refrigerant in the gas to liquid state. Besides, in compressor the refrigerant gas is compressed from low to high pressure. Expansion device such as expansion valve separates high pressure from low pressure side and evaporator removes heat from surrounding by refrigerant change from liquid to gas. Then, the refrigerant work in two condition between liquid to gas state and vice versa (Hofmann, Kroon, & Müller, 2019). In addition, low pressure and low temperature gas phase refrigerant enter and flow into reciprocating compressor. High pressure heat gas phase refrigerant in compressor outlet lead and enter into in condenser coil. In the condenser coil, the air outside surrounding entering and reacted with the refrigerant. The refrigerant absorb the heat energy and turn the gas phase to high pressure high temperature liquid refrigerant. This case leading an increase of the compressor pressure and decrease pressure on expansion valve. In expansion valve consist blower to giving refrigerant work absorb heat energy and leading to evaporator coil. In evaporator coil, the high pressure high and high temperature liquid will turn into low pressure and low temperature gas phase of refrigerant. In this case, the cool air will conditioned out with conditioning air. The low pressure and low temperature gas phase will release heat energy and turn into low pressure low temperature liquid and cycling through the compressor (Hundy, Trott, & Welch, 2008).

When surrounding of refrigeration is cooled or heated is caused by form of energy especially heat or thermal energy. When temperature of environment classified as cold or lower temperature because of absence of heat. The cold cannot be flow since the thermal energy in charged mainly on environment. The energy will flow from high to low heat energy level. This condition resulted temperature difference where the energy will flow faster when the temperature difference increase. In Basic refrigerant concept, heat measured by British Thermal Unit (BTU). BTU is unit measurement to quantify amount of heat energy is added or removed to substances. In refrigeration, heat of absorbed by the evaporator of refrigeration system described in BTU as the refrigerant evaporates and area of surrounding is being cooled. The amount of heat that measured in BTU demanded one pound of raising substance one degree in Fahrenheit.

When selecting components for a refrigeration system, various factors must be carefully considered, such as ensuring total refrigeration availability while the load fluctuates from 0 to 100%, managing frost control for continuous operations, dealing with changes in the affinity of oil for refrigerant due to large temperature fluctuations, and preventing oil migration outside the compressor crankcase. Other considerations include choosing the cooling medium (direct expansion refrigerant, gravity or pump recirculated or flooded refrigerant, or secondary coolant like brines such as salt and glycol), optimizing system efficiency and maintainability, selecting the condenser type (air, water, or evaporative cooled), deciding on the compressor design (open, hermetic, semi-hermetic motor drive, reciprocating, screw, or rotary), determining the system type (single stage, single economized, compound, or cascade arrangement), and choosing the refrigerant based on operating temperature and pressures.

Conventional compression refrigeration systems generate considerable noise and vibration. The noise results in serious, negative impacts on people. Thermoelectric refrigeration technologies are considered a potential way to overcome these challenges. A novel thermoelectric refrigeration system, wherein thermoelectric chips are coupled with ionic wind fans, is proposed. Its performance was experimentally investigated and compared with theoretical results. The actual operating noise of the thermoelectric refrigeration system is only 4.2 dB (A), which is much lower than the maximum noise value that does not affect sleep. From experiments under different operating conditions, the optimal operating voltage of the thermoelectric chip is 5.5 V at 283.15 and 313.15 K on the cold and hot sides. The maximum coefficient of performance (COP) values reaches 0.28 and 0.31 are shown in Figure 14, which are equivalent to those of a system coupled with mechanical fans. Additionally, an ionic wind fan has an optimal operating voltage of 10.8 kV to maximize its air supply efficiency. Notably, such an operating voltage might be distinguished from the optimal voltage that achieves maximum operational performance for the new system. When the operating voltage of the thermoelectric chip is 5 V, the optimal operating voltage to obtain a maximum COP of 0.31 is 11.1 kV. Moreover, the experimental refrigeration capacity is greater than 8 W. The new system shows ultra quiet ability to operate at a large refrigeration capacity, and has good potential in applications, such as advanced refrigeration, building air-conditioning and ventilation systems. (He, 2021).

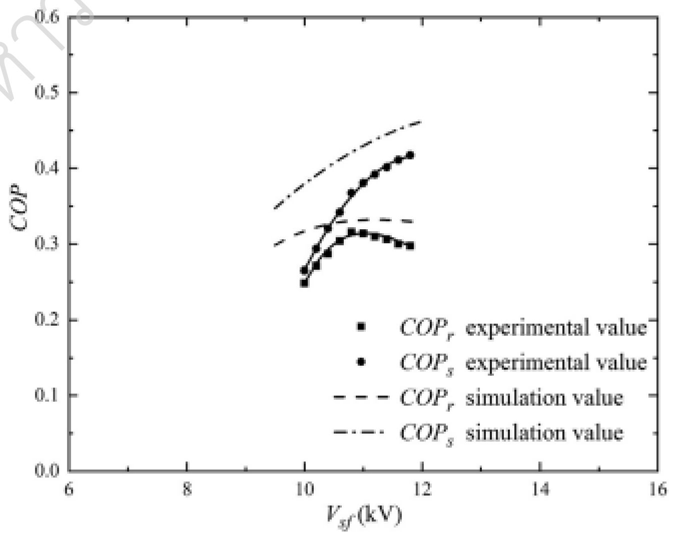


Figure 14 Effects of V_{sf} on the system COP (He, 2021).

COP_s is coefficient of performance of a thermoelectric chip.

COP_r is coefficient of performance of a thermoelectric refrigeration system.

COP_f is coefficient of performance of a thermoelectric refrigeration system coupled with mechanical fans.

V_{sf} is operating voltage of an ionic wind fan, V.

To determine the influence of the operational parameters of an ionic wind fan, the changes in the COP_r and COP_s of the thermoelectric refrigeration system were investigated by varying V_{sf}. Then, the results for T_c = 283.15 K and V_{tc} = 5 V. With an increase in the operating voltage of an ionic wind fan, the heat exchange effects of the hot side were enhanced because the air volume of an ionic wind fan increased, the temperature of the hot side was almost constant. From these results it was found that, it can be inferred that the refrigeration capacity of the thermoelectric refrigeration system was improved. Moreover, the operating power of the thermoelectric chips was constant. Thus, COP_s monotonously increased. COP_r was also affected by the operating power of an ionic wind fan. The increase in the operating voltage caused the operating power of an ionic wind fan to increase. COP_r first increased and then decreased. There is an optimal value of V_{sf} to maximize COP_r. When V_{sf} was 11.1 kV, the maximum COP_r was approximately 0.31, which was approximately 120% of that obtained by the thermoelectric refrigeration system coupled with mechanical fans under the conditions of V_{tc} = 5 V. The corresponding refrigeration capacity was 7.34 W. The refrigeration capacity was 8.10 W when the operating voltage was 11.8 kV and when the COP_r was 0.30. These experimental results are similar with the simulation ones. The difference may be mainly caused by their difference in both parameters and physical properties. Besides, the simulation results are based on two-dimensional models, and the partial symmetric boundary conditions could lead to some differences from the actual experiment (Sulaiman, Amin, Basha, Majid, Nasir, & Zaman, 2018).

2.4 Thermoelectric Air Conditioners.

Thermoelectric air conditioner is simple, convenient system and environmental friendly. The cooling and heating mode is easily changed by reversing the current input. Nevertheless, the system is costly. The low (COP) of thermoelectric is the factor that limits its application for domestic cooling even though the thermoelectric air conditioner (TEAC) is noiseless and compact. The COP of cooling performance of an air conditioner can highly performance depends on the absorption of heat from thermoelectric converter. Thermoelectric Cooler Air Conditioner or TEAC become one of the large-scale thermoelectric cooling systems generating power until kilowatt. Thermoelectric cooler air conditioner consist of combination of air conditioning and thermoelectric cooling system device with voltage generator. In TEC configuration, the cool side TEAC absorb heat from air to heat radiator and dissipate into outside of radiator (Tang, 2023).

Moreover, a TE air conditioner has an advantage of being very compact and small size and therefore it can be easily integrated into the building structure. In the near future, solar thermoelectric cooling system driven by PV will make a significant contribution, especially in zero energy buildings, in reducing fossil fuel consumption and protecting environment (Liu, Zhang, Gong, & Han, 2015; Ma, Zhao, Zhao, Li, & Shittu, 2019). Furthermore, size and cost of the TE air conditioner system is a compact flat unit around 0.38 m^2 of TE unit (with a cooling COP of 0.6 and heating COP of 1.12), which is smaller than a common room heating radiator, can satisfy the heating/cooling requirement of a 15 m^2 room based on Scotland weather conditions (Ma, 2004).

In study of heat recovery from an air conditioner to enhance thermal efficiency and prevent global warming, Wiriyasart & Kaewluan (2024) investigating by thermal performance of water heaters recovering waste heat from air conditioner by testing a double-tube heat exchanger between compressor and condenser to recover heat from air conditioner. This study resulting waste heat recovered and enhancement of thermal efficiency around 12-180% higher than the conventional air conditioner. The water heater have high thermal efficiency at low water mass flow rates. The flow rates impacted on energy consumption. Moreover, this integration leading heat recovery system by showing power efficiency as the energy consumption decreased in air conditioner (Wiriyasart & Kaewluan, 2024). Other report on development air conditioning system using thermoelectric established a good result on promoting waste heat utilization which the system can providing device for domestic drying service. This research using high power heat sinks achieve 103% and 628% higher COP more than conventional lower power heat sinks (Ma, Zhang, Han, Zang, & Liu, 2023).

The use of solid-state technology allows thermoelectric air conditioners to operate in any orientation – vertically, horizontally, or on an angle. In addition, thermoelectric air conditioners can be used in high temperature applications up to 140 °F (60 °C), and some thermoelectric coolers can be designed to operate in conditions well beyond this limit. For electronic/electrical enclosures located in desert regions or in hot industrial plant operations, the high temperature limit of thermoelectric systems can provide a significant benefit (EIC SOLUTIONS, 2024).

2.4.1 Integration of the thermoelectric air conditioning system into building structure.

The TE air conditioning system is very compact and easy to be integrated into the building structure. Some researches in building integrated TE air conditioning system can be found. Although many efforts have been made in this aspect and the progress is obvious, great improvements are still needed.

