

# Development of a Temperature-Controlled Solar Powered Ventilation System

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**Abstract.** Wind-driven ventilators like roof whirlybirds rely purely on wind and thermal expansion to operate. Consequently, they fail to function effectively in the absence of wind. Moreover, they only commence ventilating when heat accumulates in the roof space, indicating an underlying issue of the roof becoming excessively warm. Consequently, an alternative ventilation system that can effectively address the heat problem is essential. In this regard, a solar-powered ventilation system is reported as a viable solution. This developed system operates based on the temperature conditions of the ceiling, where the fan speeds up during hot weather and slows down or stops once a certain cool temperature is reached. This temperature-controlled characteristic distinguishes it from other solar-powered ventilation systems that operate at a constant speed. Through continued research and improvement, it is expected that this new temperature-controlled ventilation system has good potential to be commercialized.

## 1 Introduction

In recent years, the issue of global warming has emerged as a significant source of worry. It has a widespread impact on the overall temperature of the Earth, including indoor environments [1]. An essential aspect in maintaining a cool indoor atmosphere is roof ventilation. Roof ventilation is a vital component of any well-designed structure. It plays a crucial role in maintaining a comfortable and healthy indoor environment. By allowing the exchange of air between the inside and outside of a building, roof ventilation helps regulate temperature, remove excess moisture, and eliminate pollutants [2]. It works by harnessing natural forces such as wind and thermal buoyancy to facilitate the movement of air. Roof vents, strategically placed on the roof, provide an outlet for hot air to escape, preventing the build-up of heat and reducing the strain on cooling systems. Simultaneously, they allow fresh air to enter, promoting proper air circulation and improving indoor air quality. Effective roof ventilation not only enhances energy efficiency but also contributes to the overall durability and longevity of the structure [3].

Furthermore, proper airflow provided by roof vents also aids in reducing the potential for dam formation during raining season conditions. Additionally, roof ventilation can contribute

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to energy savings by reducing the reliance on artificial cooling systems, thereby lowering electricity consumption and utility costs. Overall, a well-designed and properly implemented roof ventilation system is essential for maintaining a comfortable, healthy, and energy-efficient living or working environment.

Ventilation systems function by withdrawing hot air from the attic of the building and bringing the outside air into it. Another objective of ventilation in buildings is to ensure the provision of healthy air for breathing by both diluting pollutants that originate within the building and effectively removing them [4]. The primary function of roof ventilation is to keep the air in a building moving especially at those higher spaces [5]. There are different methods for achieving this effect, but the fundamental principle of all forms of roof ventilation is to keep air circulating. Roof ventilation works to bring this increased temperature down to the level of the ambient temperature outside.

Roof vents, particularly the roof whirlybird, are extensively utilized in Asian countries such as Malaysia. Whirlybirds, or turbine vents are wind-powered ventilation systems used to cool down properties in warmer climates. These devices effectively regulate high temperatures during hot weather and eliminate excess moisture and dampness throughout raining season. Installing whirlybirds is an affordable method to enhance energy efficiency and ventilation within your home. With regular maintenance, these turbines can operate for more than 20 years, promoting airflow and ensuring a cool and comfortable living environment [6]. However, the current design tends to be large and cumbersome. The problem is come up with a design that the open vent can catch debris, dust leaves and other foreign objects. Then, during heavy rains, a little drizzle may also enter the structure through the holes. Besides, the design is bulky and not suitable for modern shape houses, the ventilation system also mostly relied on a wind movement to spin. So, when there is no wind the roof vent cannot function efficiently.

Therefore, this paper reports a better solution for the ventilation system design and performance. The ventilation system looks better and suit modern houses roof. It is powered by solar as an alternative energy to spin the fan. Solar power offers an efficient solution for lowering energy costs while utilizing clean and renewable energy sources. It can be categorized into two types: on-grid and off-grid systems. In this research, our focus primarily lies on the off-grid or stand-alone power system. This system entails the production of solar energy, which is then stored in batteries for later use [7]. The paper also includes findings regarding the charging duration of the batteries and the corresponding usage time based on the speed of the fan.

