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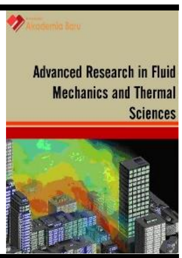

Performance Analysis of Liquid-Cooled Panel System for Air Conditioner Using Peltier Effect

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ABSTRACT

This study reviews the recent advances of thermoelectric materials, modelling approaches, and applications. Thermoelectric cooling systems have advantages over conventional cooling devices, including compact in size, light in weight, high reliability, no mechanical moving parts, no working fluid, being powered by direct current, and easily switching between cooling and heating modes. In this study, it focused on the replacement of the outdoor unit (compressor) for conventional air-conditioner. This system using water as cooling agent in replacing refrigerant system. It involves using Peltier Effect which converts current to rise the temperature between the two junctions of the Peltier. The water will flow through these changes in temperature which results in cooling the air through the process. From this process, it taken 60 minutes in order to achieve 20.2 ^{0}C and consumed 1.3 A which is better rather using the conventional method. This can reduce the cost of the project in terms of maintenance, bills, materials and gases. This system can be operated without relying to the compressor which improve the systems in terms of noise, low electricity usage, small size and use water as coolant agent.

Keywords:
Liquid-cooled pane; Peltier Effect; Thermo-electric cooler

1. Introduction

Thermoelectric cooling, commonly referred to as cooling technology using thermoelectric coolers (TECs), has advantages of high reliability, no mechanical moving parts, compact in size and light in weight, and no working fluid. In addition, it possesses advantage that it can be powered by direct current (DC) electric sources, such as photovoltaic (PV) cells, fuel cells and car DC electric sources. The main disadvantages of thermoelectric cooling are the mind-boggling expense and low vitality efficiency, which has limited its application to situations where framework cost and vitality efficiency

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are less significant than vitality accessibility, framework dependability and calm activity condition. Even though thermoelectric cooling impact was found in the nineteenth century, it hadn't come to fast advancement until 1950s when the fundamental study of thermoelectric materials turned out to be settled [1].

Thermoelectric module is a strong state vitality converter that comprises of a lot of thermocouples wired electrically in arrangement and thermally in parallel. A thermocouple is made of two diverse semiconducting thermoelements, which create thermoelectric cooling impact (Peltier-Seebeck Effect) when a voltage fitting way connected through the associated intersection. Thermo-electric module by and large works with two warmth sinks appended to its hot and cold sides to improve warmth move and framework execution. For a specific module and fixed hot/cold side temperatures, there exists an optimum current for maximum coefficient performance as shown in Eq. (1) [2].

$$(COP)_{c,max} = \frac{T_c}{T_h - T_c} \frac{\sqrt{1+ZT_m} - \frac{T_h}{T_c}}{\sqrt{1+ZT_m} + 1} \tag{1}$$

where, ZT_m is the thermoelectric material figure-of-merit at average hot and cold side temperature T_m.

Other than its applications in military, aviation, modern and scientific work, thermoelectric cooling is slowly getting greater association into individuals' everyday life. Thermoelectric cooling gadgets are broadly utilized for electronic cooling, for example, PC-processors, convenient sustenance and refreshment stockpiles, temperature-control vehicle situates and even thermoelectric air-conditioner. Scientific research group has put immense measure of endeavors on thermoelectric cooling research.

There are great survey papers on thermoelectric advancements and applications, including demonstrating and examination of thermoelectric modules [3], solar-based thermoelectric advances [4], cooling, warming, creating force, and waste warmth recuperation [5,6]. Riffat and Mama [2] displayed a survey of COP improving for thermoelectric cooling frameworks in 2004. Late research gives two potential ways that may prompt significant advance in thermoelectric cooling [4]: 1) to improve the natural efficiencies of thermoelectric materials, and 2) to improve thermoelectric cooling framework's warm structure and enhancement dependent on at present accessible thermoelectric modules. This survey work centers around the improvement of thermoelectric cooling in late decade with consideration on advances in materials, displaying and enhancement approaches, and applications.

