Arduino Based Portable Indoor Air Conditioner with Cooling, Sterilisation and Humidifier for Air Quality and Room Comfort

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Abstract
In an indoor environment, air quality and comfort rely on purification, humidification, sterilisation, and cooling. This paper presents the development of an all-in-one portable air conditioner system that monitors and controls the temperature, and humidity as well as provides air filtration and sterilisation. An Arduino microcontroller functions as the main controller, which receives inputs from the temperature, humidity, and dust sensors. In response to the received input signals, the appropriate control instructions are sent to heating or cooling elements and humidity relay actuators. Filtration was provided by a passive HEPA filter and a UV lamp. Test results show that the dust level was reduced by 27% within a half-day timeframe. For cooling, the Peltier module could reduce the temperature of a small room by up to 50 C. With the water sprayer, the humidity was able to be increased from 35% to 57% in 240 minutes. Based on the findings, it can be concluded that the overall design is effective for a small room in a controlled environment. For a larger scale application, it is suggested that the capacity of the design to be increased proportionally.

Keywords: Indoor Air Quality, Peltier Module, Air Filter, Humidity Control, Arduino Microcontroller

1.0 Introduction
In non-industrial environments, indoor air quality is instrumental to comfort and health. Dampness-contributing bacteria contributes to adverse health effects known as "sick building syndrome" which includes eye and skin irritation, headache, and breathing difficulties [1]. On the other hand, thermal comfort and humidity are essential for human well-being. In [2], for hot weather acclimatised people, an indoor temperature of 26°C to 30°C and a humidity range of 50% to 70% is acceptable. However, for workplace performance, lower humidity and temperature are desirable. Humidity too low below 50% can lead to dry eyes, airway sensory irritation, and skin itchiness [3]. In a study reported in [4], cognitive and work performance is optimal at a temperature range of 22°C to 24°C and humidity of 40% to 60%.

In many countries including Malaysia [5], air-conditioning contributes to a significant proportion of energy usage [6]. The refrigerants used in air-conditioning systems also cause depletion in the ozone layer and give rise to the greenhouse effect. Peltier thermoelectric modules operate on different mechanisms compared to the established refrigeration system. In a thermoelectric module, the temperature difference is generated by absorbing the heat on one end of the thermoelectric junction and releasing it at the other end. Therefore, due to the absence of environmentally damaging gasses in its design, Peltier thermoelectric systems are desirable for zero-emission cooling designs [7]. However, it has been reported in [8] that when compared to conventional compressor-based air-conditioning, the thermoelectric systems are more costly and has a lower cooling efficiency in both performance and economic standpoints. In response to these shortcomings, other researchers have proposed and demonstrated that if an office room is not fully occupied, the Peltier thermoelectric air-conditioner as a personal cooling system can have a more economical operational cost over a conventional global air-conditioning system [9]. Other studies have proposed that the cooling efficiency of a thermoelectric Peltier system can be increased with the increase in temperature difference [10].

The indoor air quality of a building is largely attributed to the presence of gasses, smoke, mold, and dust [11]. The combined effect of these effects can produce symptoms and ailments including headache, dizziness, coughing, and development of bacterial infection. Generally, a high-efficiency particulate air (HEPA) filter can effectively remove most of the particle matter (PM) that causes pollution in an indoor environment [12]. In addition, HEPA filters can also control aerosol pollutants including COVID-19 propagation indoors. In [13], it was demonstrated that a homemade low-cost solution can deliver a filtration efficiency of up to 90%. HEPA filters were also effective in reducing the effect of second-hand smoke. Their findings that covered PM2.5 concentration as well as blood cadmium and hair nicotine levels of subjects were significantly lower in an indoor environment with a HEPA filter [14].

In recent years, many controllers, sensors, and the internet-of-things (IOT) facilities have provided low-cost options for the inventor and maker communities to experiment and research with new designs. The heart of any automated smart system lies in the controller. The Arduino [15] is a popular general-purpose development system usually based on the ATmega or ARM microcontrollers. It is a suitable controller for Peltier thermoelectric cooling and heating systems as demonstrated in [16], [17]. The Arduino was also used to control humidity in [18] and air purifier design [19].

In [17], an air-conditioning for a mini refrigerator was proposed. The Peltier was supplied with a 12 V, 6 A supply. Control was provided by the Arduino UNO with input from the DHT11 humidity and temperature sensor. The study reported that the initial temperature (36^{o}C) of the cold side of the Peltier module reduced to 24^{o}C before rising again to 36^{o}C. On the other hand, the hot side temperature of the Peltier increased from 36^{o}C to 59^{o}C. It was suggested that the rise in internal temperature could be circumvented with a larger heatsink. The Arduino was also employed in the design presented in [16] for temperature control. In their design, the Peltier air conditioning was able to regulate the temperature at a setpoint of 25^{o}C. The design incorporated water cooling to accelerate cooling via the heat exchange process.

