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Smart Folding and Floating Shelter Design for Disaster Mitigation with Natural Ventilation and UVC System

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Abstract

The global COVID-19 outbreak has hit the world in the last two years. Indonesia itself recorded positive cases of COVID-19 of approximately 4 million cases as of September 15, 2021. In addition, the frequency of occurrence of natural disasters in Indonesia, which is relatively high every year, requires our collective attention. In early 2021, there have been several natural disasters, including floods in South Kalimantan, earthquakes in West Sulawesi, and others. If the impact of the natural disaster makes residents must do the evacuation, a proper shelter (evacuee camp) and prioritizes health protocols are needed. Therefore, this study discusses the design innovation of disaster response shelters in the form of smart folding and floating shelters designed for a shelter with a capacity of one family (4-5 people). This capacity limitation is to maintain health protocols and suppress the transmission of the Coronavirus in evacuation areas. Our designed shelter prepared in a compact form to facilitate evacuation mobility and can be implemented in all types of disasters with a folding and floating structure system (the shelter can float and be folded). The material used is light steel as the main structure and cork wall as a material that allows the shelter to float. We designed natural ventilation to regulate air circulation, integrated with an ultraviolet C (UVC) lamp. The UVC lamp is intended as a disinfectant against the Coronavirus. Thus, the application of natural ventilation and disinfection using UVC can provide a cleaner air supply. This air supply and circulation are shown in our simulation results using ANSYS Fluent. These results show that smart folding and floating shelter designs can be used for disaster mitigation.

Keywords: COVID-19; natural disaster; smart shelter; folding; floating; natural ventilation; UVC

Introduction

As of September 9, 2021, there were 4,140,634 confirmed cases of COVID-19 in Indonesia (*Satgas Penanganan* COVID-19, 2021). One of the reasons for the high number of confirmed cases is the low awareness of implementing health protocols. It is coupled with several natural disasters in early 2021, for example, floods in South Kalimantan, earthquakes in West Sulawesi, and other natural disasters. The evacuation of post-disaster victims is an important thing that must be done to save the lives of victims of natural disasters. One of the efforts in evacuating is by establishing a shelter. In Indonesia, shelters that have been established as evacuation sites for post-disaster victims have not complied with health protocols during the pandemic (*Gugus Tugas Penanganan* COVID-19 DIY, 2020). However, it is feared that it will increase the number of positive cases and create new clusters of the spread of COVID-19 if an effective solution is not found immediately. Therefore, we propose a solution of a shelter innovation that can support health protocols, effective, and efficient.

We design smart folding and floating shelters using light steel and cork walls material (floatable material). We choose folding concept because the shelter needs to be prepared in a compact form to facilitate evacuation mobility. We also choose floating concept because there is one type of disaster that requires shelter to float, that is flood disaster. The air supply of the shelter is also designed using natural ventilation, which is integrated with an ultraviolet C (UVC) lamp. UVC lamps have been widely applied for sterilization to kill viruses and germs (Lee, 2017). Thus, using wall elements in the form of natural ventilation-UVC can provide a cleaner air supply and efficient power supply usage.

Husna and Hidayat (Husnah & Hidayat, 2019) studied the strength of light steel frame structures. The comparison of the strength of the light steel frame and heavy steel (WF) was verified by using Bricscad software. The results yield maximum modulus of elasticity of the structure of 162,500 MPa (safe) < 200,000 MPa, the maximum tensile force of 406.25 MPa (safe) < 406.25 MPa, and analysis of the WF steel structure held the maximum stress of 511.73 Kg/cm^2 < permit = 1,600 kg/cm^2. So, the study concluded that at a span of 16 m without center support, light steel is still relatively safe, effective, and efficient.

Regarding cork wall materials, research conducted by Silva and colleagues (Silva et al., 2005) said that cork material is resistant to liquids and gases because there are suberin and cerin in the composition of cork cells. In addition, cork has a high tolerance to load damage, wear and fire resistance, low thermal conductivity, and excellent damping.