2.4.1.1 Solar thermoelectric air conditioner with hot water supply.

The solar thermoelectric air conditioner with heat recovery available for both space cooling and hot water supply (Liu, Zhang, Gong, Li, &

Tang, 2015). The solar thermoelectric air conditioner with hot water supply is divided into three parts: (1) the air part, (2) the TEC modules part, and (3) the water part. The TE modules are sandwiched between the hot and cold side of heat exchangers. When an electrical current passes through the junction of dissimilar conductors, heat is either absorbed or released at the junction. Reversing the direction of the current changes the direction of the heat flow. The PV system can provide a constant DC power supply during daytime, while batteries can provide power to the system at night. The system has three working modes: (1) space cooling and hot water mode, (2) space cooing mode and (3) space heating mode; As shown in Figure 15 (Ma, Zhao, Zhao, Li, & Shittu, 2019).

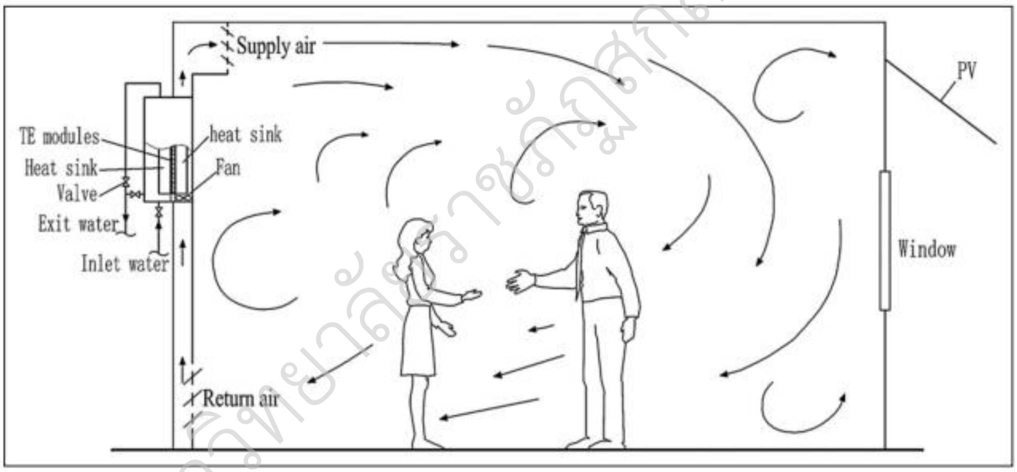


Figure 15 Shown the solar thermoelectric air conditioner with hot water supply. (Ma, Zhao, Zhao, Li, & Shittu, 2019).

Figure 15 supplementary this system is a water source heat pump when it works in heating mode, when it works in cooling mode, the water flow acts as a coolant to cool the hot side of the TE unit, when hot water is required in cooling mode, i.e., in space cooling and hot water mode, the water stops flowing and is warmed up in the water tank. Additionally, the experiment results showed the system had relatively high overall coefficient of performance in cooling and hot water mode, the overall COP (cooling energy plus energy for hot water over power input) could reach up to 4.51 when the water temperature was 20 °C and 2.74 when water temperature was 42 °C. The heating COP can be reached at 3.05 when the water inlet temperature is 24 °C. Hence, the maximum cooling COP of the system is 2.4 when the system works stably under the water inlet temperature of 12 °C.

2.4.1.2 Solar thermoelectric cooled ceiling combined with displacement ventilation system.

The solar thermoelectric cooled ceiling combined with displacement ventilation system proposed for space climate control (Liu, Zhang, & Gong, 2014). In this system, the solar thermoelectric cooled ceiling adopts thermoelectric cooler instead of hydronic panels as radiant panels, which is burdened with removal of a large fraction of sensible cooling load. The TE modules are connected in series and sandwiched between the aluminium radiant panel and heat pipe sinks in solar thermoelectric cooled ceiling. The heat sinks are used to dissipate heat for TE modules. The fan can provide forced air convection to help the TE modules to release heat more efficiently into the atmosphere. By controlling the direction of the current, the functions of cooling and heating can be easily achieved. In addition, the combined system dehumidifies the supply fresh air using a thermoelectric dehumidified ventilation system. The thermoelectric dehumidified ventilation system is responsible for removal of a small fraction of sensible cooling load and all latent cooling loads. As shown in Figure 16 (Ma, Zhao, Zhao, Li, & Shittu, 2019).

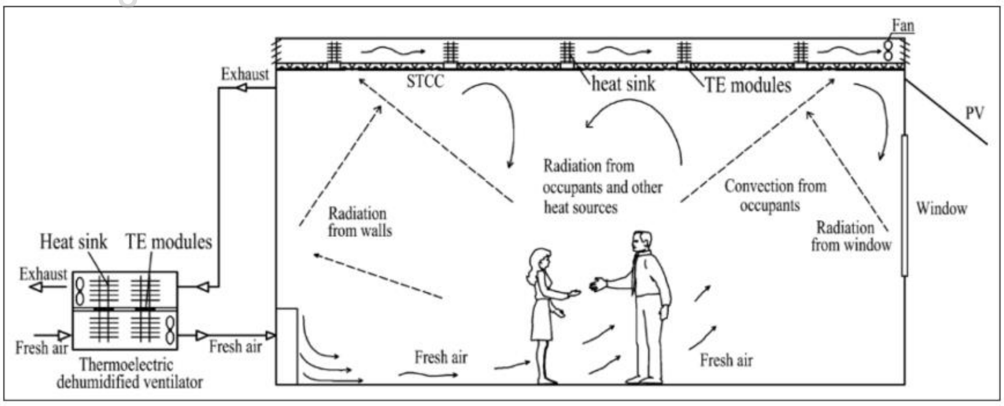


Figure 16 Shown the solar thermoelectric cooled ceiling combined with displacement ventilation system (Ma, Zhao, Zhao, Li, & Shittu, 2019).

Figure 16 supplementary the dehumidified ventilation system was composed of thermoelectric modules heat exchanger made by thermoelectric modules, fans, and flat-fin heat sinks. In summer, the fresh air side behaves as cold side, while the exhaust air side is hot side. The fresh air is cooled down when it flows through heat sink into the indoor. At the same time, the exhaust air cooled down the heat sink on the other side of the TE modules. In winter, reverse the cold side and hot side by changing the direction of the current. The fresh air is heated up and while the exhaust air is cooled down. Therefore, thermal energy can be recovered from the exhaust air and the fresh air could be handled in high energy efficiency. The system COP can reach 0.9 in cooling mode and 1.9 in heating mode (Ma, Zhao, Zhao, Li, & Shittu, 2019).

2.4.2 The Advantages of Thermoelectric Air Conditioners.

The utilization of a thermoelectric cooling system to cool electronic/electrical enclosures provides a number of significant advantages for certain applications when compared to other cooling methods such as compressor-based air conditioners, vortex coolers, and air-to-air heat exchangers (heat pipes). The solar thermoelectric air-conditioning system is predicted using advanced optimized artificial intelligence models (Almodfer, Zayed, Elaziz, Aboelmaaref, Mudhsh, & Elsheikh, 2022), hybrid air cooling systems integrated with TED (Thermoelectric Devices) (Mansoor, Ali, & Jabbar, 2023), Thermoelectric Cooling Devices in Commercial Vehiclesthis (Wan, Su, Huang, Wang, & Liu, 2022) and thermoelectric air conditioning system for electric vehicles (Ahmed, Megahed, Mori, Nada, & Hassan, 2023) this is some example for advantages thermoelectric air Conditioner. These include: (EIC SOLUTIONS, 2024)

2.4.2.1 Reliability.

Thermoelectric air conditioners exhibit very high reliability due to their solid-state construction. Although reliability is somewhat application dependent, the life (MTBF) of a thermoelectric module in a typical thermoelectric cooling system is greater than 150,000 hours. In comparison, the life (MTBF) of a compressor in typical refrigerant based system is less than 100,000 hours. Because of their reliability, thermoelectric cooling systems often are used in remote locations, where they provide trouble-free service with minimal monitoring.

2.4.2.2 Maintenance.

A thermoelectric cooling system has few moving parts and no filters or oil so it is virtually maintenance free, with the only moving parts being the fans used to circulate the air across the heat sinks. Compressor based systems require periodic changing of filters and charging of the refrigerant. Vortex coolers require filters/separators to remove particulate, oil and moisture from the air supply, which need to be changed or drained on a regular basis.

2.4.2.3 Size & Weight.

Thermoelectric air conditioners offer a cooling system of moderate size and weight that is comparable to compressor-based air conditioners and air-to-air heat exchangers. Vortex coolers are considerably smaller, but must rely on a much larger plant air system to operate.

2.4.2.4 Environmentally Friendly.

Unlike compressor-based air conditioners, thermoelectric air conditioners do not need chemical refrigerants (CFCs, HCFCs or oils) that are harmful to the environment.

2.4.2.5 Ability to Cool Below Ambient.

Similar to compressor-based air conditioners and vortex coolers, thermoelectric air conditioners have the ability to cool below the ambient temperature outside the enclosure. In contrast, heat pipes are not able to cool below ambient. Additionally, the effectiveness of a heat pipe in an air-to-air heat exchanger relies on very specific environmental temperatures. A very high ambient temperature will affect the performance of a standard heat pipe, which is not a factor with thermoelectric cooling systems.

2.4.2.6 Temperature Control & Stability.

Thermoelectric air conditioners also have the advantage of a readily available controller that provides more precise temperature management than a standard compressor-based air conditioner that requires down time between operating cycles. Thermoelectric air conditioners can maintain a target temperature to within ±0.5 °C, while conventional refrigeration target temperatures can vary over several degrees.

2.4.2.7 Heating Options.

Extreme cold can be as damaging to electronic components as extreme heat. For outdoor enclosures in regions that experience extreme variance in temperatures throughout the year, systems that can both heat and cool provide a way to protect sensitive equipment year-round. In some thermoelectric systems, the switch from cooling to heating is accomplished by reversing the polarity through the device. However, it should be noted that this effect can shock thermoelectric modules and reduce their useful life. Other thermoelectric cooling systems use embedded cartridge heaters in the base of the cold-side heat sinks. These heaters ensure that the system remains above a minimum temperature in winter without compromising the reliability and durability of the thermoelectric modules.