## **2 Objectives**

There are many drawbacks for the current roof whirlybird as stated by an article [6]. According to the article, problems such as the system cannot work under no wind condition and an inefficient design is the most concern and motivate us to develop and alternative ventilation system. The purpose of this project is to develop a ventilation system that can work in any weather condition which is not depending on the wind. By using this solar powered ventilation system, the ventilation system can operate at any time since it is powered by a battery that is charged by the solar energy.

Secondly, the objective of this project is to create a roof ventilation system that effectively prevents the entry of water or rain splashing into the building. The design incorporates a 45° angled awning and strategically placed holes to facilitate the flow of hot air. Additionally, a flat and modern look ventilation system design is introduced. The ultimate goal is to develop a ventilation system that can automatically adjust its fan speed based on the temperature conditions. The implementation of a temperature-controlled system is crucial for reducing energy consumption of the ventilation system, thereby eliminating the need for

a larger battery in the project. Lastly, the objective of this project to analyze the power consumption of the ventilation system's fan according to its speed. Additionally, the project aims to examine the charging time of the battery utilized by the ventilation system.

### **3 Literature review**

Ventilation is the mechanical system in a building that removes contaminated and hot air and brings in the fresh outdoor air [8]. A good ventilation system is a need in order to supply good quality air and clear out smoke, cooking, and indoor pollutants. Besides, a ventilation system is also important to maintain temperature and humidity at comfortable levels. There are three basic elements for building ventilation which is ventilation rate, air flow direction and air distribution and airflow pattern.

There are many main types of ventilation systems which are natural ventilation, task ventilation, mechanical ventilation, hybrid ventilation and spot ventilation [9]. Each one of them have their own advantages and disadvantages but all of them serve the same purpose which is to circulate air by pulling the hot air out from a building [10].

Mechanical ventilation is a ventilation that requires air flow at a constant rate in order to spin, helping remove overheated air and moisture from the attic and roof system and reduce the impact of changing temperatures and moisture conditions inside the home [11]. An example of mechanical ventilation device is a roof ventilator.

Natural ventilation is the use of wind and temperature differences to create airflows in and through the buildings. Natural ventilation effects are divided into two categories which are buoyancy and wind [12]. Temperature induced or stack ventilation are other terms for buoyancy ventilation. Wind ventilation draws air from a positive pressure source and exhausts it to a negative pressure on the building's leeward side through openings on the windward side. The rate of airflow is determined by wind speed and direction, as well as the size of the holes.

Personal ventilation and task ventilation are innovative approaches to empowering occupants with the ability to regulate their immediate airflow, thereby customizing their individual thermal comfort [13]. These advanced systems furnish conditioned air directly to the designated space, and in some cases, the entire room. Given their capacity to deliver supply air precisely to the breathing zone, task-specific or personalized ventilation systems provide a significant ventilation experienced within an occupant's breathing space.

Hybrid ventilation is a combination of natural and mechanical ventilation [14]. It seeks to optimize indoor air quality and thermal comfort by harnessing the advantages of both methods. It may incorporate sensors, controls, and automated systems to adjust ventilation strategies based on factors such as outdoor weather conditions, indoor air quality, and occupant preferences. By utilizing natural ventilation when conditions are favourable (e.g., during mild weather) and seamlessly transitioning to mechanical ventilation when needed (e.g., during extreme temperatures or high pollutant levels), hybrid ventilation optimizes energy efficiency and indoor environmental quality.