Escombe and colleagues (Escombe et al., 2007) studied the natural ventilation applications. They researched eight hospitals located in Lima, Peru. Five of these eight hospitals, five of them were the"old-fashioned" before hospitals-1950, the rest was a newer design established between 1970–1990. There were seventy natural ventilation in the room where the habitant was the infectious patient. These ventilations were in several types of rooms, e.g., available rooms, i.e., waiting rooms, consultation rooms, general medic rooms, other consultation rooms that are more specific, and emergency rooms. All of the mentioned rooms were then compared to the 12 mechanically ventilated negative-pressure respiratory isolation rooms built post-2000. The Wells-Riley model of airborne infection was used to estimate the infection risk of TB exposure. This model can predict the number of susceptible persons infected within 24 hours of exposure to untreated TB patients of infectiousness in mechanically ventilated rooms. The exact number of prediction values was 39%. This number was relatively higher than the 33% of modern ventilated rooms and 11% for old-design natural ventilation with both doors and windows open.

Furthermore, related to UVC, a study was carried out by Azza et al. (Azza et al., 2021) to design a smart sterilization system in a classroom-based on UVC at a wavelength of 254 nm. This smart classroom is also equipped with a security system such as automatic locking, contactless sensors to open and close doors, automatic lighting, and a real-time Internet of Things (IoT) based monitoring system. Tinkercad and the Thingspeak web server were utilized for simulation. The process of room sterilization is designed for 30 minutes with a UVC dose of 220 J/m^2. In a classroom with a total floor area of 64.08 m^2, a dose of 14,097.6 J is needed to take 2 Philips UVC lamps of type TMS030-1x-Tubular Ultraviolet (TUV)-T8-18W-High Frequency Performer (HFP), which has irradiation of 0.09 W/m^2.

Methods

Design Procedure and Parameters

We implement the data collection method as our study method, namely writing based on reliable sources, reviewed, studied, interpreted, and presented in written form. Data collection is carried out comprehensively by reviewing various scientific articles discussing evacuee camps, natural ventilation, UVC light, and other supporting scientific articles. The data obtained is then processed to become the basis for designing smart folding and floating shelters. In the data analysis, we simulated the air conditioning in the shelter using ANSYS Fluent software. This simulation aims to determine the magnitude and pattern of wind distribution through natural ventilation, in which these parameters include the dependent variable. The independent variable in the air conditioning in this shelter is the width of the ventilation. The ventilation width design is varied based on the theoretical basis so that a comfortable and healthy indoor air quality (IAQ) can be obtained according to applicable standards. In data analysis, the instrumentation system design of the UVC lamp is also simulated. Instrumentation system simulation using Tinkercad software. This simulation aims to find out the diagrams and a systematic instrumentation system's circuit design.

Natural Ventilation

WHO guides recommendations regarding appropriate natural ventilation models to deal with COVID-19. These guidelines recognize that current epidemiological evidence between ventilation rates and airborne infections is weak. However, it is necessary to appreciate the importance of ventilation both from a theoretical point of view and current practice in indoor air shelters. There are three models of natural ventilation systems, which are as follows (Atkinson & World Health Organization, 2009):

1. Crossflow, this model is the most straightforward ventilation system without any obstacles and is suitable for buildings in tropical climates.
2. Wind tower, this model uses the concept of pressure, which is the wind will flow from high pressure (positive) to low pressure (negative), the positive pressure and negative pressure on the wind tower serves as a wind catcher from the outside, as well as exhausting the wind outside the room.
3. Stack, this model uses the concept of vertical ventilation, which is the direction of airflow from the opening will be expelled through a vertical vent whose ventilation mouth is on the roof of the building.

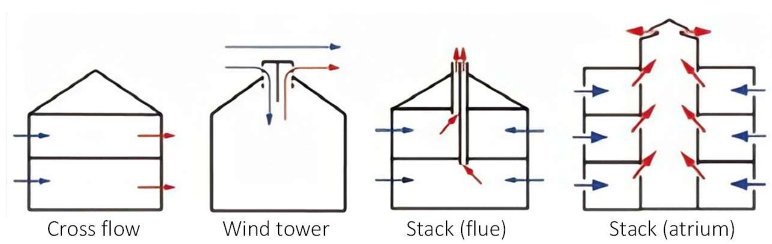


Figure 1. Natural ventilation model (Atkinson & World Health Organization, 2009).