2.4.2.8 Orientation.

The self-contained, solid-state construction of thermoelectric air conditioners greatly enhances their flexibility. There is near limitless mounting flexibility since thermoelectric air conditioners can work in virtually any orientation, including vertically, horizontally or at an angle, without concern for liquid (such as refrigerant, water, or oil) circulation or interference from external chiller connections or condensate hoses – all in direct contrast to the limitations of other cooling devices.

2.4.2.9 Portability.

Thermoelectric air conditioners are ideal for portable cooling applications such as mounting in transit cases. In addition, standard units can operate while in motion and even in zero gravity environments.

2.4.2.10 Power.

Similar to air-to-air heat exchangers, thermoelectric air conditioners can operate on a wide range of voltages and with either DC or AC power. Compressor-based air conditioners primarily rely on AC power only, while vortex coolers are dependent on the power supplied to the plant air system.

2.4.2.11 Noise & Vibration.

Thermoelectric coolers operate with fewer moving parts, producing far less vibration than other cooling methods.

2.4.2.12 Initial Cost.

Within their cooling range of up to around 2,500 BTU, the cost of thermoelectric cooling systems is comparable to that of compressor-based systems and slightly higher than vortex coolers and air-to-air heat exchangers.

2.4.2.13 Operating & Maintenance Cost.

While the initial cost of a thermoelectric system is comparable to compressor-based systems, the long term reliability of thermoelectric coolers drives down the total cost of ownership over time. For example, based on MTBF data, a typical thermoelectric system will outlast a compressor-based air conditioner by 5 years.

Conclusions: While no one cooling method is ideal in all respects and the use of a thermoelectric cooling system will not be suitable for every application, thermoelectric air conditioners will often provide substantial benefits over alternative technologies. Additionally, the use of thermoelectric air conditioners often provides solutions to many complex cooling problems where a low to moderate amount of heat must be handled in a harsh environment. Using solid-state technology to accomplish temperature change, thermoelectric coolers eliminate the need for refrigerants and operate with fewer moving parts.

They can cool enclosures to temperatures below ambient conditions while producing little noise and vibration. Featuring reliability and a long life span coupled with flexible input power requirements and mounting arrangements, thermoelectric air conditioners offer conventional electronic equipment cooling methods. In addition, they are ideal solutions for applications where the cooling system must be portable or subjected to motion. Therefore, these is need for an alternative air conditioning system (Adeyanju & Manohar, 2020).

2.4.3 Commercial TEC Air Conditioner (TEAC).

In our daily life, the refrigeration is required for many applications and Peltier Effect is more interesting for air conditioner. The efficiency of an air conditioner is measured by the COP, the rate of heat transfer and the maximum value of temperature that can be reached from hot side and the cold side. The COP depends on the figure of merit of semiconductor material.

TEAC is widely used in the lower cooling capacity because it can be powered directly with a DC supply. The TEAC is also convenient, light, easy to control and can be set up quickly. Riffat & Qiu (2004) reported that the range of operating temperature is about -4 °C to 70 °C and can be directly powered to sources or photovoltaic cell is shown in Figure 17.

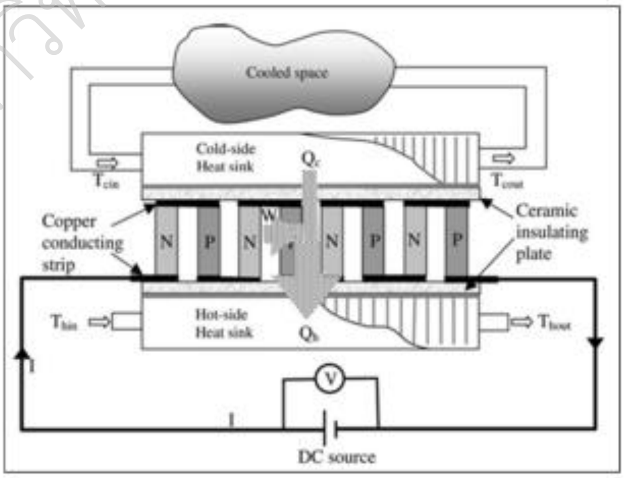


Figure 17 Schematic of TEAC (Riffat & Qiu (2004).

Figure 17 shown the process of removing heat from the room which is then utilized by the air conditioner which produces a cooling effect to the refrigerant. However, the refrigerant used in the air conditioner may cause the release of harmful gases such as Freon, Ammonia and chlorofluorocarbons by installing the TE module to the air conditioner might reduce the air pollution as it is an eco-friendly device. In addition, the air conditioner conclude that the lower power input can be obtained at higher COP (Benziger, Anu, & Balakrishnan, 2015). So, the rate of energy consumption can be reduced. However, thermoelectric cooling capacity will proportionally increase depending on the current electrical input and ratio of thermoelectric element (Tipsaenprom, Lertsatitthanakorn, Bubphachot, Montana, & Soponronnarit, 2012).

2.5 Researches related.

Li, Xie, Quan, Huang, & Fang (2018) Reporting localized air conditioner in commercial vehicles electrical system on a hybrid energy system using configuration of thermoelectric generation (TEG), $LiFePo_4$ battery pack, lead-acid battery pack, and thermoelectric cooler (TEC) in proposed to minimized electricity cost in commercial vehicles by recover the waste heat from exhaust gas resulting power consumption of this research reduced 45.8% to be compared with the conventional air conditioner system in commercial.

Ma, Zuo, & Wang (2019) Design and experimental study of an outdoor portable thermoelectric air-conditioning system. This study aims to identify suitable microclimate cooling systems to reduce heat stress and improve human thermal comfort. A portable thermoelectric air conditioner was developed for local cooling of the human body. Effects of core components thermoelectric refrigerators (TECs), hot end heat dissipation, intake flow and cold end heat exchangers on TEAC performance. It is shown that, remarkably, this operating voltage can be distinguished from the optimal voltage for the maximum operational performance of TEAC. When the TECs operating voltage is 4V, the maximum COP is 2.2, and the best operating voltage is 10V, the maximum cooling capacity is 26.7 W (COP =0.92). Simulation data show that the area of the diffuser can effectively control the contact between the air and the cooling surface with an error of less than 10% compared to the experimental results. The fans and radiators attached to the hot side of the TEM play an important role in keeping the temperature difference on the hot side of the TECs as small as possible, by dissipating the heat generated on the hot side of the TEM to the external environment. In addition, the experimental refrigeration capacity is greater than 26.7 W and the new system has ultra-quiet operation at large refrigeration capacity, which has promising potential for advanced refrigeration, building air conditioning, ventilation systems and other applications.

Chen, Mao, Lin, Tu, Zhu, & Wang (2020) Design and testing Performance and optimization of a thermoelectric elevator car air conditioner. First, the thermoelectric elevator car air conditioner (TE-ECAC) is designed for these EC based on the actual application, the TE-ECAC's cooling characteristic and performance are experimentally investigated in an Enthalpy Lab, and its performance is optimized after the analysis. According to the results, it's found that a stable working state of the TE-ECAC can be achieved at about 200s. Moreover, an optimal cooling coefficient of 1.24 and a maximum air cooling capacity of 324W are achieved under an operation condition at the cold side flow rate of 1.75 m^3/min and the ambient temperature of 28 °C. In addition, since TE-ECAC has greater advantages in economy and weight than conventional elevator air conditioner, it's particularly suitable for EC. Especially suitable for some old EC with a broken air conditioner and must to be replaced with a new air conditioner. All in all, it's a good application prospects for TE-ECAC applying to EC.

Bakthavatchalam, Habib, Saidur, & Saha (2022) Development and Fabrication Cooling performance analysis of nano fluid assisted novel photovoltaic thermoelectric air conditioner for energy efficient buildings. This work presents a novel idea of utilizing a nano fluid cooled radiator as an external cooling jacket around the thermoelectric module's hot side to enhance the heat transfer rate of thermoelectric air conditioners. In this research, the performance of a newly designed thermoelectric air conditioner (TEAC) powered by photovoltaic systems (PV) installed in a residential building is analyzed using nano fluid as a coolant. Furthermore, by supplying different input currents (2-6A), the cooling characteristics and performance of the newly designed nano fluid assisted thermoelectric air conditioner (NTEAC) system were experimentally studied in a test room of 25.6 m^3 volume in Malaysia's tropical climate. The system's best performance was at 6A, with a maximum temperature drop of 4.9 °C, a cooling capacity of 571 W, and a coefficient of performance of 1.27. In addition, the NTEAC system showed an energy saving of 67% and CO_2 emission mitigation of 76% when compared with a conventional split air conditioner. Thus, an alternative to the traditional air conditioning system was developed from this research, which is Freon free. This system is expected to consume less energy and emit less CO_2 for the tropical climatic conditions.

Buchalik & Nowak (2022) Study about technical and economic analysis of a thermoelectric air conditioning system. This work presents simulations of an air conditioning system based on thermoelectric modules. The proposed system is of a very simple structure, easy to control, scalable, noiseless, and harmless to the environment. The most important parameters that were to be changed were the number of modules, the electric current, and the size of the heat exchangers. The analyses were carried out for a commercially available thermoelectric module whose parameters were determined experimentally. The air conditioning system was analysis in terms of its cooling capacity and COP. Furthermore, it was optimized with economic criteria to achieve the highest cooling capacity of 1 dollar of total cost (electricity and investment) in a set period of device lifetime (ETCC – economic total cooling capacity). For 2400 h of device operation, at a temperature difference of 5 K and the average electricity cost in the EU, the optimized ETCC totals about 0.58 W/$. With the possibility of altering the inner geometry of the thermoelectric modules, the factor increased to 0.64 W/$. The test results showed that the device optimized in terms of ETCC did not operate with maximum cooling power and could be overloaded by about 30% in the reference working conditions.

Mona, Chaichana, Rattanamongkhonkun, & Thiangchanta (2022) Development Energy harvesting from air conditioners by using a thermoelectric application. This working cycle led to an idea to use low-temperature condensed water and high-temperature air for energy generation by using a thermoelectric module. The purpose of this study was to harvest energy from air conditioners by using thermoelectric power generation. This work used eight thermoelectric power generators (TEGs) attached to an aluminum heat sink, where the TEGs were heated on one side. The cooled side of the TEGs was attached to three aluminum water-cooled blocks. The necessary data, such as the condensed water temperature, heated air temperature, the condensed water rate, and the power generation, were collected. Besides, the thermostat of the air conditioner was set at 20, 21, 22, 23, 24, and 25 °C. The results show that the thermostat setting significantly affected the power generation of thermoelectric power generation module because the condensed water rate increased when the thermostat setting decreased. The condensed water rate, the hot-side and cool-side of TEG. The power generation values were 4.28, 4.05, 3.74, 3.56, 3.36, and 3.15 mW for the thermostat settings of 20, 21, 22, 23, 24, and 25 °C, respectively. Therefore, in their results, the energy harvesting from air conditioners by using a TEG can be used for applications such as monitoring systems.