The IOT is another recent technology which simplifies the collection and analysis of data. In [12], a HEPA filter was integrated with an IOT enabled Arduino to obtain reading humidity and temperature and gas presence. Various sensors were used in the design: MQ135 for CO_2, MQ7 for CO, PM2.5 sensor for particle matter detection, and DHT11 detection. For dust detection, in [19] a design that incorporates the Arduino Uno and GP2Y1010AU0F Optical Dust Sensor was used with accurate results.

Based on the findings of previous researchers, the aim of this work is to design a multi-purpose air perfection system with the following objectives: To control the temperature and humidity of a small room, to purify the air using the HEPA filter, and to sterilize any harmful microorganisms using UV light.

2.0 Methodology

From the previous discussion, the following design recommendations were observed: First, Peltier thermoelectric air-conditioning systems are suitable for personal cooling or enclosed cooling of small spaces. Next, Arduino and common maker-grade sensors for control, sensing, and actuation are reliable for long-term usage. Finally, water cooling can be used to accelerate the cooling process.

Figure 1 presents the system architecture of the study design. The system is controlled by two Arduino Uno. The first Uno receives input signals from the inputs and provides actuation signals to the power, fan, pump, humidifier, and UV lamp relays. The sensors used were the DHT11 temperature and humidity sensor, LM393 3.3V-5V moisture sensor to detect coolant leakage, and Sharp GPY P2Y1010AU0F dust sensor for PM2.5 particle detection. The second Arduino serves to control the TFT 2.4-inch LCD touchscreen. This arrangement was necessary because a single Uno could not support the electrical loading of an LCD screen.

Figure 2 shows the block diagram of the system which represents the electrical layout of the interface. The Peltier is water-cooled for maximum cooling compared to air-cooling [15]. Three Peltier modules with dimensions of 40 x 40 mm are integrated into the cooling system. It was powered by a 12 V 10 A DC power supply. When the 12 V power supply is received by the Peltier, the fan located at the hot side and cold side of the element heatsink will turn on at the same time as the water pump. With the Bluetooth module, the temperature setpoint can be set by the mobile phone app.