We used a cross-flow natural ventilation model in this study. We do not consider the stack model because a significant pressure difference must flow upward, even though the pressure inside and outside the shelter is not too different. If it does not use pressure, it can be replaced by using a fan assist which will increase the design cost and complicate the system design, so that the application of the stack model is considered less effective in this study. The wind tower model was also not chosen because it tends to form a circular pattern of wind movement in the room, even though such a circular pattern is not well applied to the COVID-19 pandemic. The recommended movement pattern is linear so that the air entering from the vent will directly exit through another vent on the opposite side of the building envelope. Therefore, the suitable model to be adopted is the cross-flow model. In addition, the cross-flow model is considered the simplest model, healthy, and suitable for buildings in tropical climates like Indonesia.

Tolerance to higher temperatures can be achieved by increasing the airflow in the room. For natural ventilation in hot and humid (tropical climates), higher air velocities are required to increase occupant thermal comfort. Another critical factor is the opportunity for occupants to control the airflow within the building according to their preferences. The study results on acceptable airflow velocity tolerance showed that most subjects wanted a higher airflow velocity, even at speeds above 0.50 m/s (Candido & Dear, 2008). Otherwise, the number of subjects desiring a "lower airflow rate" was low. The results indicate that inhabitants prefer higher airflow rates to improve thermal comfort conditions (*Pemprov DKI Jakarta, n.d.*).

Ultraviolet C (UVC) Light

In terms of wavelength, ultraviolet light can be classified into three types, namely ultraviolet C (UVC) or short wave, which has a wavelength of 100-280 nm, ultraviolet B (UVB), or medium wave, which has a wavelength of 280–315 nm, and ultraviolet A (UVA) or long-wave (blacklight) which has a wavelength of 315–400 nm (Seran et al., 2018). The use of light needs to be considered because it is exposed to the human body for too long, exposure to both UVA, UVB, and UVC lights can cause negative impacts in the form of skin, burning skin, cataracts, erythema, wrinkles on the skin, to skin cancer (Isfardiyana & Safitri, 2014). UVB lights can also cause cell damage but are 20-100 times less efficient than UVC. Meanwhile, UVA lights are much less effective than UVB and UVC because they are absorbed weakly by RNA and DNA (Darnell et al., 2004). The UVC performance examples show that UVC light is the most effective UV light in killing bacteria or viruses. Therefore, it is not surprising that product and room sterilization applications often take advantage of UVC lights. At a wavelength of 254 nm, viral ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) can absorb UVC lights well, causing damage to cells. Therefore, we will utilize UVC-type light with a wavelength of 254 nm.

Components of Instrumentation System

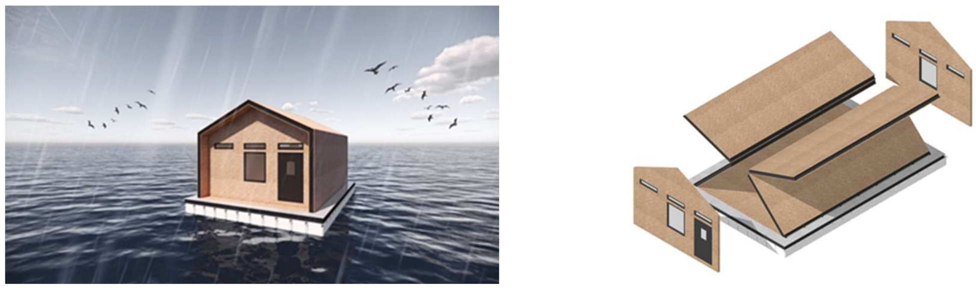
The components of the instrumentation system used in this system are the microcontroller (Arduino Uno R3), temperature & humidity sensor (DHT11), passive infrared (PIR) sensor (HC-SR501), and WiFi module (ESP8266).

Table 1. Instrumentation system component function features (Beetrona, 2020; Sinaga, 2017).

Component	Function Feature
Arduino Uno R3	Reading and processing sensor output data
DHT11	Measuring temperature and humidity parameters
HC-SR501	Detecting human movement based on infrared ray technology
ESP8266	As an additional device for microcontrollers such as Arduino, which connect directly to Wifi and make internet protocol (IP) connections

Result and Discussion

Smart Folding and Floating Shelter Design Results



(a) (b)

Figure 2. Design results: (a) Whole view and implementation on the water; (b) Folding concept.