Because of low COP, thermoelectric cooling has been limited to specialty applications, for example, space missions, scientific and therapeutic hardware, where COP isn't as significant as vitality accessibility, dependability and calm activity condition. Be that as it may, as innovation propelled, an ever-increasing number of new applications are rising.

Flow thermoelectric cooling applications can be classified into five application territories. Initially, in the common market, thermoelectric cooling gadgets are utilized for cooling little walled in areas, for example, residential and compact fridge, convenient refrigerator, drink can cooler and cookout crate [7-10]. Furthermore, they have likewise been connected to medicinal applications [11], research center and scientific hardware cooling for laser diode or incorporated circuit chip [12]. Thirdly, thermoelectric cooling gadgets have pulled in incredible consideration for warmth scattering in electronic gadgets cooling and mechanical temperature control [13-16]. In addition, applications can be found in car industry, for example, car smaller than usual iceboxes, thermoelectric cooler/radiators in vehicle seats [17-18] and car cooling applications [19-20].

Not only that, there are many researchers who works on this Peltier application. Some of them focusing on implementing Peltier as cooling system such as portable O-REF (oven & refrigerator) application [21], Peltier cooling system utilizing liquid heat exchanger combined with pump [22], and portable air conditioning system [23]. Not only that, some of them using Peltier as energy harvesting itself such as generating electricity using heat loss at engine and exhaust vehicle [24-25], flexible thermoelectric foil for wearable energy harvesting [26], road thermal energy harvesting [27] and gas turbine sensing and monitoring system [28].

2. Methodology

In order to develop a cooling system, a project flow can be divided into two main stages. These three stages require investigating on Peltier itself and both software and hardware being integrated into a system which capable of replacing compressor as an outdoor unit.

2.1 Investigating on Peltier That Have Potential of Cooling Effect

In this stage Peltier is a Peltier cooler is also referred to often known as a thermoelectric (TE) segment, which are small solid-state devices that function as heat pumps. Which means it will pump heat from one side the other. This means that a Peltier factor has a hot side and a cool side. To achieve this, the Peltier factor uses electricity and quite a lot. This also means that in conjunction with pumping heat, the Peltier factor will produce heat, the system will run hotter, but the Peltier factor will cool were it should be used. Figure 1 below show the cooling effect from Peltier module.

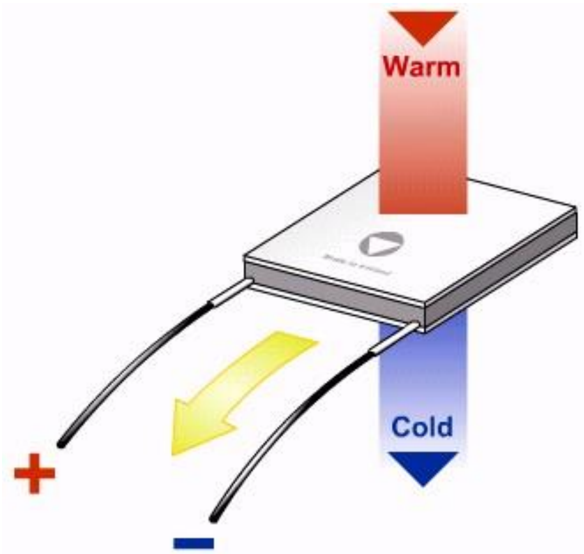


Fig. 1. Peltier module

In order to choose the best of Peltier, an experiment will be conducted to determine suitable Peltier to be applied in the System liquid-cooled panel air conditioners. This is to optimize the performance of the system such as power consumption, costing and the effective of cooling. This study [29] was showed the option for choosing the Peltier and give the distinctions and the favorable circumstances and disservices of three diverse standard air-cooling frameworks in a thermoelectric setup. Next to the examination of their efficiencies, additionally the fields of use of every one of the three conceivable outcomes have been inspected. To make noteworthy adequacy charts, a progression of estimations has been led. For that reason, distinctive Peltier components or thermoelectric coolers (TECs), individually, produced using bismuth telluride-based amalgams were used to temper a metallic test example comprising of a copper piece, that was warmed up by an outside source with a predefined vitality. On the hot side best in class heatsink were connected, while the cool side was furnished with a copper obstruct and in addition an electric radiator. Because of estimations at surrounding temperature, the warmth stream itself was thought to be flawlessly consistent, no warmth misfortunes must be considered. By temperature estimations on the hot and in addition on the frosty side of the Peltier components, the disseminated heat that was led by the air-cooling frameworks has been resolved. Notwithstanding that, the outcomes are imagined in expressive charts that permit the viewer to judge the execution of the cooling frameworks and Peltier components at to start with sight.

