Design and Fabrication of a Vaccine Refrigeration Box

Safaa Najah Saud Al-Humairi
Faculty of Information Sciences and Engineering, Management and Science University 40100, Shah Alam, Selangor, Malaysia
safaa_najah@msu.edu.my

Mohammad Ali Ghani
Faculty of Information Sciences and Engineering, Management and Science University 40100, Shah Alam, Selangor, Malaysia
billypiediepie@gmail.com

Wee Ying Ci
Faculty of Information Sciences and Engineering, Management and Science University 40100, Shah Alam, Selangor, Malaysia
ycwee@msu.edu.my

***Abstract*—Lately, vaccination has been a widespread action to fight the pandemic, requiring the vaccines to be sent out to various places at various distances while staying at optimal quality, usually using cooler boxes. However, today's cooler boxes use ice instead of having a continuous refrigeration system. Thus, this paper presents a vaccine refrigeration box design and fabrication that uses a modified thermoelectric system as the refrigeration system, a conventional and solar charging system as its charging system, and a Bluetooth temperature sensor. From the result of the experiment, the box maintained full functionality for 210 minutes after being charged using a solar charging system. In terms of fully charging the power source, the conventional charging system takes 4 hours and 8 hours using the solar charging system.**

Keywords—Vaccine, Covid 19, Refrigeration box, Refrigeration system, cooler box, Thermoelectric system, Design, Fabrication, Solar, Charging.

I. Introduction

COVID-19, or SARS-COV-2, is an infectious disease that was first found in December 2019 in Wuhan, China [1-3] and was declared a pandemic scale disease by the World Health Organization (WHO) on 30 January 2020 [4]. According to the WHO, this disease has made more than 100 million confirmed cases by march 2021 and has now mortally claimed more than 2.4 million lives, with the elderly and those with certain underlying medical conditions as the most susceptible victims [5-7]. Originating from the reservoir of bats and other unknown intermediate hosts, COVID-19 marked the third appearance [8, 9] of highly pathogenic and large-scale epidemic coronaviruses since the SARS-COV (severe acute respiratory syndrome coronavirus) in 2002 and MERS-COV (Middle East respiratory syndrome coronavirus) in 2012 [10]. However, with a lot of research and experimentation, scientists were able to develop vaccines in response to fight the disease.

Vaccines are specially modified antigens that function as a simulation to prepare one's immunity against a particular biological threat (in this case, it's COVID-19). In October 2020, around forty-nine vaccines were in different phases of clinical development and in December 2020, many of them from several manufacturers were approved for mass distribution [11]. However, due to the temperature requirements (-20 ◦C for six months or around 2 ◦C to 8 ◦C for 30 days), COVID-19 vaccines need to be distributed under temperature control [11, 12]. These vaccines are mainly transported by refrigerated trucks or cooler boxes [4]. However, these methods aren't fully proven.

Refrigerated trucks are suitable for large quantities only, explaining why cooler boxes are used. However, today's cooler boxes function by slowing down the temperature change rather than keeping their inside at a specific temperature due to the lack of a continuous refrigeration system. This prevents the vaccines from being stored in the cooler box for an extended period of time and possibly causes many unnecessary wastages. According to a study in Nigeria in 2017, around 50% of the vaccines were wasted [6, 11].

By designing a cooler box with a continuous refrigeration system, this project aims to provide a way to allow a limited quantity of vaccines to be distributed and kept under controlled temperature for a long time [13]. The solar panel and charging system aid this function in this design. In addition, due to the refrigeration mechanism, the use of ice will not be necessary anymore, giving the box more space to store more vaccines. This project is contributing to SDG 9 (Enhance Research and Upgrade Industrial Technologies) to help enhance scientific research, upgrade industrial and technological advancement, encourage and support innovation, and increase the number of research and development workers. This paper focuses on designing and fabricating a low-cost and efficient vaccine refrigeration box with a mobile monitoring system.