This smart shelter is in the form of a multifunctional empty space prototype. We designed the shelter for one family with a capacity of about 4 to 5 people with a building area of 40 m2 (8 x 5 m) and a height of 4 m. The capacity limitation is essential considering the demands for enforcement of health protocols that must be carried out in response to COVID-19. Due to its emergency nature, the shelter must be built quickly with a folding and floating structure system.

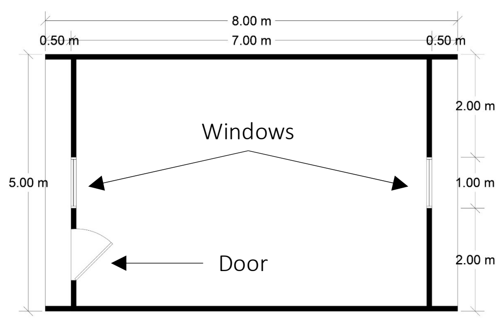


Figure 3. Shelter size details.

The folding system aims to facilitate the assembly of shelters as an effort to evacuate a disaster so the shelter can be moved or assembled flexibly. While the floating system is functioned to respond to disasters related to water (e.g., floods). The floating system tries to keep the shelter from being submerged in water.

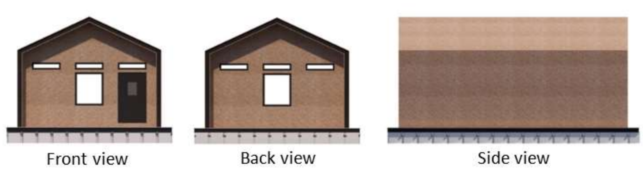


Figure 4. Shelter view design.

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We divided the shelter structure into several elements, namely floor, wall, and roof elements. The three become separate elements and are connected using a folding system along with its light steel joints. The main structure in a frame entirely uses light steel material, considering its lightweight characteristics but high resistance. Then the main structure is wholly covered with cork material which is very light and environmentally friendly, as shown in Figure 5.

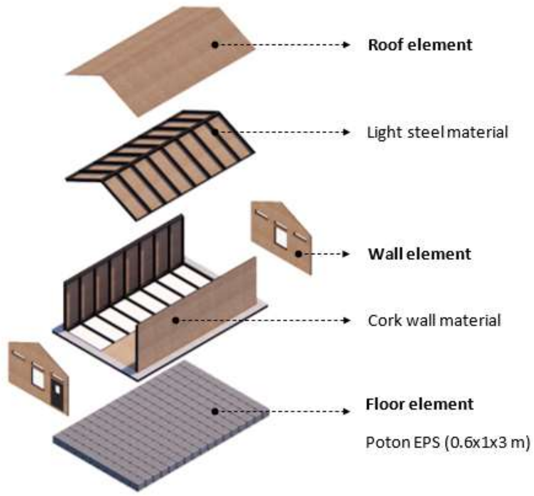


Figure 5. Shelter elements explode.

On the wall element, there are three types of natural ventilation or building openings, namely six vents (three vents on one side and three others on the opposite side), two windows (one vent on one side and one on the opposite side), and a door (one door on one side only). We designed these apertures and integrated them with an ultraviolet C (UVC) lamp. Thus, using wall elements in the form of natural ventilation-UVC can provide a cleaner air supply and optimize renewable energy using natural ventilation.

Air Conditioning Simulation Results

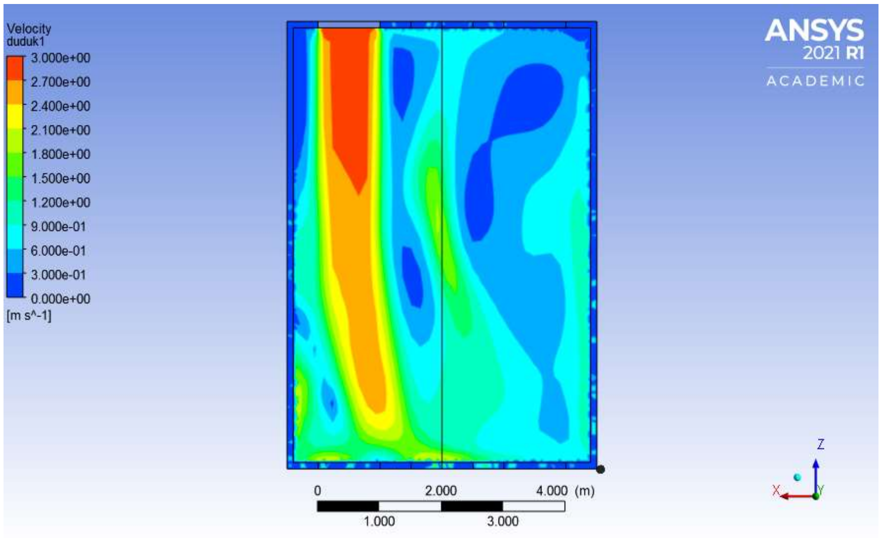
We determine the magnitude and pattern of wind distribution by analyzing the air conditioning simulation. The width of natural ventilation or building openings such as vents, windows, and doors are assumed to be a length that allows for optimal result. The simulations also made contain several assumptions, as shown in Table 2.