2.2 Software and Hardware Development for Cooling System

This system is using Arduino UNO microcontroller as a brain for whole system. Arduino will control all the operation for cooling system and for monitoring purposes. Cooling system part involved are water block, water pump, water tank, cooling piping and air-conditioning itself. Monitoring system will be involved more on controller such as Arduino, temperature sensor, water sensor and Peltier. All the operation system is shown in Figure 2.

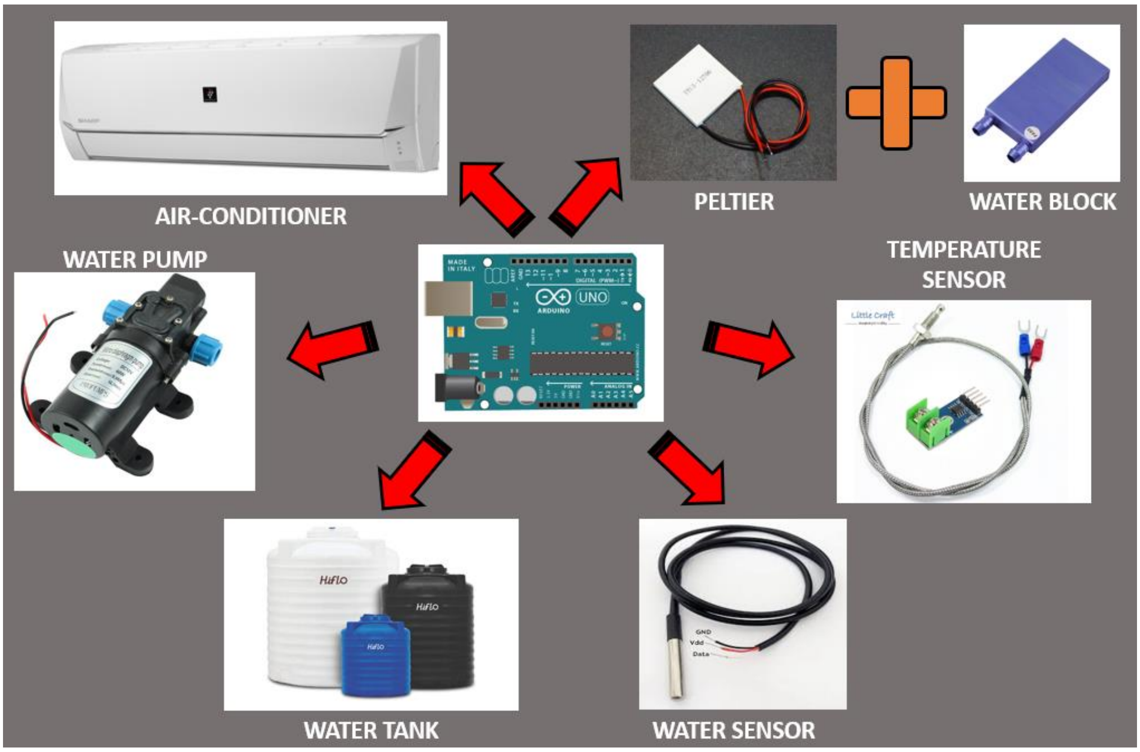


Fig. 2. Overall Process of Proposed System

Four Peltier is using with heatsink attached to each other in order to remove the heat from it. From there, water block is placed near the heatsink to ensure that it can be cooled directly from the heatsink. Water from the tank will flow through the water block continuously and it will be cooled from time to time. The combination of the Peltier and water block is shown in Figure 3. It consists of four Peltier and four water blocks to ensure the system able to produce lowest temperature within 100 minutes.