Spot ventilation is indeed another type of ventilation that complements both mechanical and natural ventilation systems. It serves as a supportive system to enhance overall ventilation effectiveness [15]. To put it simply, spot ventilation refers to the localized use of exhaust fans, typically installed in specific areas such as bathrooms and kitchens. The primary purpose of spot ventilation is to target and remove moisture, odors, and indoor air pollutants at their source. By installing exhaust fans in areas where these pollutants are generated, spot ventilation prevents them from spreading throughout the entire building. Instead, it expels them directly to the outdoors, effectively improving indoor air quality.

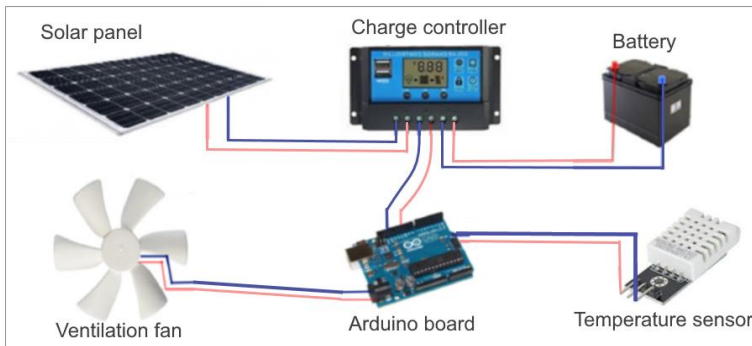
## 4 Methodology

In this section, the detail of the ventilation system setup is displayed and its working principle is briefly described. The list of components and their specification including their specific function are also reported.

### 4.1 System setup

In this project, an integrated system which consists of a solar panel, charge controller, temperature sensor, motor, battery, fan blade top, control unit and a display unit. An Arduino board is used as a control unit for fan speed where the input signal comes from the temperature sensor. The temperature from a ceiling is acquired by a sensor device where the value is used to determine the speed of the ventilation fan. The temperature reading can be viewed using an LCD panel and it can display the fan speed as well.

The output of the Arduino board is connected to the fan of the ventilation system. The solar panel is connected to a charge controller and it is used to recharge the battery. The charge controller is used as a distributor and to ensure the battery is not damaged if it is fully charged. The detail of parts connection for the ventilation system setup is shown in pictorial diagram in Figure 1. The scope of the project is limited to a unit of temperature-controlled ventilation system which is suitable to withdraw heat from a ceiling from a room sized of around 100 ft<sup>2</sup>.



**Fig. 1.** Pictorial diagram of the ventilation system.

### 4.2 List of components

#### 4.2.1 Solar panel

This solar panel is made up from monocrystalline solar cells which is the best material for solar cells. The solar panel of 10W is used in this project due to its size preference which is 28 cm x 28 cm. The bigger the size of the panel, the higher the wattage. In addition, the safe operating temperature is between -40°C to 85°C which is quite good for solar panel to operate longer. This solar panel can be used with a 10A-50A controller.

#### 4.2.2 Lead-acid rechargeable battery

The battery used in this project is a sealed lead-acid rechargeable battery. The nominal voltage of the battery is 12 V. The battery is compatible with the controller since the charger controller is also has 12 V. The nominal capacity is 7.2 Ah. In theory, the charging time by the solar panel can be calculated by employing the following formulas [16];

$$\text{Charging Time (hours)} = \text{Battery Capacity (Ah)} / \text{Solar Panel Power (A)} \text{-----(1)}$$

$$\text{Solar Panel Power (A)} = \text{Solar Panel Wattage (W)} / \text{Battery Voltage (V)} \text{-----(2)}$$

#### 4.2.3 Charge controller

A solar charge controller, also known as a solar regulator, is a device used in solar power systems to manage the flow of electricity between solar panels and batteries. It acts as an intermediary between the solar panels, which generate electricity from sunlight, and the batteries, which store the generated power for later use. The type of charge controller used in the project is PWM (Pulse Width Modulation) controller. Compared to MPPT (Maximum Power Point Tracking) controller, this one is way cheaper, and suitable to use in this project. The charge output is 40 A and it contains two outputs with different voltages. One is for 5 V while the other one is for 2.5 V. This charger controller comes in size (13.3 x 7 x 3.5) cm. The floating charge is 13 V. The working temperature is from -35 up until 60 °C.