Ahmed, Megahed, Mori, Nada, & Hassan (2023) Development a novel air conditioning system for electric vehicles based on thermoelectric and photovoltaic (PV) panel. The thermoelectric were designed as thermoelectric cooler (TEC) sandwich model between two heat sink and PV panel. The TEC and PV system performance resulting 2.8% of reduction energy consumption and to compare with batteries as daily required energy decrease around 19%. Moreover, TEC also giving another influence as preventing cabin mobile temperatures overheated above 40 °C.

Aljolani, Heberle, & Brüggemann (2023) Design and fabrication the thermodynamic analysis of a CO_2 air-conditioning concept for multi-family houses in temperate and subtropical climates based on experimental data. It was found that, the use of synthetic refrigerants is strongly restricted worldwide to combat the double threat of ozone layer depletion (ODP) and global warming (GWP). Carbon dioxide (CO_2), as a natural refrigerant, has been attracting more and more attention in applications involving refrigeration and air-conditioning systems. With reference to a transcritical CO_2 cycle, this study evaluates the energetic and exergetic efficiency of an air-conditioning system for multi-family houses in temperate and subtropical climates. Multi-family houses in three European countries (Germany, Italy, and Spain) with an identical cooling capacity of 19.4 kW at the design point, but different cooling areas and annual cooling demands, are considered. The air-conditioning system has been investigated by simulation over the period of one year, considering the corresponding cooling profiles depending on time and location (Munich, Florence, and Malaga). The applied off-design model of the CO_2 plant is validated by experimental data. The relative deviation between the simulation and experimental results concerning the cooling capacity is below 5.5%. For the Munich case, the results show, for the cooling area of 375 m^2, a yearly averaged energy efficiency ratio (EER) of 6.82. Based on the identical system capacity, a living area of 322 m^2 and 283 m^2 can be cooled for the Florence and Malaga cases, respectively. Due to the different climatic boundary conditions, a lower yearly performance with an EER of 6.07 for the Florence case and 5.87 for the Malaga case are obtained. In terms of the energy loss for each component, the results show that the highest losses are obtained for compressor and gas cooler, respectively. Together they account for more than 50% percent of the total energy loss of the system. The lowest losses are related to the recuperator with about 6.6% of the total energy loss. Furthermore, the results indicate that the studied CO_2 system is more appropriate for countries in the temperate zone than countries in the subtropical zone. Moreover, the considered CO_2 air-conditioning concept shows an acceptable EER compared to the typical

EER values of the European market, which is based on conventional air conditioning systems, coupled with a significant reduction in the global warming. Therefore, the findings and implications of this work address the gap and remove doubts on using carbon dioxide as a working fluid for the air-conditioning of multi-family houses in temperate and subtropical regions.

Irshad, Rehman, Zahir, Khan, Balakrishnan, & Saha (2024) Analysis of photovoltaic thermoelectric air conditioning for personalized cooling in arid climate. This study addresses the challenge of developing energy-efficient cooling solutions for arid climates through the experimentation of a solar photovoltaic (PV) powered thermoelectric cooler (TEC), known as a photo thermoelectric air conditioning (PTE-AC) system. The research aims to offer a sustainable alternative to traditional air conditioning systems, particularly in hot, arid regions like Dhahran, Saudi Arabia. The methodology involves fabricating and evaluating the PTE-AC system, which operates exclusively on solar PV power to create distinct hot and cold chambers for personalized cooling. Experimental results reveal that the PTE-AC system reaches its peak performance at an electrical input of 6 A and 5V, achieving a maximum coefficient of performance (COP) of 0.498 and a cooling capacity of 54.8 W. The system ability to produce condensate varied, with average outputs of 11.7 g/h, 13.8 g/h, and 16.4 g/h recorded under power settings of 4 A, 5 A, and 6 A respectively. In operational conditions, the system maintained an ambient temperature range around the occupants between 22.1 °C and 29.2 °C, with an average of 24.5 °C, at the optimal input setting of 6 A and 5 V. The research contributes significantly to the field by presenting a Freon-free, low-carbon dioxide, and energy-efficient cooling solution, demonstrating a practical application of solar-powered thermoelectric technology in building engineering. The novelty of this study lies in the approach to leveraging solar energy for efficient personal cooling, offering a viable and sustainable alternative to conventional air conditioning in arid climates.

CHAPTER 3

METHODOLOGY

The chapter 3 of our research, we have presented in the section like. First, the thermoelectric solid-state air conditioner (TESSAC) were design and fabricated. Second, the TESSAC were study and measurement toward cooling of thermoelectric devices in order to provide information for the construction, so that our TESSAC can practical applying to thermoelectric air conditioners. Finally, we had tested performance our TESSAC systems with step-by-step and also make a result and discussed. The details of the experiment are shown as follows.

3.1 Thermoelectric Solid-State Air Conditioner Design and Fabrication.

3.1.1 Thermoelectric Solid-State Air Conditioner Design.

3.1.2 Thermoelectric Solid-State Air Conditioner Fabrication.

3.2 Thermoelectric Solid-State Air Conditioner Data measurement.

3.2.1 The TEC1-12710 module tested.

3.2.2 The TESSAC simulated.

3.3 Thermoelectric Solid-State Air Conditioner Efficiency Test Systems.

3.3.1 Efficiency Method.

3.3.2 The TESSAC cooling systems test.

3.1 Thermoelectric Solid-State Air Conditioner Design and Fabrication.

3.1.1 Thermoelectric Solid-State Air Conditioner Design.

First, the TESSAC was written working diagram (Figure 18) and design by program Autodesk Inventor software and circuit diagram. Next, the TESSAC 400 BTU/h are consists with 1) steel structure 2) 3 thermoelectric cooling modules (TEC) TEC-12710 (Hebei I.T. Shanghai Co., Ltd) were obtained and immediately performance test, after the TEC module was checked then the TEC system can cool up to 400 BTU/hr. 3) Ducted fan blades and 4) Operation controlled unit thermoelectric air conditioner by cooling systems and TEC modules are also controlled by the system. The TESSAC was designed to be movable and has a width equal to 315, 215 and 620 mm length and height (Figure 19(a)) all of designed are shown in Figure 19.

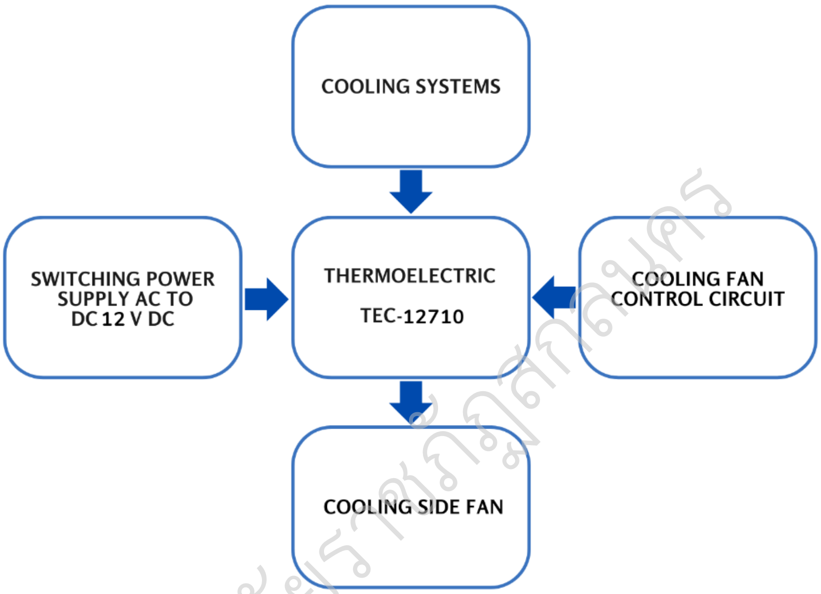
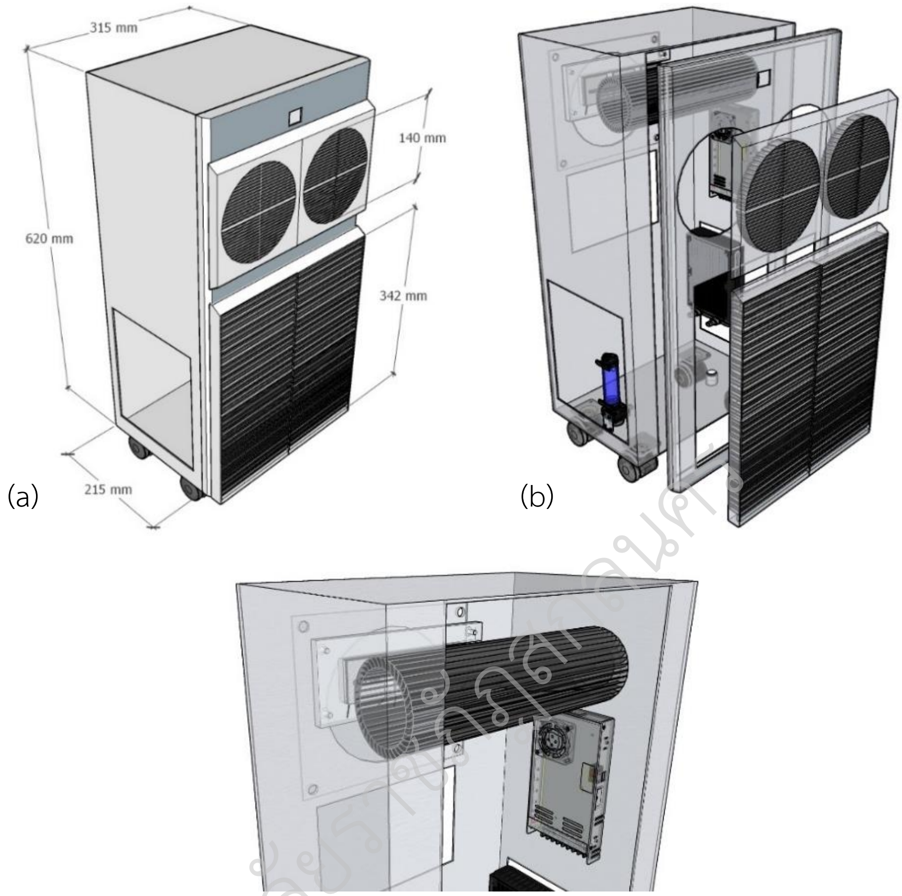


Figure 18 Shown working diagram of the TESSAC.