Fig. 3. Combination between Peltier and water block

Water pump is used to flow the water through the whole system continuously. Two water pumps are used in order to support the pressure needed to flow the water smoothly. This system unable to operate using one water pump because of the pressure is not enough to flow the water in whole system. The water pump uses capable of flow the water 5L per minutes and operating at 12-volt supply. The connection and the position of water pump is shown in Figure 4.

Fig. 4. Connection of water pump

In this stage, the base station will operate with a +12V power supply. This voltage will be used as the operating voltage for all the circuit elements in the base station. It will use a water block to reduce the heat from Peltier and improved the cooling element. After that by using cooling coil are used for water to flow into air conditioner and cold the air at indoor system. Then, temperature controller is used to control the heat and cold at liquid-cooled panel air conditioners because the temperature needs to control for more effective when indoor air-conditioner was turn on. Water pump function to circulate the water from water block to indoor air-conditioner. The process shown in Figure 5.

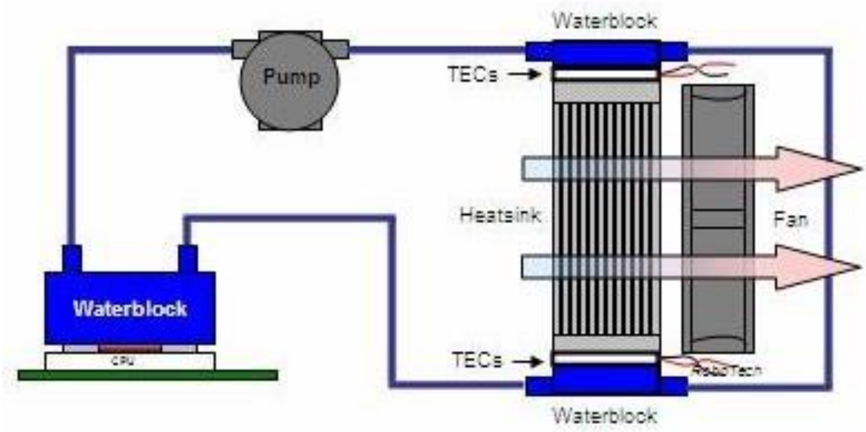


Fig. 5. Block Diagram Overall Process

In the tested room, humidity sensor and temperature sensor are placed to gather the temperature and humidity data while the system is tested. Humidity sensor is used to identify either it in high or low humidity while the temperature sensor to obtain the changes in temperature. Figure 6 shows the configuration of the humidity sensor before integrating into the system.

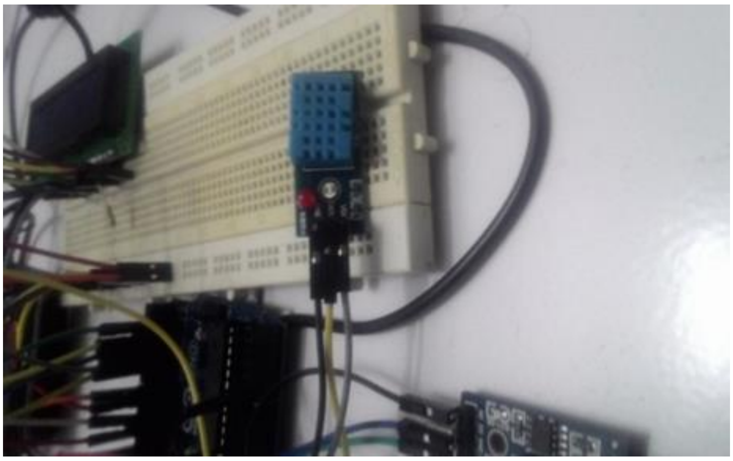


Fig. 6. Configuration of humidity sensor

By integrating all the component, a complete liquid-cooled air conditioner system builds according to each characteristic. Figure 7 shows the fully integrated of the proposed system. As a short practical idea, water will be filled from hose to the correct repository tank and will stream the water through the water siphon and ventilate into water tank. In this water tank system, the combination of the Peltier cell with the water block will experience biasing of water temperature which is hot and cold. The high temperature water will leave the tank and flow through the left tank. The left tank comprises of heated water will stream over into water square to change being cold water. Along these lines, this cycle is continuously and utilizes a similar measure of water. The cool air is being blown through the indoor unit.