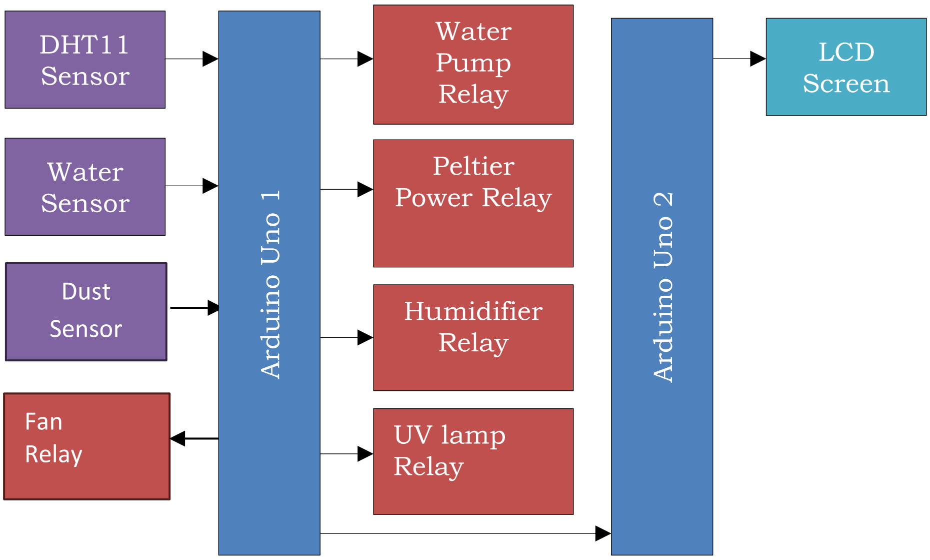

Figure 1: System architecture

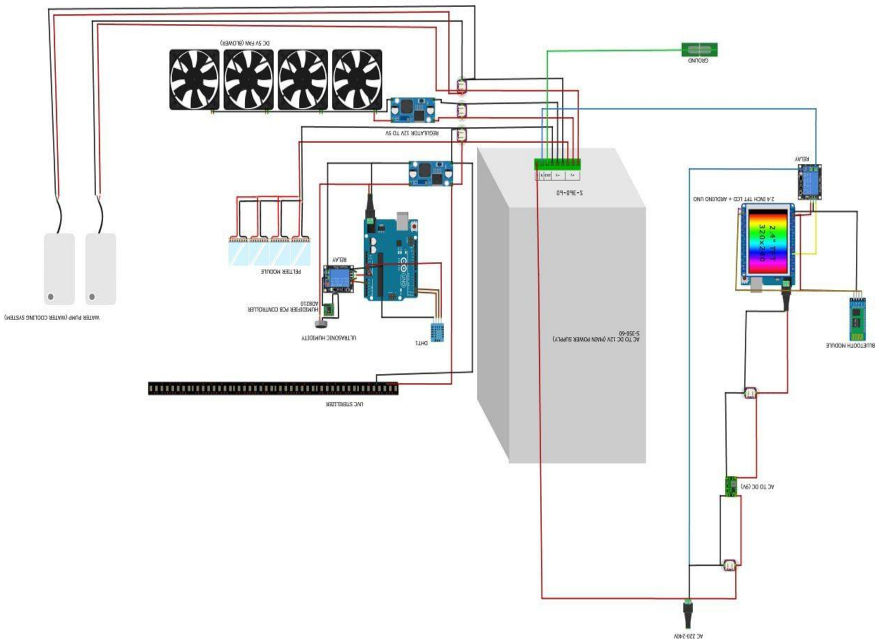

Figure 2: Block diagram of design

Table 1 shows the detail measurements of seven items involved in the proposed product design. The items consist of the lid size, the body size, the lower body size, the ventilation hole size, the air intake size, the airflow diameter size, and the room size.

Table 1: Detail measurements of the proposed product design

Item	Measurement
Lid size (L x W x H)	40cm x 40cm x 3.6 cm
Body size (L x W x H)	40cm x 40cm x 35cm
Lower body size (L x W x H)	30cm x 30cm x 5.3cm
Ventilation hole size (L x H)	0.8cm x 3.5cm
Air intake size (L x W x H)	12.7cm x 12.7cm x 22cm
Airflow diameter size	11cm
Room size	1m x 1 m x 1.5 m

3.0 Results and Discussion

This section presents the results and discussion of the proposed system. Several tests were carried out to validate the performance of the design, and to measure the four features which include the process of cooling, particle filtering, humidification, and ultraviolet (UV) sterilisation.

Figure 3 shows the constructed air conditioner design. The electrical components are enclosed in an acrylic casing. Apart from the main function of cooling, humidification is provided by water sprayer which is in another tank. Both the humidity and humidity can be controlled via the app and the LCD touchscreen. The UV LED lamp is fixed around the air outlet and can be turned on and off through the controller. The HEPA filter is attached to the cool air outlet and is always in use as it is a passive element attached to the outlet fan.

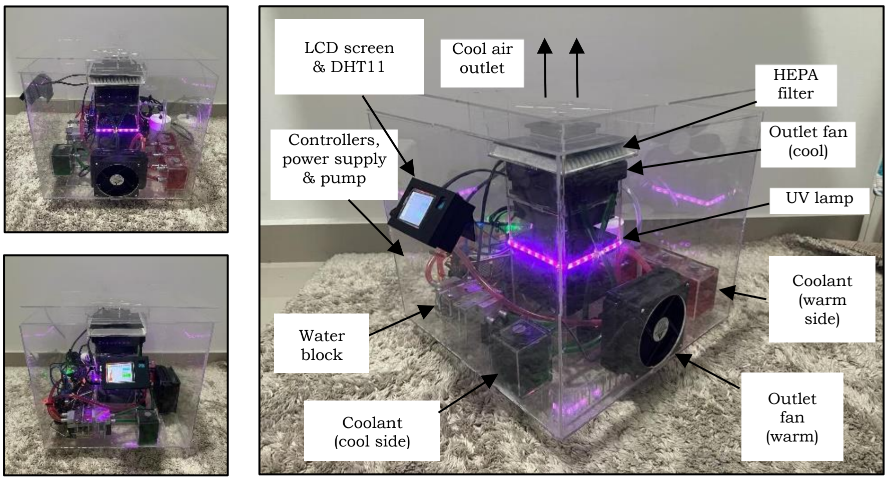

Figure 3: Constructed air conditioner design

3.1 Cooling performance

Table 2 shows the data measured for temperature level. Based on Table 2, the cooling performance is assessed based on an environment where the initial room temperature is 25°C. The reading was taken for 30 minutes, and the temperature reduction was measured. For the purpose of taking temperature, it used an infrared digital thermometer. After 30 minutes, the inside room temperature was reduced by 5°C.