#### 4.2.4 Fan motor and blade

In this project, a recycled car radiator fan motor and blade have been employed to operate the ventilation system. To accommodate the available space, the blade was modified by reducing its overall spinning diameter to 24 cm. The motor, powered by a battery, is responsible for initiating the fan's rotation, enabling the removal of hot air from the attic. The 12 V DC motor offers the flexibility to adjust the fan speed according to specific requirements. The energy usage of the motor determines how long its operation and can be referred from the equation as stated in this paper [17].

#### 4.2.5 Arduino and motor driver

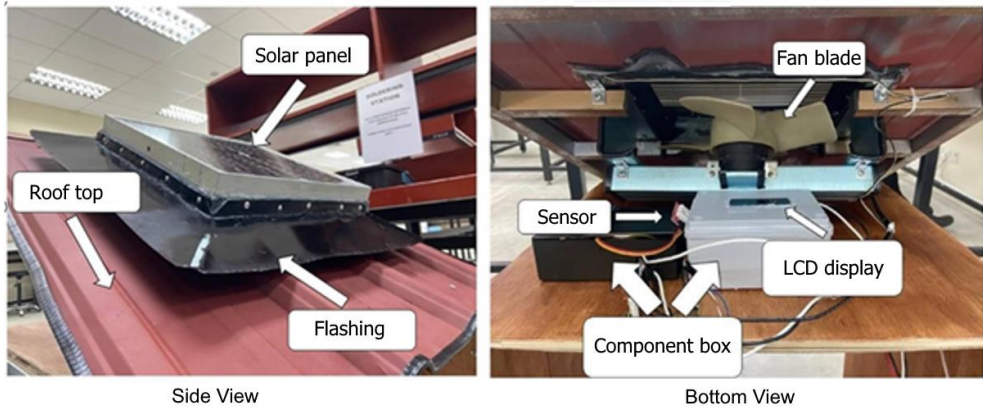
In this setup, both the Arduino board and motor driver components are powered by a battery. The Arduino UNO which is more convenient as compared to ATmega1280 used in previous project [18] was selected. It can be easily programmed using the Arduino Software (IDE), which offers a user-friendly interface for writing and uploading code. The Arduino UNO board is equipped with a boot loader, which facilitates the uploading of new code without the need for additional hardware, streamlining the programming process. A motor driver, L298N employed in this project offers simplicity in operation and the ability to modulate the PWM wave generated by the control panel. This motor driver serves the dual purpose of regulating the speed of the DC motor as well as controlling it. Furthermore, the L298N model incorporates a built-in over-current protection mechanism, ensuring the safety of both the circuit and the motor in case of motor lock. The fan's speed is precisely managed through a motor driver and a PWM interface program.

#### 4.2.6 Temperature sensor

In this project, the DHT22 Temperature and Humidity sensor is utilized for detecting temperature in order to control the operation of the ventilation fan. The DHT22 sensor is a digital sensor that offers an affordable solution for temperature and humidity measurements. It incorporates both a capacitive humidity sensor and a thermistor to accurately measure the air and provides a digital signal output on the data pin, eliminating the need for analog input pins. The DHT22 sensor is well-suited for this project due to its simplicity and cost-effectiveness.

### 4.3 Components assembly

After all the components has been identified and selected, the ventilation system needs to be assembled. For the design of the ventilation system, the fan is located behind the solar panel as shown in Figure 2 (bottom view). The space created so that hot air can flow out from the attic. The design of the metal frame at attic is being tilted  $20^\circ$ . This is to ensure the solar panel can expose directly  $90^\circ$  with the sun light to get maximum irradiation during peak hours. At the edge of the zinc roof is attached with rubber edge protection to ensure the safety near this project prototype.