II. RELATED WORK

Thermoelectric systems are (in Figure 1a and b) solid-state heat systems that dissipate heat using electrical power [14]. Due to its low cost, efficiency, and environmental friendliness, this system is widely used [15]. On cooler boxes, they are usually supported by another device called a heat sink fin fan, as shown in Figure 1a. This device creates a continuous airflow and helps disperse the heat from the thermoelectric plates. However, some of them use a heat pipe system as support. This system uses a heat pipe system instead of a heat sink system, as displayed in Figure 1b. Based on an experiment, they both seemed to have the same performance. However, considering the energy consumed by each system, the heat sink fin fan seemed to be much more reliable [16].

Fig. 1. (a) Heat sink fin fan, (b) Heat pipe system [16].

The result of this experiment in Figure 2a and b shows that the cooler box temperature decreases with time, even reaching below 0◦C depending on the electrical power with obtaining the highest coefficient of performance at 1.04 watt and 1.05

watt for the heat sink fin-fan (HSF) and double fan heat pipe (DFHP), respectively. The effect of the heat removal unit is not clear. However, considering the energy consumed by each unit, the heat sink fin-fan is more reliable

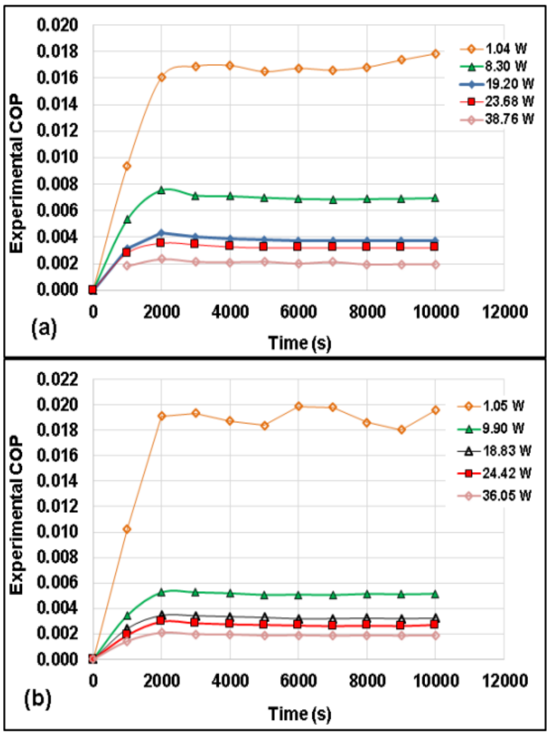


Fig. 2. Relationship between experimental COP and observation time for: (a) HSF, (b) DFHP [16].

Regarding the cooler box (Figure 3), the materials can range from wood [17] and Styrofoam to two layers of Polyethylene with Polyurethane foam in the middle. However, in terms of the performance, the positioning of the refrigeration system must be considered. Based on an experiment by M. Mirmanto et al. [18], the best position for the refrigeration system is on the wall of the cooler box.

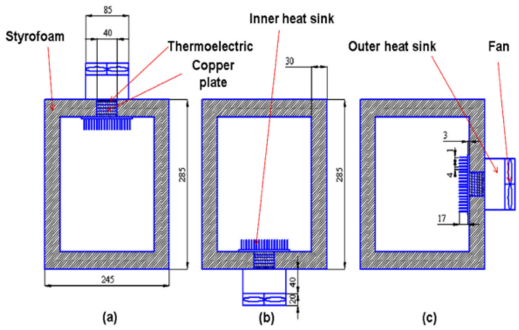


Fig. 3. Thermoelectric positions; (a) On the top, (b) On the bottom, (c) On the wall [18].

Concerning the charging system, this project implemented the solar charging system as one of the charging systems. This idea is acquired from a design of an experiment conducted by Mirmanto et al. [19] that uses a water flow system instead of the heat sink fin fan. However, in addition to the fact that this system isn't entirely successful, the author also suggested using more than one solar panel module to power the power supply. This suggestion makes sense considering the technology of today's affordable solar panel that is reasonably available. However, this will significantly reduce the convenience of using and storing this project's product. However, in this project, the solar charging system is intended to be used as the supporting or the alternative charging system for the conventional technology.