For gathering the temperature, three temperature sensors will be attached at the tested room (master bedroom), air-conditioner itself and water tank. This is to measure the current temperature while the system operating for 100 minutes. All the temperature sensor link with the Arduino and displaying the data through serial link communication. Each data taken every 5 minutes to measure the efficiency of the system compared to conventional air-conditioning.

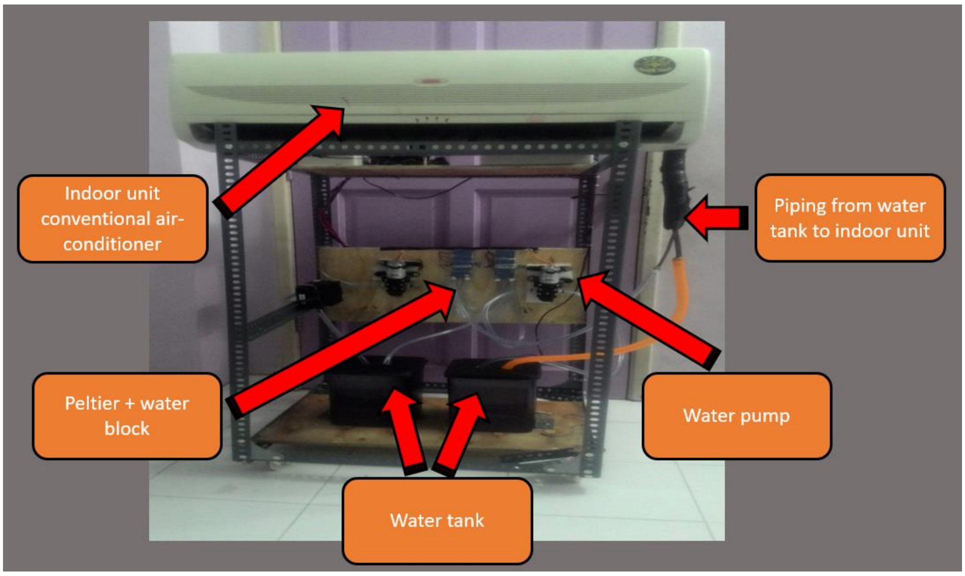


Fig. 7. A complete liquid-cooled air conditioner system

3. Results & Discussion

The experiment being conduct in master bedroom which size is 14 feet x 11 feet. In this testing room, two types of air conditioning are placed to identify the different between those types. One is conventional air-conditioning using 1hp and the other one using the proposed cooling system. Figure 8 shows the plan of the testing room.

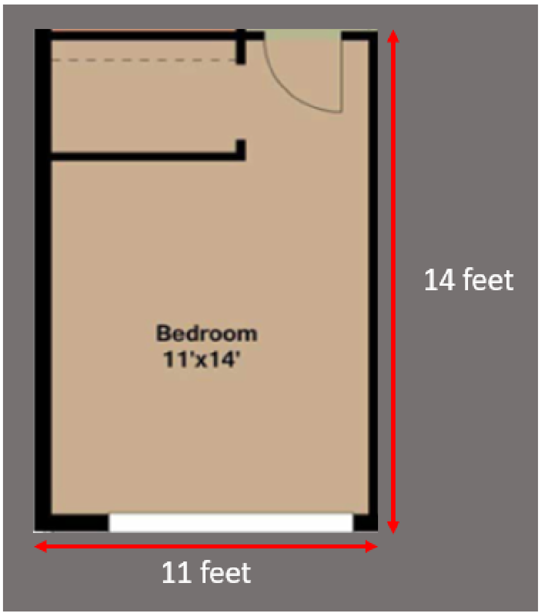


Fig. 8. Size of testing room

The experiment has been conducted 5 times using both types of air-conditioning. Each data taken every five minutes for total 100 minutes. 1 horsepower conventional air-conditioning is using because of the testing room size which is suitable using 1 horsepower. Data for conventional air-conditioning is using only to provide the final temperature and the current usage along the testing period. Data gathered for proposed cooling system is shown in Table 1 and Figure 9 which the temperature result using the average of 5 testing conducted.