(c)

Figure 19 Shows the Schematic diagram of TESSAC. (a) TESSAC sectional. (b) Overall view and dimensions. (c) Centrifugal Blower.
Air Conditioner Brand on company and specification of them

Figure 19(b) Shows the TESSAC sectional compose of schematic diagram such as 1) cooling generation position and compact TEC1-12710 modules installed with water-cooled aluminium mounting plate. In addition, in Figure 19(b) also have DC power supply for TEC point, cooling radiator, water pump 12 V (water flow rate 300 L/h), fan air flow, air flow grille and air vents to ventilate air and filter dust into the machine. Figure 19(c) shown the Centrifugal blower is enlarged cooling generation position or TEC modules compact with water-cooled aluminium mounting plate are consist with 1) aluminium plate supporting TEC modules, 2) water-cooled aluminium mounting plate, 3) TEC modules and 4) screw hole to hold tight, respectively.

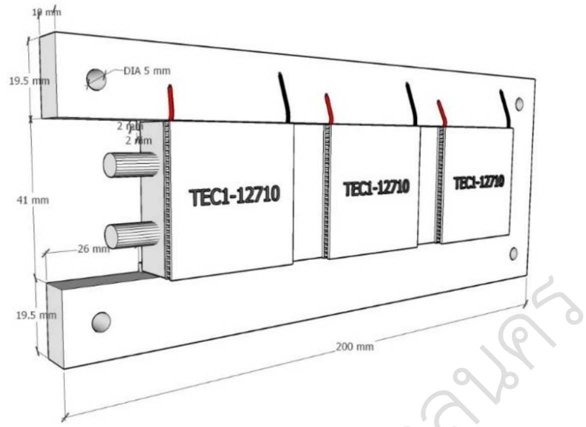


Figure 20 Shown the TEC1-12710 3 modules are installed at water-cooled aluminium mounting plates in TESSAC.

Figure 20 shown the TEC1-12710 3 modules are installed plate, the TEC1-12710 were made from acrylic sheet to hold the thermoelectric cooler and installed in conjunction with the aluminum water-cooled unit. Moreover, the design of a 400 BTU/hr TESSAC system was relies on the TEC principle. The hot and cold sides of the TESSAC was designed by using a water cooling system controlled, so the air conditioning system can work and use the fan control the circuit to spread cooling vapor out of the front of the machine to distribute the cold.

3.1.2 Thermoelectric Solid-State Air Conditioner Fabrication.

3.1.2.1 The TEC1-12710 specification module.

The fabrication of TESSAC was used TEC1-12710 module size 40x40x3.2 mm^3 and specification data including hot side temperature ~25-50 °C, Q_{max} = 85-96 W, ΔT_{max} = 66-75 °C, I_{max} = 10.5 A, V_{max} = 15.2 V, and module resistance ~1.08-1.24 Ω, respectively. The support details shown in Figure 21.

Hot Side Temperature (°C)	25°C	50°C
Qmax (Watts)	85	96
Delta Tmax (°C)	66	75
Imax (Amps)	10.5	10.5
Vmax (Volts)	15.2	17.4
Module Resistance (Ohms)	1.08	1.24

Figure 21 Shown the TEC-12710 module.

3.1.2.2 The TESSAC equation.

The TESSAC system was calculate by Eq. 14 as follows:

$$P\left(\frac{BTU}{hr}\right) = 3.412141633 \times \left(P_{(W)}\right) \tag{14}$$

$$P\left({}^{BTU}\!/_{hr}\right) = 3.412141633 \times 85\left(P_{(W)}\right)$$

$$P\left({}^{BTU}\!/_{hr}\right) = 290.03\ BTU/hr$$

**Outside heat control of thermoelectric 25 °C, ΔT_{max} = 66 °C.

** The researcher used 3 TEC1-12710 modules.

Additionally, the second law of thermodynamics need to estimate the heating and cooling systems. The calculation was take place when the electric current had applied as shown in the Eq. 15 (Ma, Zhao, Zhao, Li, & Shittu, 2019).

$$Q_h = Q_e + Q_E \tag{15}$$

3.1.2.3 The TESSAC cooling system circuit.

In the TESSAC cooling system had connected in parallel type, there is a cooling fan to blow the heat toward aluminum cooling in cooling system and also have water pumping motor to support water for circulate in the system during work. Furthermore, The TESSAC cooling system circuit there is a fan motor for control circuit to support and adjust the level according to the appropriate temperature. The schematic diagram of cooling system circuit is shown in Figure 22.

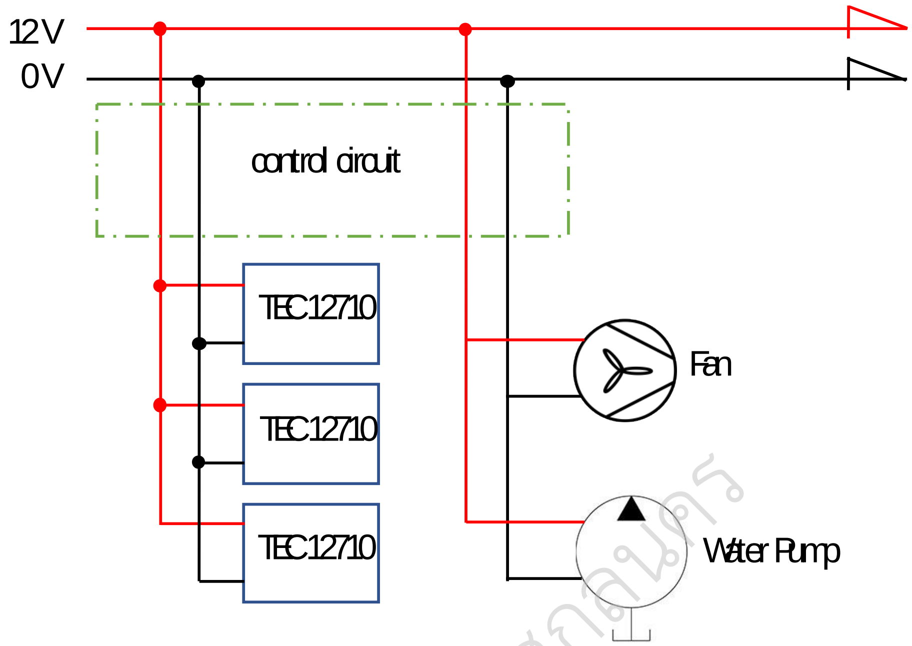


Figure 22 Shown the Schematic diagram of TESSAC cooling system circuit.

3.1.2.4 The TESSAC cooling system control board.

In TESSAC cooling systems, we selected commercial ready-made boards for fabrication to control the cooling operation consist with remote control, remote control on-off and fan control for support thermoelectric air conditioning working. The commercial ready-made board is shown in Figure 23.

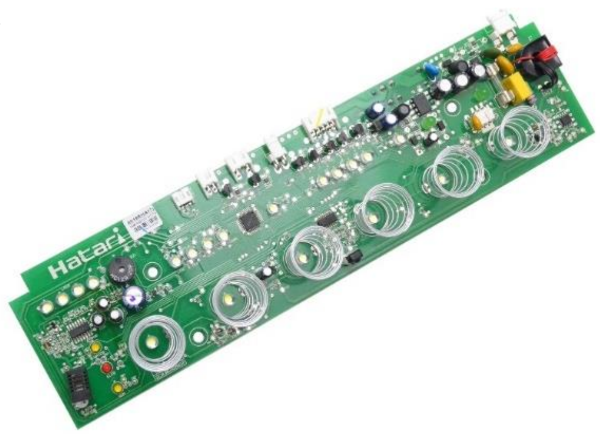


Figure 23 Shown the Cooling system control board in TESSAC (ref).

3.2 Thermoelectric Solid-State Air Conditioner Data measurement.

3.2.1 The TEC1-12710 module tested.

The TEC1-12710 module data measurement was tested with current power supply 5.90 A. Next, the TEC1-12710 module was investigated and application to the cooling efficiency in cold side for 3 hours (10,800 s).

3.2.2 The TESSAC simulated.

The TESSAC was created and activated in a simulated room of 1 cubic meter for 3 hours. Cooling efficiency of TESSAC was determine in terms of cooling ability in difference temperature, for the instrumentation air conducting.

3.3 Thermoelectric Solid-State Air Conditioner Efficiency Test Systems

3.3.1 Efficiency Method.

The difference temperature indicated the efficiency of cooling can calculate by Eq. 13 (Sulaiman, Amin, Basha, Majid, Nasir, & Zaman, 2018; Ma, Zhao, Zhao, Li, & Shittu, 2019).

$$COP = \frac{1}{(T_h - T_c) - 1} = \frac{T_c}{(T_h - T_c)} \qquad (13)$$

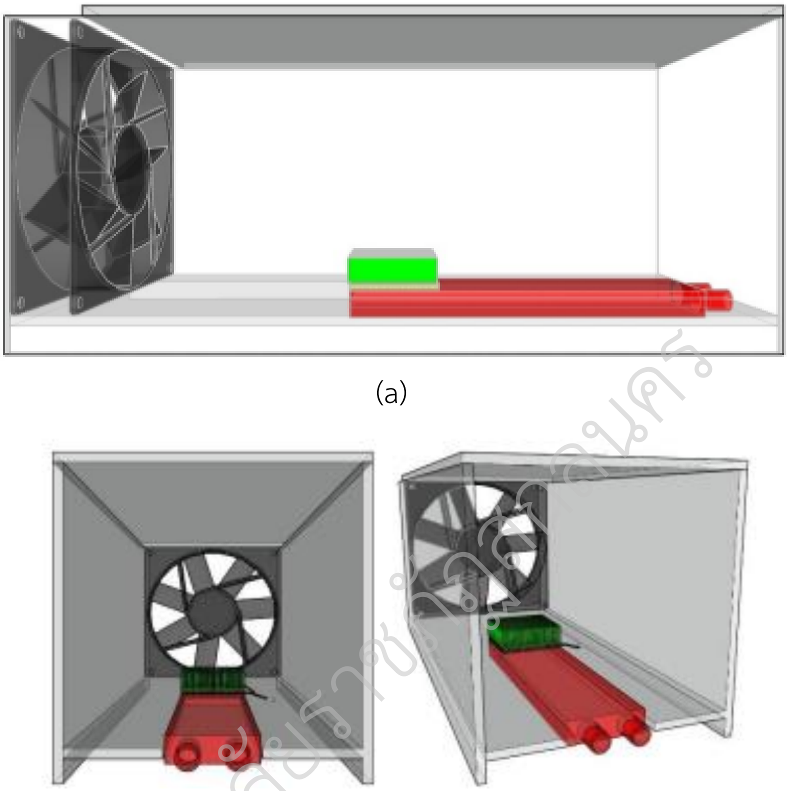
COP = Coefficient of performance.