III. METHODOLOGY

A. *Project Methodology*

The methodology used in this project is System Development Life Circle (SDLC), as shown in Figure 4. In SDLC, each phase would have its specific task description while maintaining the project's objectives [16]. Each development phase proceeds in strict order, without any overlapping or iterative steps.

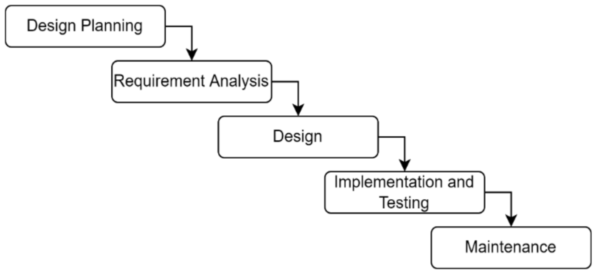


Fig. 4. Project methodology.

a) Phase 1: Design Planning

The first phase of this project focuses on planning to develop a vaccine refrigeration box and analyzing the possible designs and methods for the project. The first phase will also decide on the tools, hardware, and software requirements.

b) Phase 2: Requirement Analysis

The second phase focuses on analyzing the requirements, analyzing on the versions and specifications, as well as the dimensions of the vaccine refrigeration box. This process will help deter the next phase of the development methodology process.

c) Phase 3: Design

The third phase focuses on designing the vaccine refrigeration box. In this case, the box will be designed with the help of Solidworks. This phase can cause a reconsideration of the methods and design of the project.

d) Phase 4: Implementation and Testing

The Implementation and testing phase is when the vaccine box is fabricated. The fabrication would follow the physical design and the requirement of the project's objective. The limitations of this project would serve as a consideration to help fabricate the box as best as possible.

e) Phase 5: Maintenance

The maintenance phase is an optional phase that takes place after the implementation phase. In this phase, the vaccine refrigeration box would be tested and analyzed. Any errors detected would be taken into consideration to be solved.

B. *Development Methodology*

As illustrated in the block diagram Figure 5, the vaccine refrigeration box system can be divided into three segments, input, processor, and output. The input segment consists of the temperature sensor, solar energy through the solar panel, and electrical energy through the electrical charger. The processor segment has a power supply that powers the thermoelectric plate and heat sink fin fan. The output segment consists of the temperature displayed by an LCD, and the refrigeration system consists of a thermoelectric plate and heat sink fin fan.

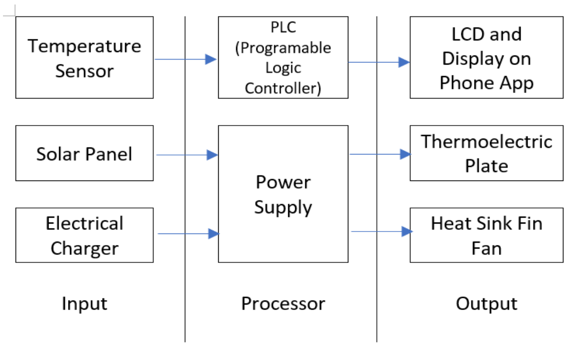


Fig. 5. Block diagram of the proposed system

Based on the flowchart in Figure 6, the power supply, which is charged by the solar panel and through the conventional method, will have to be turned on. Then, the power supply will give its electrical power to the refrigeration system, which of thermoelectric plates and a heat sink fin fan. This will cause the temperature inside the box to drop over time. The temperature sensor will detect the temperature inside the box and display it to the reader either directly or through the mobile application. After the box is finished, the power supply can be turned off to conserve its electrical power for later use.