Table 1
Data tabulation of room and water temperature in the right reservoir tank for 100 minutes using proposed system

Time, (minutes)	Initial Room Temperature, (°C)	Average Room Temperature, (°C)	Average Water Temperature, (°C)	Average Temperature Difference, ΔT (°C)
0	34	34	28.9	0
5	34	33.2	27.6	0.8
10	34	32.6	26.7	1.4
15	34	31.3	26.0	2.7
20	34	29.8	25.4	4.2
25	34	28.4	24.6	5.6
30	34	27.3	23.4	6.7
35	34	26.2	21.9	7.8
40	34	25.5	20.7	8.5
45	34	24.8	20.2	9.2
50	34	24.2	19.6	9.8
55	34	23.7	18.9	10.3
60	34	23.1	18.1	10.9
65	34	22.6	17.4	11.4
70	34	22.3	17.0	11.7
75	34	22.0	16.7	12.0
80	34	21.7	16.3	12.3
85	34	21.3	16.0	12.7
90	34	20.9	15.8	13.1
95	34	20.6	15.6	13.4
100	34	20.2	15.5	13.8
Standard Deviation		4.4364	4.4455	4.4364

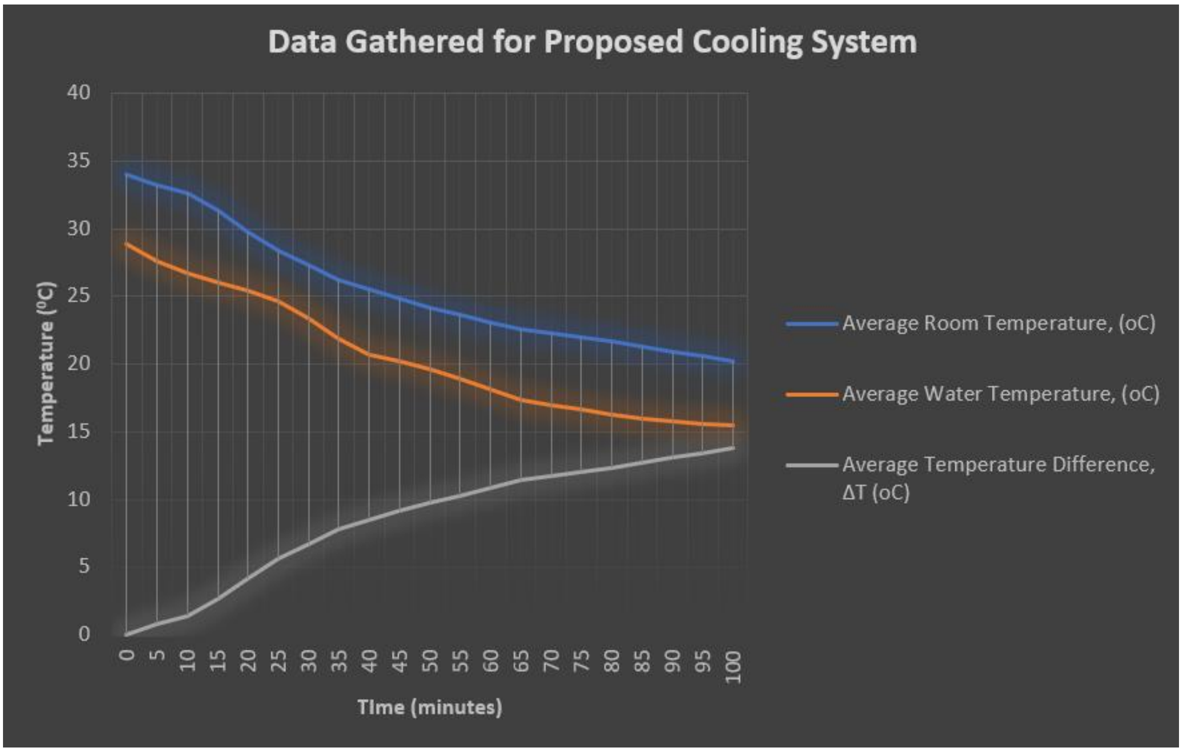


Fig. 9. Data gathered for proposed cooling system

In order to validate the data, each data is analysed using standard deviation method. This method is to prove either the data has any disturbance while the process run through 100 minutes. The calculation shows that the difference between average room temperature, water tank temperature and temperature different just slightly different to each other. This prove that the data don't have any disturbance during the process.