Table 2. Assumed parameters set.

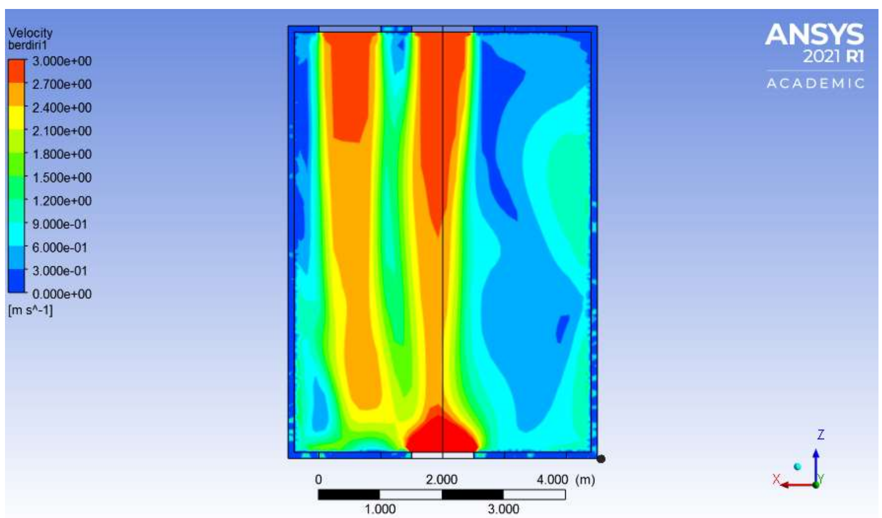
Parameter		Value
Wind speed around building[a]		2.78 m/s
Cork wall material density		240 kg/m^3
Width of building openings[b]	Windows	1 x 1 m
	Vents	1 x 0.25 m
	Door	2 x 1 m

[a] The wind speed used is the average wind speed in the Depok, Sleman, D.I Yogyakarta area on the 3rd week of March 2021 (BMKG, 2021).

[b] All building openings are 100% open.



(a)



(b)

Figure 6. Distribution of wind speed at different altitudes: (a) Altitude 0.75 m; (b) Altitude 1.5 m.

Figure 6 shows wind speed distribution at different altitudes, 0.75 m and 1.5 m, respectively. We selected the altitude of 0.75 m because the expected standard for humans in activities such as sitting, studying, and resting is at that altitude. On the other hand, we selected an altitude of 1.5 m to simulate the stand activities. Figure 6(a) and 6(b) depict the average wind speed at each point at the two altitudes is above the comfort standard of 0.5 m/s (Candido & Dear, 2008). The indicator of color indicated that the minority of dark blue contours where the color represents a wind speed of 0-0.6 m/s.