Table 2: Data measured for temperature level

Time (minutes)	Initial temperature (°C)	Data temperature (°C)
5	25°C	24.3
10	25°C	23.8
15	25°C	23.2
20	25°C	22.4
25	25°C	21.2
30	25°C	20.0

3.2 Dust recording

Table 3 shows the measured dust level based on sensor voltage output. The dust sensing was provided by the Sharp GP2Y1010AU0F sensor at a sensitivity setting of 0.5V/100μg/m^3 [20], [21]. In air cleaning by the HEPA filter, it was estimated that reduced PM2.5 particle concentrations by 27% over a 12-hour period, with initials level of 763μg/m^3 decreasing to a final measurement of 450 μg/m^3.

Table 3: Measured dust level based on sensor voltage output

Time (hours)	Initial dust level (μg/m^3)	Final dust level (μg/m^3)
0	763	692
4	763	640
8	763	560
12	763	450

3.3 Humidity control

The DHT11 sensor also provides humidity readings. For this experiment, the humidity was set at 60%, when the humidity is less than the setpoint, the water spray relay will actuate for 3 seconds every 5 minutes. At this rate, the humidity of the room was raised to 57% after 240 minutes. Figure 4 shows the humidity measured over a 240-minute period. As shown in Figure 4, the room temperature is maintained at setpoint towards the end of the data collection.

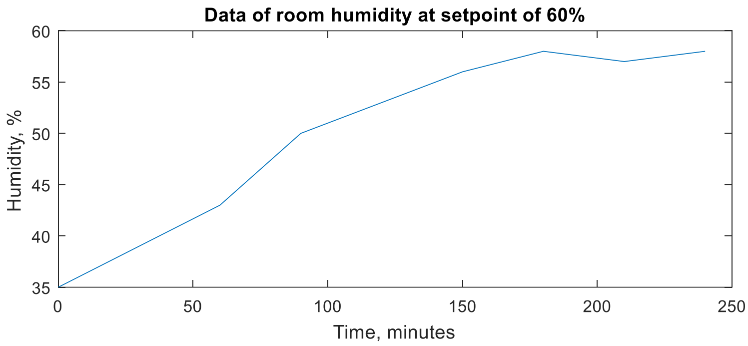

Figure 4: Humidity measured over a 240-minute period

3.4 Energy consumption comparison

In this section, the power consumption of the Peltier air-conditioning system is compared to a conventional 1 HP air-conditioner. Although it has been established that Peltier thermoelectric cooling systems are less efficient than conventional compressor air-conditioning systems, it will consume less power for personal cooling in a small place. Table 4 shows the energy consumption comparison between the proposed design and the conventional air-conditioner. As shown in Table 4, the power consumption is considerably less than a 1 HP conventional air-conditioner.

Table 4: Energy consumption comparison

Parameter	Proposed design	Conventional air-conditioner
Power usage	12V x 15A / 1000 = 0.18 kW	1 horsepower = 0.7457 kW
Time operates	8 hours	8 hours
Total energy	0.18 kW x 8 Hours =1.44 kWh	0.7457 kW x 8 Hours = 5.9656 kWh

4.0 Conclusion

In this research, a multi-purpose air conditioner that covers the needs of human well-being was proposed. From the data presented in the previous section, it is evident that the proposed design was capable of cooling a small room. The power consumption and cooling efficiency is consistent with [10], [22]. For a higher efficiency, we propose a better separation of the hot and cold air flow outlets. An insulated pipe could channel the hot air out, so it does not mix with the cool air.

The humidity control is a simple on-off operation that can be adjusted programmatically to different setpoints. The single sensor was attached to the outer case by the LCD panel. Therefore, it is not known if the humidity was constant for the whole room. For future work, we suggest data collection with more sensors. Likewise, the dust sensor was also placed at the casing, therefore dust further away from the device may not be sufficiently reduced. For UV sterilisation, the benchmark of the bread mold is a basic indicator of the effect of the UV lamp. However, more tests are needed for commercialization efforts. For future work, we also suggest user perception and satisfaction tests.

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Author Contributions

Zinvi Fu: Conceptualization, Initial study, Methodology, Analysis, Writing; **Nurhanum Omar:** Software Design, Data Collection, Validation, Supervision; **Noraishah Masrom:** Hardware Design, Editing, Writing;
Desmarita Leni: Writing-Reviewing, Technical Content, Proofreading.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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