$$Room\ Temperature, S_R = \sqrt{\frac{\sum(x-\overline{x})^2}{n-1}}$$

$$S_R = \sqrt{\frac{393.633}{20}} = 4.4364$$

$$Water\ Tank\ Temperature, S_W = \sqrt{\frac{\sum(x-\overline{x})^2}{n-1}}$$

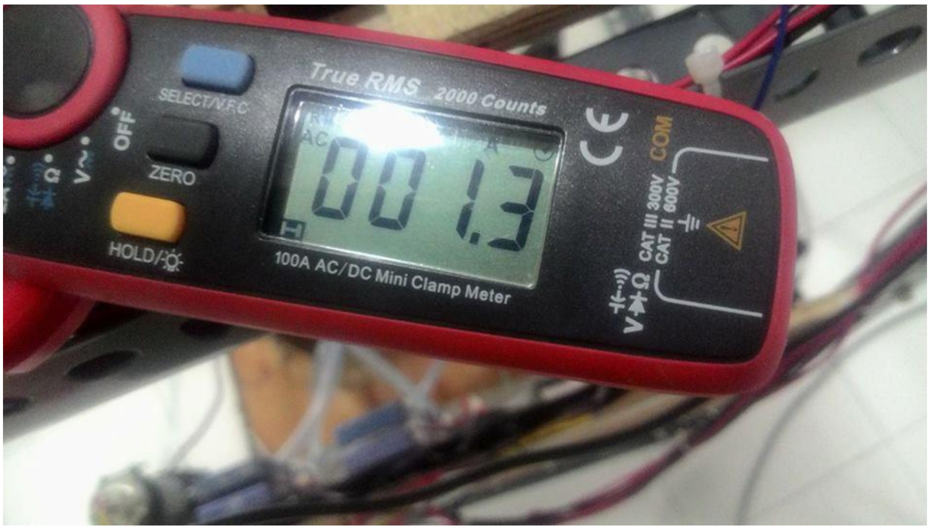
$$S_W = \sqrt{\frac{\sum 395.249}{20}} = 4.4455$$

$$Temperature\ Different, S_D = \sqrt{\frac{\sum(x-\overline{x})^2}{n-1}}$$

$$S_W = \sqrt{\frac{393.633}{20}} = 4.4364$$

From the data gathered, it shows that this system capable of producing cool air as much as conventional air-conditioning using compressor. This system able to produce around 13.8 °C temperature difference and can cool the room up to 20.2 °C. Not only that, this system only used up to 1.3 Ampere rather than average usage from the conventional air conditioning that used up to 5.67 Ampere. Figure 10 shows the current usage from the liquid cooled panel system.

In a nutshell, the system has achieved a lowest temperature of 20 °C without using the compressing gas as per air conditioner at the market. With its capability of just consuming 1.3 Ampere of current which is ¼ of the consumption of usual air conditioner, it can be said this system is energy efficiency. This is also supported with its 56 Watt/hour power consumption whereby normal air conditioner consumes double of it. The effect of this system can be significantly seen during noon time as surrounding is hotter than room temperature. It functions the best creating temperature difference of 14 °C compared to the surrounding temperature.



(a) Current usage for proposed system

(b) Current usage for 1 horsepower conventional air-conditioning

Fig. 10. Comparison of current usage between 2 system

4. Conclusions

As a conclusion, it shows that this proposed system is capable to work as conventional air-conditioning which it can produce up to 20.2°C in 100 minutes. Not only that, proposed system used up to 1.3 Ampere compared to conventional air-conditioning usage up to 5.67 Ampere. This save about 70% current usage compared to conventional one. Meanwhile, this proposed system erases the compressor system that use refrigerant as cooling agent for conventional air-conditioning that save mostly on maintenance cost. Proposed system used water as cooling agent and the maintenance cost is less than the conventional. The life cycle of the proposed cooling system is much higher rather than the conventional air-conditioning because of the elimination of the compressor part that proves much costly in maintenance and refilling the refrigerant.

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