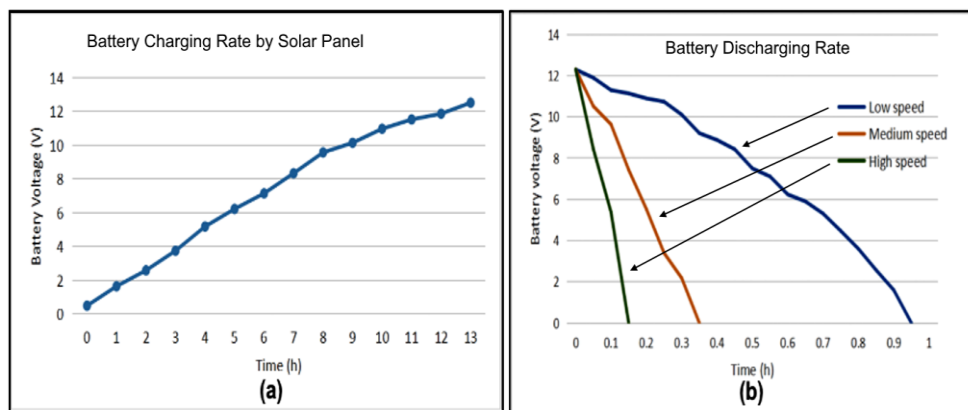


**Fig. 2.** Final product of the ventilation system.

## 5 Result

In this section, the charging characteristic and the performance of the ventilation project is reported. In theory, the charging time for a 12V battery with a capacity of 7.2 Ah using a 10W solar panel can be calculated to be 8.64 hours. However, in this project, it took approximately 13 hours to fully charge the battery as shown in Figure 3 (a). This longer charging time could be influenced by various factors, such as resistance in the system, temperature effects, and the sun irradiance angle. Higher temperatures, for example, can lead to cathode electrolyte oxidation and reduce the battery's capacity [19]. It's important to consider these real-world factors that can impact the actual charging time of a solar-powered system, as theoretical calculations assume ideal conditions.

In the second part of this project, the performance of the ventilation system is being tested. The fan speed is programmed based on three temperature levels, which are  $< 26^\circ\text{C}$ ,  $26^\circ\text{C} - 32^\circ\text{C}$  and  $> 32^\circ\text{C}$ . This represent low (150–250 rpm), medium (500-700 rpm) and high speed (1100-1400 rpm) rotation respectively.



**Fig. 3.** (a) Charging and (b) Discharging rate of the battery.

In this project's context, the fan control system activates when the temperature within the house is classified as low, medium, or high, respectively. The time taken for the battery drain is also recorded and plotted on a graph as shown in Figure 3 (b). The results reveal that the battery's lifespan is relatively short, lasting less than an hour, and only last around 10 minutes when operating in high-speed mode. This limited usage time is not suitable for real-world applications that require continuous operation for more than 6 hours. However, the primary objective of developing a temperature-controlled ventilation system has been achieved. The system effectively operates when the ambient temperature is manipulated using a hot air blower directed towards the temperature sensor.

## 6 Conclusion

In conclusion, all the objectives of this project have been successfully accomplished. The temperature-controlled ventilation system was designed and developed using cost-effective components. The first objective aimed to design a ventilation system that prevents the entry of water or rain splashing into the building was achieved. Additionally, the system effectively controls the fan speed based on the ambient temperature, and this was also achieved. On the last objective to analyze the power consumption of the ventilation system's fan according to its speed, it shows that the ventilation system can only last for around 10 minutes. This finding highlights the necessity for a larger battery capacity in order to support the ventilation system for practical applications. Overall, this project has fully met its goals of creating a modern flat ventilation system that can operate at different speeds based on the ambient temperature. It is hoped that this ventilation system can be commercialized and prove useful to humans, simultaneously reducing energy consumption and creating a pleasing ambient indoor air quality.

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