T_c = Thermoelectric cold side cooling temperature.

T_h = Thermoelectric cold side heating temperature.

3.3.2 The TESSAC cooling systems test.

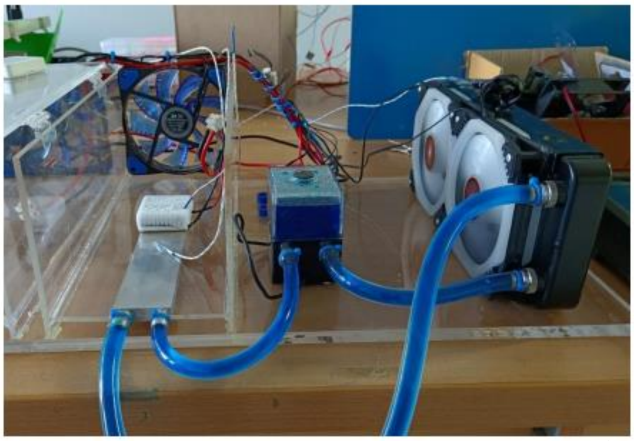
The TESSAC test systems are designed by simulates the actual working conditions of each thermoelectric device as shown in Figure 24. The test was used TEC1-12710 modules with the working conditions of the pouring device. After, the TEC1-12710 module is cooled by attached in the heat sink while the fan is turned on and off. Finally, the TESSAC cooling system was tested by installed with equipment and tools in two clear acrylic box size 13×30×13.5 mm, the cooling systems test are shown in Figure 25.



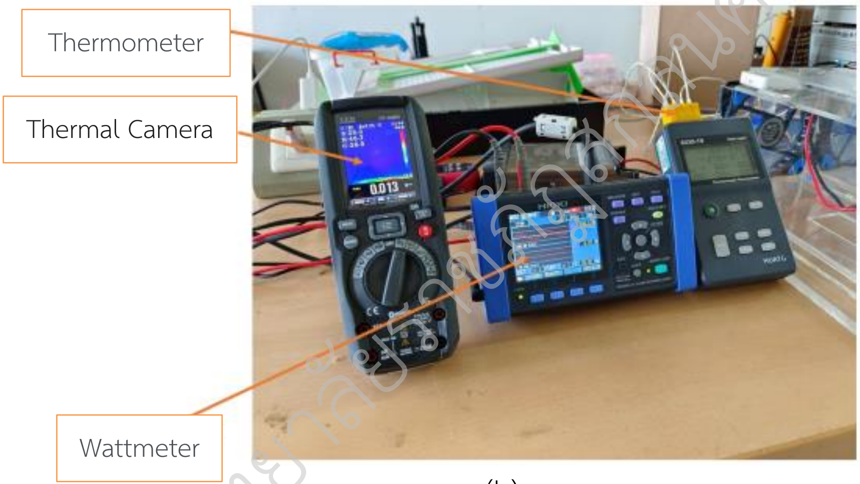
(a)

(b) (c)

Figure 24 Shown the 3D designed for studying the cooling system with TEC1-12710 module attached under flow air. (a) Lateral, (b) Front, and (c) Beveled sides.



(a)



(b)

Figure 25 Shown the TESSAC cooling systems tested. (a) Cooled TEC!-12710 modules by attached in a heat sink during testing. (b) Actual testing equipment and apparatus.

CHAPTER 4

RESULTS AND DISCUSSION

The Chapter 4 we have presented the results and discussion of Design and Fabrication of Thermoelectric Solid-State Air Conditioner (TESSAC) include with 3 section like. First, thermoelectric Solid-State Air Conditioner Design and Fabrication. Second, Thermoelectric Solid-State Air Conditioner Data measurement and Third, thermoelectric Solid-State Air Conditioner Efficiency Test Systems all of data are reported as below.

4.1 Thermoelectric Solid-State Air Conditioner Design and Fabrication.

The Design and Fabrication of TESSAC is shown in Figure 26.

Figure 26 Shown the Realistic TESSAC.

The TESSAC was designed conditioning relies system of 400 BTU/h by using TEC principle and cooling temperature on the thermoelectric hot side as shown in Figure 26. This process was performed by providing a water cooling system to make the air conditioning system work and used the fan control circuit to send cool vapor out of the front of the machine to distribute the cold

4.2 Thermoelectric Solid-State Air Conditioner Data measurement.

In process, we have measurement our TESSAC. So, in the experiment we was supplying the AC current 5.90 A to TEC1-12710 module for 3 h (10,800 s). It was found that, the temperature at cold side of TEC1-12710 module was suddenly decreased from 26.8 °C to 11.1 °C in 60 s, then slightly decreased and tended constant at -7.85 °C after 3,600 s. Nevertheless, the hot side temperature is increased with exponential curve from 26.8 °C until 31.9°C and then tended constant at 31.9 °C after 1,800 s. The measurement of TEC1-12710 module is shown in Figure 27.

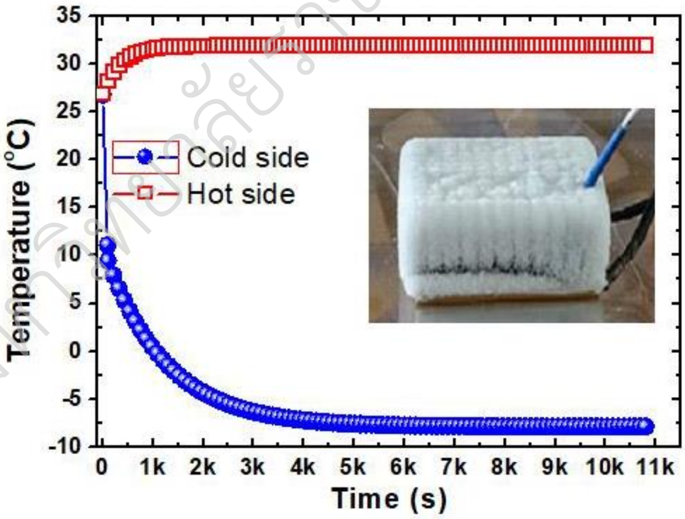


Figure 27 Shown the Cold side and Hot side of TEC1-12710 module as produced with the current of 5.90 A for 10,800 s.

4.3 Thermoelectric Solid-State Air Conditioner Efficiency Test Systems.

The cooling efficiency of TESSAC was determined in terms of cooling ability, temperature difference of thermoelectric and performance of TESSAC are used TEC1-12710 3 modules. Moreover, the performance of the temperature measurement for cold side (T_c), hot side (T_h), center of simulation room (T_{cr}) and ambient (T_a) to be determined the coefficient of performance (COP) values follow that. The TESSAC was supply by AC electric power (W) and tested is in Figure 28.

The temperature of hot and cold side thermoelectric is shows in Figure 28(a), which test of turning for 3 h. It was found that, the temperature of cold side is decrease from 30.5 °C to 5.1 °C within 30 s. After that, the temperature was increasing to 15.5 °C within 570 s. Then, the cold side is average temperature of 9.3 °C and the hot side average temperature of 40.12 °C to be generated the temperature difference of 30.82 °C.

The temperature of TESSAC matter of simulation room was showed in Figure 28(b) to be compared with the cold side and ambient temperatures. The TESSAC was simulated room built with a size of 1.0×1.0×1.0 m^3 for 3 h. It was found that the average temperature at center room of around 28 °C, and the ambient temperature of 33.16 °C. Therefore, an average temperature difference between the room and the ambient temperature is 5.16 °C.

Figure 28(c), shown the evaluate COP of the TESSAC after operating 60 s is around 12.5, then the TESSAC was decreased with steps to 10.7 at 600 s and 9.3 at 2,300 s to be tended to constant.

Finally, the AC electrical power supply to TESSAC was shown in Figure 28(d). The TESSAC was consummated electrical an average voltage of 223.04 V AC, an average current of 0.907 A AC, and the average power of 202.3 W, which switching to DC current as supplied for TEC1-12710 module. Then, the thermal management was play an important role when the electricity is supplied to the thermoelectric because it causes cooling system on the cold side and heating up on the hot side. Therefore, an optimal cooling method is discovered.