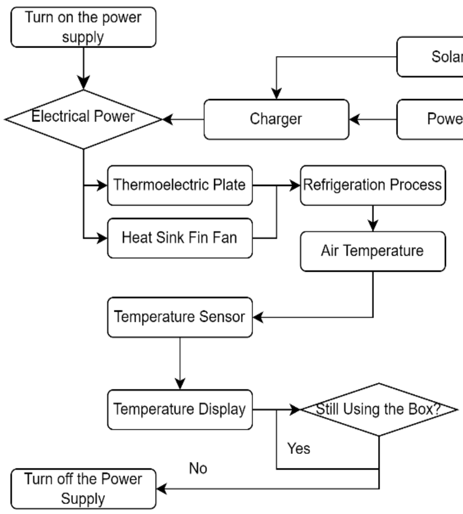


Fig. 6. Flowchart of the proposed system

C. 3D Design

The 3D design was made using the help of SOLIDWORK, as shown in Figure 7. The vaccine box has a dimension of around 25 cm x 27 cm x 36 cm. The box will have holes of some sort at the back that act as a way for air to flow in and out. The box consists of a thermoelectric plate, heat sink fin fan, a power outlet, a power switch, and cables. In addition, the box will also have other features such as the solar power bank at the top and a Bluetooth temperature sensor inside it.

The solar power bank was located on the top of the box to maximize the solar power input. However, the specific position of this does not necessarily have to follow the original design as long as the solar power bank can have an input of solar power to help increase its battery power duration. In addition, the position must also consider the existence of the box handle that helps the user carry the box anywhere. This device will be connected to a cable plugged into the power outlet. This cable, however, will go through inside the rear space of the box to keep the box look presentable. The power outlet and power switch will be connected and located at the bottom left of the back of the box.

The switch will then be connected to the heat sink fin fan and the thermoelectric plate. This thermoelectric plate is attached to the heat sink fin fan to help with the refrigeration system and will be located in the particular hole made for it in the middle of the back side of the refrigeration space. This position is proven to be the most optimum in its refrigeration effect, according to the literature conducted by M. Mirmanto et al. [18].

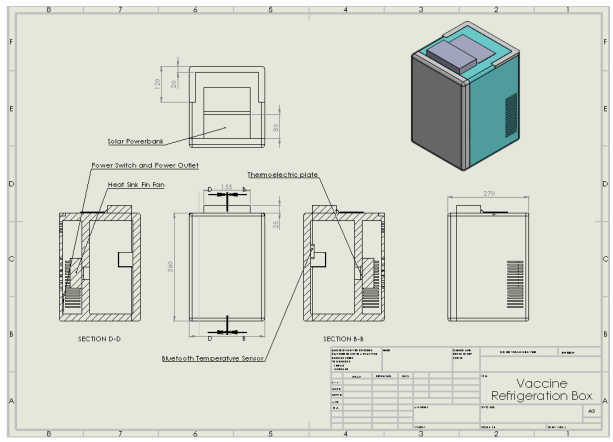


Fig. 7. Technical drawing 3D design.

D. Hardware Used

The vaccine box comprises a Xiaomi Bluetooth temperature and humidity sensor, a 20000mAh solar power bank, a charger, and the vaccine refrigeration box. The refrigeration box includes the 25 cm x 27 cm x 36 cm box, power outlet, power switch, cables, and refrigeration system. The refrigeration system consists of a TEC2-25408 thermoelectric plate and a heat sink fin fan.

E. Software Used

The software used in this project is Solidworks. This software is used to make the 3d design of the vaccine refrigeration box.

IV. RESULTS AND DISCUSSION

A. Prototype Design

For the most part, the fabricated design follows the 3D design. However, there are a few key things that must be considered. One of them is considering the cable hole position—specifically, the cable that connects the solar power bank and the power outlet, as shown in Figure 8.

The cable must go through inside the rear space of the box to keep the box look presentable. In order to do this, two holes were made, on the side of the box and at the back near the power switch and power outlet. Inside the rear space of the box, the cable is tied to keep it from moving all over the place.

For the monitoring purpose, the box has added a window on the door of the box, which gives the user a choice to monitor the temperature directly without having to open the refrigeration box when not using the Bluetooth method without sacrificing too much of the box's temperature insulation ability.