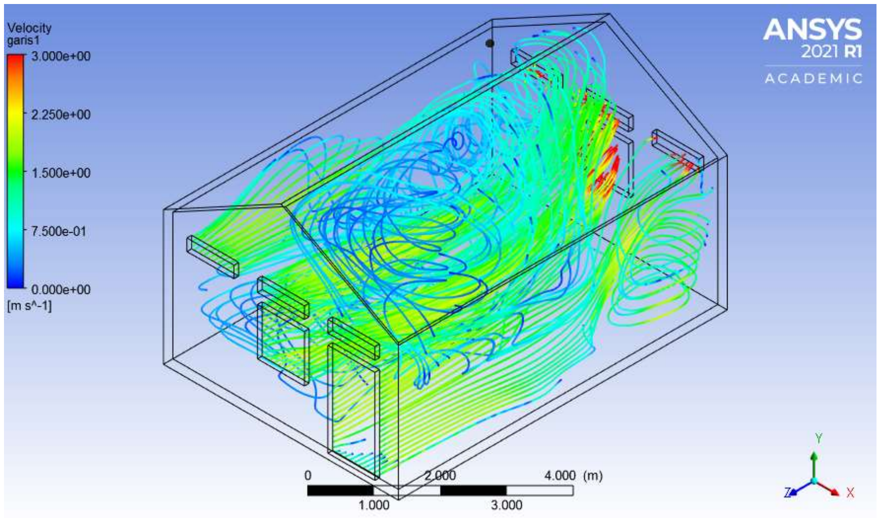


Figure 7. The pattern of wind distribution in the shelter.

The simulation results also show the pattern of wind distribution in the shelter, as shown in Figure 7. The pattern of wind distribution has a different pattern at each altitude. The wind has a linear movement pattern at 2 m altitude; this pattern is desirable and recommended. The results also show that the distribution of wind is a random distribution pattern and swirls. Especially at an altitude of about 3 m and above, at the corner of the shelter, this pattern is undesirable and endangers human health because of the high possibility of spreading the COVID-19 virus. One effort to deal with this is by installing a UVC lamp.

Circuit of Ultraviolet C (UVC) Lamp System Analysis

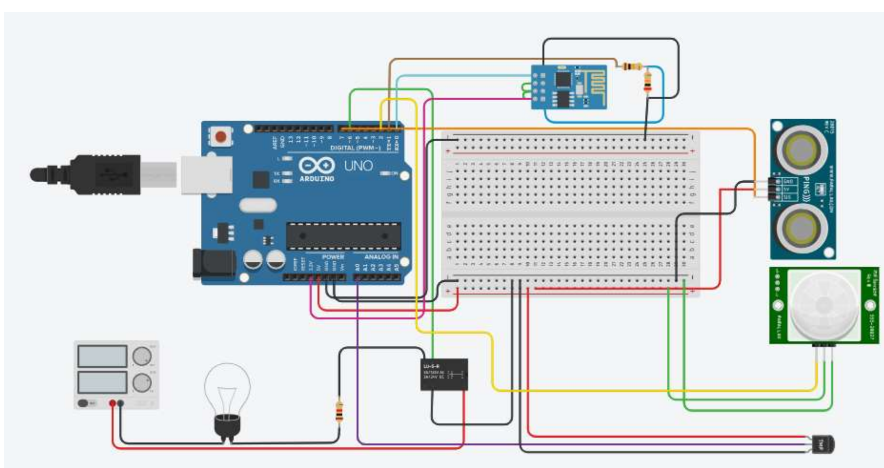


Figure 8. UVC lamp system circuit.

The core of this circuit is the Arduino UNO R3. Arduino receives information from two sensors, namely one PIR sensor and one temperature & humidity sensor. The two sensors are connected to the Arduino's two digital pins and connected to 5V power and ground, respectively. When the temperature and humidity sensor measures temperature and humidity levels above the standard limit, which is indicated by the saturation of the wind in the shelter due to the circular movement pattern, this sensor will send a signal to the Arduino. Arduino has two main outputs, a 10A relay and a status LED. The relay functions as connected to the Arduino via a level-shifter to power. The Arduino worked at 3.3V, while a 5V signal could only trigger the relay. The level-shifter is connected to 3.3V power from Arduino for 3.3V logic reference, 5V power from voltage regulator for 5V logic reference, and common ground. The level shifter also has an actuation pin, which, when moved high, allows output from the level-shifter. Therefore, it is connected via a 1K ohm resistor to the digital pin on the Arduino. The relay is also connected to 5V power and ground. The lamp's main electrical line runs through a relay, switching on and off. The status LED is connected to the Arduino digital pin via a 1K ohm resistor. It acts as a visual indicator of the power and connection status of the control unit. DC Power supply is from the HiLink HLK-PM01 5V AC/DC Regulator and connected to the main power via a 13A fuse, so the UVC light will be on as long as someone is detected in the shelter.