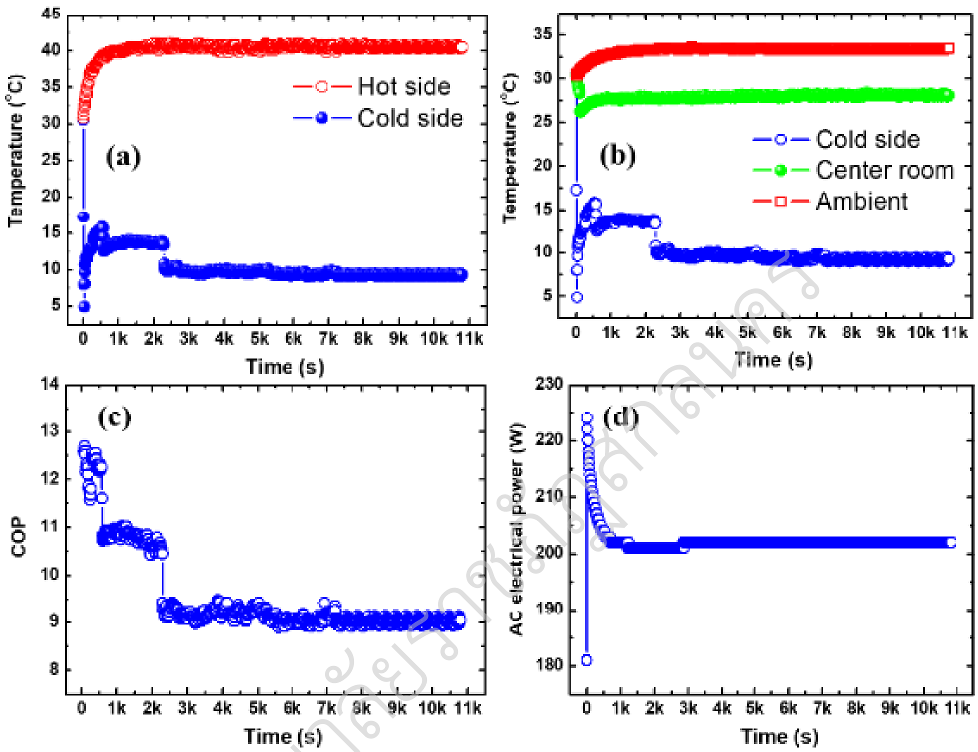


Figure 28 Shows the TESSAC cooling systems efficiency test. (a) The temperature of the hot side and cold side at cooling generation position, (b) The temperature of cold side, center of simulation room and ambient, (c) COP calculation values and (d) the electric power (AC) as supported TESSAC operating.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

This chapter is the conclusions and suggestions of our work, Design and Fabrication of Thermoelectric Solid-State Air Conditioner (TESSAC) and design of solar power thermoelectric radiant panel as cooling system in small buildings under tropical climate based on the pronouncement as below:

CONCLUSION

First, we achieved to designing and fabrication on TESSAC within 400 BTU/h by using TEC1-12710 3 modules. The experimental result of TEC1-12710 one module could be generated the maximum cooling system as performed with temperature decrease to -7.85 °C within DC current applied of 5.90 A for 3,600 s. Furthermore, the realistic TESSAC was shown the temperature of hot and cold side around 40.12 °C and 9.3°C, respectively. Although, the TESSAC was obtained the difference temperature equal 30.82 °C and COP value evaluated around 9.3. However, the average temperature at center of simulation room is around 28 °C within the ambient temperature around 33.16 °C. Then, the average AC power was supplying ~202.3 W and used switching DC current for supplying the TEC1-12710 module.

Finally, the design and Fabrication of Thermoelectric Solid-State Air Conditioner (TESSAC) can be functional capable. Furthermore, our work TESSAC was adapt toward solar power thermoelectric radiant panel cooling system in small buildings. Then, the PV-TERP can be used as an alternative to conventional AC systems for maintaining the indoor thermal comfort in this system consumes less energy than the conventional AC systems. This system also is refrigerant-free and powered by clean energy that can sustain and preserve our environment for a better future.

SUGGESTION

The successful design and fabrication of TESSAC system requires detailed study of the thermal properties of this system, otherwise, the system may affect the building's thermal comfort and cooling efficiency. Therefore, it is necessary to develop a thermal analysis for this system using simulation to support the design feasibility and followed by experimental verification. In addition and other necessary aspects, then a comparison with AC air conditioners has the potential to replace conventional AC systems for environmental protection. And only one module should be tested or analyzed to obtain more detailed Efficiency.

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APPENDICE

APPENDICE A

Nomenclature

TEM	Thermoelectric Module
ZT	Figure of merit
COP	Coefficient of performance
Q_h	Heat energy produced on the hot side
Q_c	Cooling energy produced on the cold side
Q_E	Electrical energy input
T_c	Thermoelectric cold side cooling temperature
T_k	Thermoelectric hot side heating temperature

Greek Symbols

α	Seebeck coefficient of thermoelectric material
σ	Electric conductivity of thermoelectric material
κ	Thermal conductivity of thermoelectric material

APPENDICE B

INTERNATIONAL CONFERENCES PUBLICATIONS

INTERNATIONAL CONFERENCES 1

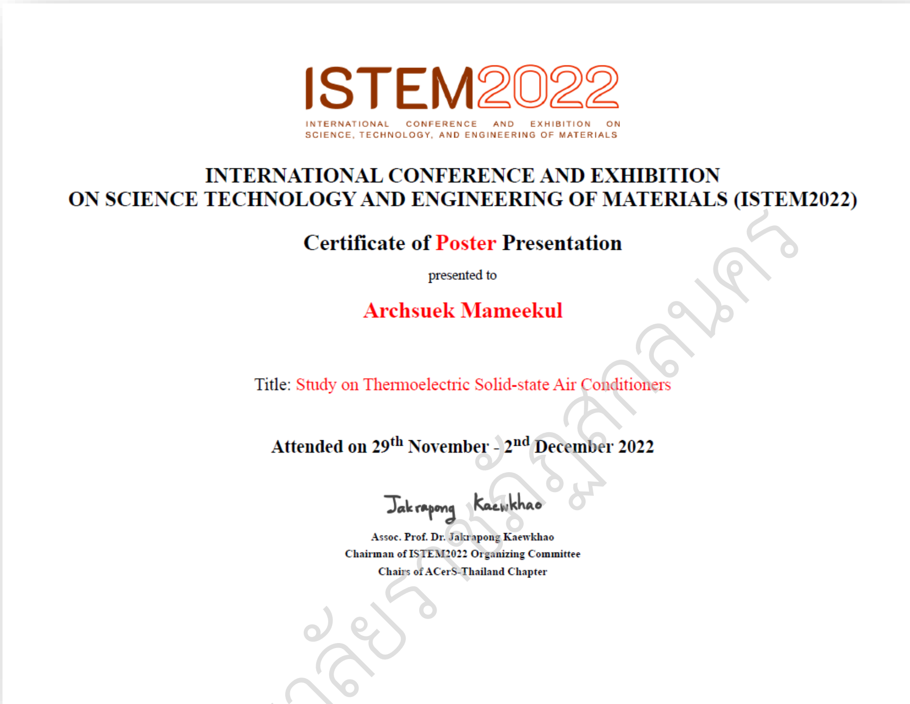
FIRST AUTHOR: Archsuek Mameekul

CO-AUTHOR: Tosawat SEETAWAN

INTERNATIONAL CONFERENCES 2

FIRST AUTHOR: Archsuek Mameekul

CO-AUTHOR: Tosawat SEETAWAN



ISTEM2022

INTERNATIONAL CONFERENCE AND EXHIBITION ON SCIENCE, TECHNOLOGY, AND ENGINEERING OF MATERIALS

INTERNATIONAL CONFERENCE AND EXHIBITION ON SCIENCE TECHNOLOGY AND ENGINEERING OF MATERIALS (ISTEM2022)

Certificate of Poster Presentation

presented to

Archsuek Mameekul

Title: Study on Thermoelectric Solid-state Air Conditioners

Attended on 29th November - 2nd December 2022

Jakrapong Kaewkhao

Assoc. Prof. Dr. Jakrapong Kaewkhao

Chairman of ISTEM2022 Organizing Committee

Chairs of ACerS-Thailand Chapter

PUBLICATIONS

FIRST AUTHOR; Archsuek Mameekul

Mameekul, A., Vora-ud, A., Ruamruk, S., Namhongsa, W., Pilasuta, P., Singsoog, K. Seetawan, T. (2023). DESIGN AND FABRICATION OF THERMOELECTRIC SOLID-STATE AIR CONDITIONER. *Suranaree J. Sci. Technol,* 30(5), (1-5). DOI: https://doi.org/10.55766/sujst-2023-05-e02930

CO-AUTHOR; Tossawat Seetawan

FULL PAPER

DESIGN AND FABRICATION OF THERMOELECTRIC SOLID-STATE AIR CONDITIONER

Archusuek Mameekul[1], Athorn Vora-ud[1], Surasak Ruamruk[1], Wanatchaporn Namhongsa[2], Panida Pilasuta[2], Kunchit Singsoog[2], Somporn Thaowankaew[3], and Tosawat Seetawan[1,*]

Received: January 15, 2023; Revised: August 04, 2023; Accepted: August 15, 2023

Abstract

In this study, we designed and fabricated of thermoelectric solid-state air conditioner (TESSAC) within 400 BTU/hour by using a thermoelectric cooling (TEC) module (model: TEC1-12710) for 3 modules. Thermal management was carried out with the aluminum water-to-radiator system through the liquid moly coolant for controlling the temperature on the hot side of the TEC module. The cooling performance and electrical power were measured during the operating system as performed in one cubic meter for 3 h. According to the experimental results, the TEC1-12710 of one module could be generated cooling by decreasing the temperature to -8.5°C. After useful TEC of 3 modules as useful TESSAC fabrication, TESSAC could be cooled at the cold side around 9.3°C, then the temperature at the center simulation room is around 27.5°C within the ambient temperature of 33.5°C. The coefficient of performance (COP) of TESSAC was calculated to be obtained around 5.5 with the AC power used of 202.31 W.

Keywords: **Thermoelectric solid-state air conditioner, thermoelectric cooling, liquid moly coolant**

Introduction

Air conditioners were first made in the 1900s by using the process of dehumidification, which involves condensing the water vapor in the air to form water droplets, then sending cold air with low humidity instead. The air conditioners available on the market today use refrigerant, which has been continuously developed (Saini *et al.*, 2011). These results are increased energy consumption, emissions of greenhouse gases, and noise from the operation of the system. For example, in the United States,

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DOI: https://doi.org/10.55766/sujst-2023-05-e02930

Suranaree J. Sci. Technol. 30(5):030146(1-5)

electricity accounted for more than 76% of total consumption, more than 40% of all types of energy consumption and related greenhouse gas emissions occur in the building sector. Heating, ventilation, and heat pump air conditioning are account for 35% of both residential and commercial energy use which energy consumption is increased. The share of annual electricity consumption is rose from 25% in the 1950s to 40% in the early 1970s and to 76% in 2012 (Gao *et al*., 2021).

Unlike solid-state refrigeration systems, current compression cooling technology does not use refrigerants or compressors. It has significant advantages in terms of zero emissions and noise (Ma *et al*., 2017; He *et al*., 2021). The thermoelectric also has a service life of more than 100,000 h (Charilaou *et al*., 2021). It is a solid-state cooling system that uses the Peltier effect to obtain cooling from a thermoelectric source. Thermoelectric cooling technology is one of the most promising. It is an alternative technology of the 21st century (Zuazua-Ros *et al*., 2019). The thermoelectric refrigeration systems were devel oped and applicated in the air conditioning field Ventilation and heating are two of the major trends for the future.