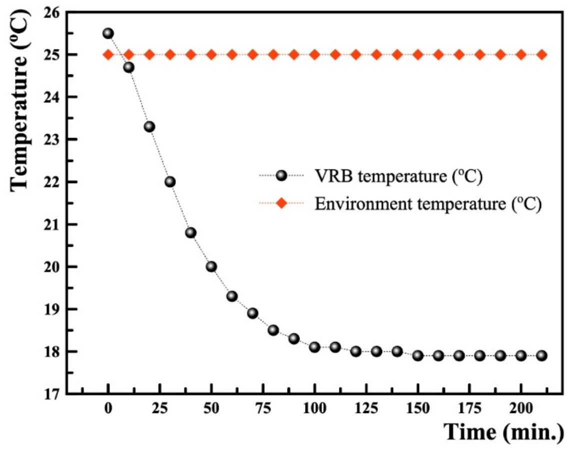
Fig. 8. Prototype design

B. Prototype Testing

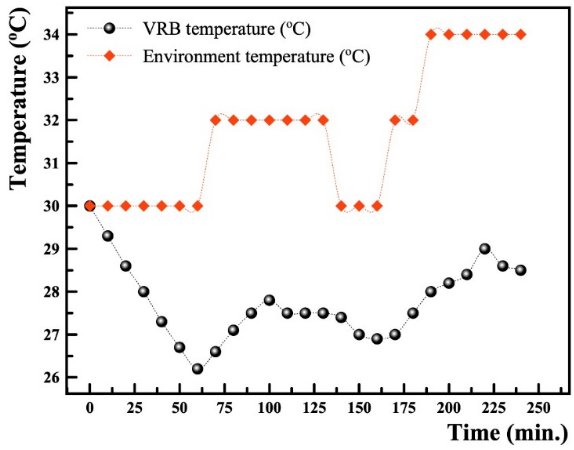
In this project, the vaccine refrigeration box underwent several experiments and observations shown in Figure 9a and b. Firstly, the experiment of the conventional charging and solar power charging duration. The solar power charging experiment is quite tricky since it depends on the weather and the intensity of the sunlight, which can cause this part of the experiment to take days to complete. Because of this, the experiment can only be done in two ways, try to charge it fully and sum up the periods of solar charging time or charge it for only one or two hours and make the result of the duration as how many battery-power percentages per hour. The result shows that for the power bank to be fully charged, the conventional charging method takes around 4 hours, while the solar power charging method takes around 8 hours.

The next is trial with the duration of the battery on powering the vaccine refrigeration box. While doing this, the progression of temperature over time will be observed. In addition to these, to fully experiment with the performance of the box and solar power bank, the experiment will be done under two conditions, average temperature and sunlight, while being charged by the solar charging method.

Based on the results, the solar power bank lasted for 210 minutes and around 4 hours while being charged by the solar charging method. Under the environmental temperature of 25◦C, the temperature inside the box can reach around 18◦C (Figure 9a). Under sunlight, on the other hand, the temperature inside the box changed according to the environment temperature (Figure 9b). However, it seemed that the temperature inside kept around 4-5◦C difference from the environment.



(a)



(b)

Fig. 9. Temperature progression over time; (a) Normal temperature and (b) Under sunlight.

V. CONCLUSION

Due to the lack of a refrigeration system as a portable and affordable approach, a study of the design and fabrication of a vaccine refrigeration box has been introduced in this research. By giving a thermoelectric system, solar power bank, and a Bluetooth temperature sensor, today's cooler box can be turned into a convenient vaccine box with a continuous refrigeration system. From the experiment results, the box has working durations of 210 minutes and 4 hours while being charged using a solar charging system, charging durations of 4 hours for a conventional charging system and 8 hours for the solar charging system. It is able to reach a temperature of around 18◦C under the environmental temperature of 25◦C. This project is perfect for health companies or organizations like the Association of Private Hospitals, the Malaysian Pharmacists Society, or even the Malaysian Ministry of Health. For future developments, it is recommended to increase the solar charging ability and the power source capacity without sacrificing the convenience of the overall design of the box.

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