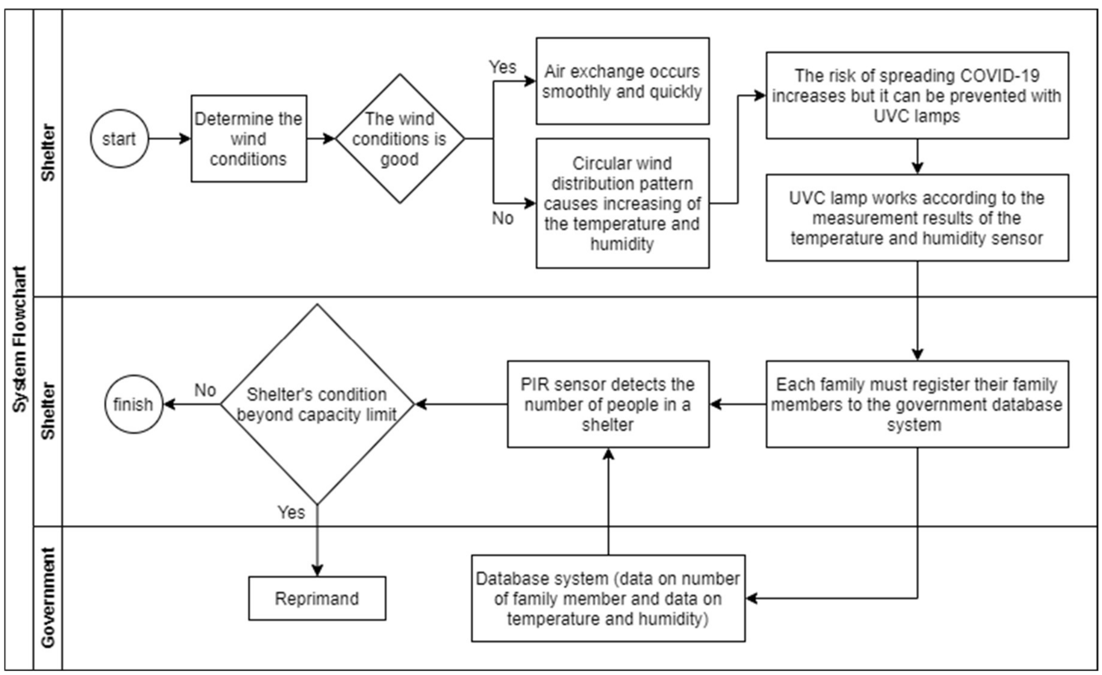


Figure 9. System flowchart.

A family who wants to occupy a shelter must first register the number of family members with the authorities (e.g., the government) to ensure unknown or unauthorized person enters the shelter. The PIR sensor will detect the presence or absence of additional people in the shelter. If the number of people previously registered in one shelter does not match the number of people at that time, then the competent authority (government) has the right to reprimand and give warnings. This system is also equipped with a WiFi module ESP8266. This module sends measurement data from sensor detection to a place far from where the sensor is installed. The authorities located far from the shelter location can monitor temperature, relative humidity, and the number of people inside the shelter in real-time. That way, the authorities can immediately act according to the problems that occur.

Conclusions and Suggestions

The conclusions of this study are:

1. Smart folding and floating shelter with natural ventilation and UVC system serves as a healthy shelter for victims of natural disasters and utilizes environmentally friendly materials such as light steel (relatively safe, effective, and efficient material) and cork walls (floatable material).
2. The width of the building openings that are determined are windows = 1 x 1 m, vents = 1 x 0.25 m, and door = 2 x 1 m. These openings' width produces an average wind speed distribution at each point above 0.5 m/s so that the air condition of the shelter has met the standards of health and thermal comfort.
3. The ultraviolet C (UVC) lighting systems circuit consists of a PIR sensor, a temperature & humidity sensor, and an ESP8266 WiFi module. The working principle of the design of these electronic components, namely the UVC lamp, is influenced by the temperature and humidity conditions of the shelter through the measurement of temperature and humidity sensors. Furthermore, the ESP8266 WiFi module allows the authorities (government) to monitor temperature & humidity and the number of people in one shelter through temperature & humidity sensors and PIR sensors.

The suggestions of this study are:

1. Studies in building physics, i.e., analyzing optimization of thermal, visual, and acoustic of the room to achieve residential comfort, can be more described.
2. Estimate the cost of designing smart folding and floating shelters.

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