Adeyanju and Manohar (2020). reported prototype thermoelectric air conditioner with a cooling capacity of 286 W using three Peltier TEC1-12730 modules with an installation of the heatsink on the cold side of the thermoelectric. The experiment was conducted in a foam box, measuring 1.6414 m^2. It was found that it took a thermoelectric air conditioner 4 min to reach the desired temperature of 22°C, while a standard air conditioner system (the refrigeration cycle) took 20 min to cool down to room temperature. The experiment was determined the cooling efficiency using a thermoelectric (TEC1-12708, China) and performed by installing the heatsink to cool both the cold, hot sides by using the hot side cooling fan, spreading the coolness on the cold side and optimum current of 1 A. The cooling capacity is 29 W with a COP of 0.34, a cold air temperature of 28°C, and an air velocity of 0.9 m/s (Maneewan *et al*., 2010). Thermoelectric analysis method based on thermoelectric mathematical modeling to study the effect of the thermoelectric properties of materials on power based on four thermoelectric air-cooling systems: 1) Scenario 1: α, σ, and κ changing in equal proportions 2) Scenario 2: α, σ, and κ changing for equal zT values 3) Scenario 3: α, σ, and κ changing for maximum of COP 4) Scenario 4: Relationship of the maximum COP with the zT value and a constant voltage of 4 volts. During the experiment, water circulated from the water tank that was equipped with a fixed frequency pump measured by two high-precision power meters and a T-type thermocouple sensor. The temperature of the TEM critical points was measured using this device and four sensors were evenly placed on the surface of the heat pipe. The study also measured the temperature of the sensor facing the center of the module for thermoelectric material applications. The cooling efficiency of the thermoelectric air-cooled system has been significantly increased when the temperature difference between hot and cold is reduced for applications with small temperature differences. Modules with higher α values were offered better performance with thermoelectric materials of the same virtue. According to the experimental results, the thermoelectric performance is sensitive to the α and the optimum value is the increasing zT (Duan *et al*., 2021).

In research work, we have designed and fabricated of thermoelectric solid-state air conditioner (TESSAC) within 400 BTU/h. The experimental to find the suitability of the construction, cooling performance, and electrical power useful of TESSAC were investigated and reported.

Nomenclature

TEC	Thermoelectric cooling
zT	Dimensionless Figure of merit
COP	Coefficient of performance
Q_h	Heat energy produced on the hot side
Q_c	Cooling energy produced on the cold side
Q_E	Electrical energy input
T_c	Cold side temperature of TEM
T_h	Hot side temperature of TEM
TESSAC	Thermoelectric solid-state air conditioner

Greek Symbols

α	Seebeck coefficient value of TE material
σ	Electric conductivity value of TE material
κ	Thermal conductivity value of TE material

Materials and Methods

The fabrication of TESSAC was used the TEC module with the TEC-12710 model as shown in Figure 1, conclude the performance Table 1. The dimension of TEC module is 40×40×3.2 mm^3 and then specific data showed V_{max} = 15.2 V, I_{max} = 10.5 A and Q_{max} 85 W.

Figure 2 shows the experiment as produced with the current of 5.90 A apply to TEC for investigating on the cooling efficiency of the cold side in the experiment for 3 h (10,800 s).

Table 1. Specific data of TEC module

Hot side temperature (°C)	25°C	50°C
Qmax (Watts)	85	96
Delta Tmax (°C)	66	75
Imax (Amps)	10.5	10.5
Vmax (Volts)	15.2	17.4
Module Resistance (Ohms)	1.08	1.24

Figure 1. (a) Specific data of TEC module and (b) TEC module of TEC-12710 model

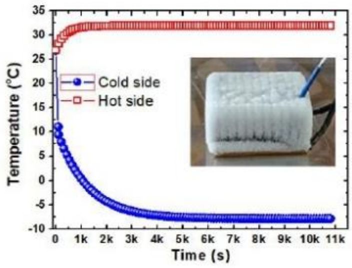

Figure 2. Cold side and hot side temperature of TEC module as produced with the current of 5.90 A for 10,800 s

The temperature at cold side of TEC was suddenly decreased from 26.8°C to 11.1°C in during time 60 s and then slightly decreased and tended constant at -7.85°C after 3,600 s. While the hot side temperature is increased with exponential curve from 26.8°C to 31.9°C and then tended constant at 31.9°C after 1,800 s.

The thermal management was play an important role because, when electricity is supplied to the thermoelectric, it causes cooling on the cold side and heating up on the hot side. Therefore, an optimal cooling method is discovered. The second law of thermodynamics was calculated the heating and cooling that take place when an electric current is applied as shown in the equation below (Ma *et al.*, 2019):

$$Q_h = Q_c + Q_E \tag{1}$$

The TESSAC was designed conditioning relies system of 400 BTU/h by using TEC principle and cooling temperature on the thermoelectric hot side as shown in Figure 3. This process was performed by providing a water cooling system to make the air conditioning system work and used the fan control circuit to send cool vapor out of the front of the machine to distribute the cold.

From Figure 3, Figure 3(a) showed TESSAC sectional compose of 1) cooling generation position or TEC modules compact with water-cooled aluminium mounting plate as enlarged in Figure 3(c), 2) DC power supply for TEC, 3) cooling radiator, 4) water pump 12 V (water flow rate 300 L/h), 5) fan air flow, 6) air flow grille and 7) air

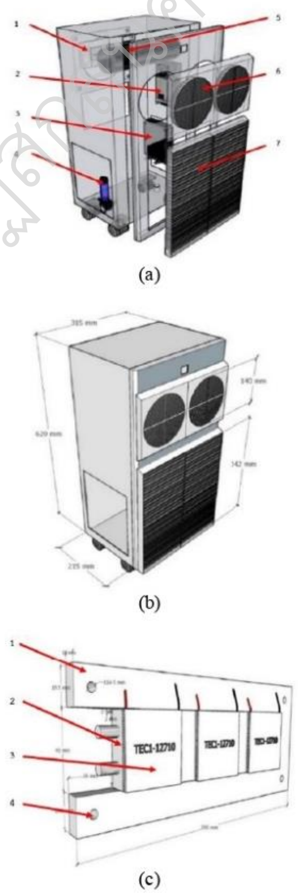

Figure 3. (a) TESSAC sectional image, (b) overall view and dimensions and (c) TEC modules compact with water-cooled aluminium mounting plate

vents to ventilate air and filter dust into the machine. The dimensional of TESSAC are displayed in Figure 3(b) as obtained 315 mm of width, 215 mm of length and 620 mm of height. Figure 3(c) is enlarged cooling generation position or TEC modules compact with water-cooled aluminium mounting plate consist of 1) aluminium plate supporting TEC modules, 2) water-cooled aluminium mounting plate, 3) TEC modules and 4) screw hole to hold tight. The TESSAC was created and activated in a simulated room of 1 cubic meter for 3 h, the results as following by Figure 4. The cooling efficiency of TESSAC was determined in terms of cooling ability, temperature difference of thermoelectric. The difference temperature indicated the efficiency of cooling as shown in the Equation (2) (Sulaiman *et al.*, 2018; Ma *et al.*, 2019).

$$COP = \frac{1}{(T_h - T_C)} = \frac{T_C}{(T_h - T_C)} \qquad (2)$$

Figure 4. Instrumentation, air conditioning experiments

Results and Discussion

The performance of TESSAC as used TEC for 3 modules was illustrated in Figure 5 as performed by the temperature measurement for cold side (T_c), hot side (T_h), center of simulation room (T_{cr}) and ambient (T_a) to be determined the coefficient of performance (COP) values as following the Equation (2). Also, the AC electric power to support TESSAC was measured and reported in Figure 5(d).

The temperature of hot and cold side thermoelectric is shows in Figure 5(a), which test of turning for 3 h. It was found that the temperature of cold side is decreased from 30.5°C to 5.1°C within 30 s and then increasing to 15.5°C within 570 s. Hence, the cold side is average temperature of 9.3°C and the hot side average temperature of 40.12°C to be generated the temperature difference of 30.82°C. The temperature of TESSAC matter of simulation room was showed in Figure 5(b) to be compared with the cold side and ambient temperatures. The thermoelectric air conditioner was simulated room built with a size of 1.0×1.0×1.0 m^3 for 3 h. It was found that the average temperature at center room of around 28°C, and the ambient temperature of 33.16°C. Therefore, an average temperature difference between the room and the ambient temperature is 5.16°C. Figure 5(c), the evaluate of COP of TESSAC after operating 60 s is around 12.5, then decreased with steps to 10.7 at 600 s and 9.3 at 2,300 s to be tended to constant. Finally, AC electrical power applied to TESSAC was shown in Figure 5(d). The TESSAC was consummated electrical an average voltage of 223.04 Vac, an average cur rent of 0.907 Aac, and the average power of 202.3 W, which switching to DC current as supplied for TEC1-12710.

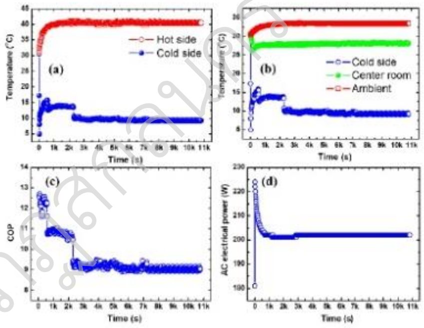

Figure 5. (a) The temperature of the hot side and cold side at cooling generation position, (b) The temperature of cold side, center of simulation room and ambient, (c) COP calculation values and (d) the electric power (AC) as supported TESSAC operating

Conclusions

We achieved to designing and fabrication on TESSAC within 400 BTU/h by using TEC model: TEC1-12710 for 3 modules. The experimental result of TEC one module could be generated the maximum cooling as performed with temperature decrease to -7.85°C within DC current applied of 5.90 A for 3,600 s. For TESSAC fabrication, the results showed that the temperature of hot and cold side were 40.12°C and 9.3°C, respectively, to be obtained the temperature difference of 30.82°C and evaluated of COP value of around 9.3. The average temperature at center of simulation room is around 28°C within the ambient temperature of 33.16°C. The average AC power of 202.3 W was used to switching DC current for supplying the TEC1-12710.

Acknowledgements

This work has financial supported by the Council of Thailand (NRCT) through Program Management Unit for Human Resources & Institutional Development Research and Innovation (PMU-B) (B16F650001) and the e-ASIA Joint Research Program.

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