DESIGN AND FABRICATION OF A SOLAR POWERED ROOF EXHAUST FAN

U., Nirmal[1], W.T., Chan[2], S.T.W., Lau[3] and P., Maratha[4]

[1, 2, 3, 4]Center of Advanced Materials and Green Technologies
Faculty of Engineering and Technology,
Multimedia University, Jalan Ayer Keroh Lama, 75450,
Melaka, Malaysia.

Email: [*1]nirmal@mmu.edu.my

ABSTRACT: In modern societies, every building should have a heating, ventilation and air conditioning (HVAC) system that provides sufficient comfort. However, the affordability and ease of installation of these systems vary widely. This research intends to design a solar powered roof exhaust fan with a simple installation design. The design has a structure such that parts are oriented around the axis of the fan. Two types of fans were tested: a centrifugal fan and an axial fan. In these experiments, parameters such as ambient, room and attic temperature were measured. The results showed that the centrifugal fan is more effective than the axial fan.

KEYWORDS:Centrifugal Fan, Axial Fan, Exhaust Fan, Ventilation, Indoor Temperature

1.0 INTRODUCTION

When they are not outdoors, people spend their time in the interior of buildings. Therefore, the quality of indoors air is important. However, indoors air is not guaranteed to be clean. It can have pollution levels which are 2 to 5 times greater than outdoors pollution [1]. One of the examples of indoors pollution is sick building syndrome (SBS), which is caused by inadequate ventilation [2]. Windows alone may not be able to provide adequate ventilation for the interior of a building [3]. Where this occurs, mechanical ventilation is needed in order to improve the ventilation of the building, as well as expel vapours such as moisture from bathrooms and remove pollutants such as fumes from cooking in the kitchen [4]. Ventilation is defined as the natural or mechanical process of delivering conditioned or unconditioned air to a place, or eliminating such air from this place [5]. Ventilation can be classified into three categories which are natural ventilation, spot ventilation and whole-house ventilation [6]. Among these, natural ventilation offers energy savings because it utilizes natural driving forces, such as temperature differences and wind [7]. These driving forces induce the movement of air through small holes, cracks, windows and doors [8]. The interaction between these two forces also depend on the placement of openings in the building, as well as other factors such as wind direction [9].

Spot and whole-house ventilation are also known as forced ventilation because they utilize machines to vent air. Spot ventilation controls air movement through the use of localized exhaust fans, generally with the aim of removing pollutants and moisture from small areas [10]. In contrast, whole-house ventilation works at a large scale by providing fresh air to the whole interior while expelling stale air. Whole-house ventilation is further classified as exhaust ventilation if it forces interior air out of the building, as supply ventilation if it forces exterior air into the building, or as balanced ventilation if it exchanges equal amounts of air into and out of the buildings [11]. In ventilation systems, exhaust fans are used to vent out air, along with odours, particles, smoke, moisture and other contaminants which may be present in the air. Commercial exhaust fans can be powered by solar, wind and thermal forces, as well as electricity [12]. The roof turbine fan, also known as the roof turbine vent, is a type of fan which utilizes changes in temperature and/or wind pressure between the interior and exterior of the building in order to force air through the opening of a vent [13]. Roof turbine fans are generally installed on the top of a house, namely its roof [14].

Hence, the current work is to design and fabricate a solar powered roof exhaust fan for home applications. The main scope here is to keep the roof exhaust fan as small as possible where it will be less noticeable when installed on the roof of a house as compared the conventional 'bulky' roof turbine exhaust fan. There are two variants of fans considered for the design: the centrifugal impeller fan (henceforth referred to as the "centrifugal fan" for convenience) and the axial impeller fan (henceforth referred to as the "axial fan", also for the same reason). Ostensibly, the centrifugal fan can produce more pressure for a given volume of air compared to an axial fan. The centrifugal fan can also blow air at right angles to the air intake direction, as well as spin the air outwards from the outlet. In contrast, the axial fan discharges air at a direction which is parallel to the axis of the impeller, and is presumably suitable to be used in conditions of high volume but low pressure [1]. In addition to the aforementioned objective of making a small fan for home application, this work also intends to determine which fan design is more suitable for this application.

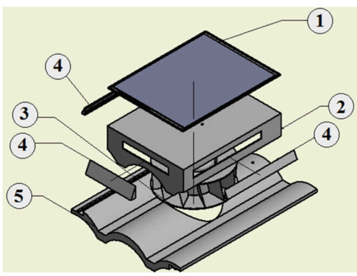
2.0 METHODOLOGY

2.1 Structure Design Criteria

A solar powered roof exhaust fan is to be designed. This fan is to regulate the temperatures of the insides of a house through ventilation. The criteria for the structural design of the fan are as follows:

a) The installation has to be simple, i.e. only requiring the replacement of a tile.
b) The complexity of the design has to be simple in order to make maintenance and repair work more convenient.

Consequently, the roof fan has to be built into a roof tile, which can then be placed onto the roof like any other tile. The fan will have mountings centred on its axis such that its parts can be serviced by removing them along the axis of the fan. The final structural design of the fan and its supporting parts is shown in Figure 1. Autodesk Inventor has been used to generate the exploded view of the structural design.



Labels:

1. Solar panel housing
2. Fan body casing
3. Impeller fan
4. Cover for housing slots
5. Modified ceramic roof tile

Note: The fan displayed here is the centrifugal fan, but it is just a placeholder. For the experiments, it can be swapped with an axial fan.

Figure 1: Explode view of fan design structure

2.2 Experimental Setup

Figure 2 shows the experimental setup. The experiments were performed using a model plywood house with the following dimensions: 1.1m × 1.1m × 0.8m of interior space, which will henceforth be referred to as the “model interior”, and ½ (1.1m ×0.3m) of attic space, which will henceforth be referred to as the “model attic”. The size of the model house will be used for the estimation of the number of fans that are needed to ventilate an actual house.

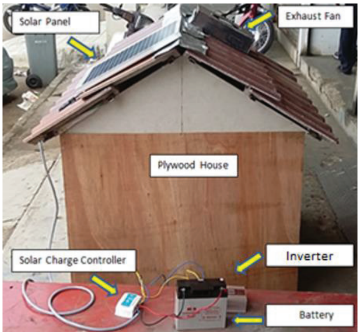
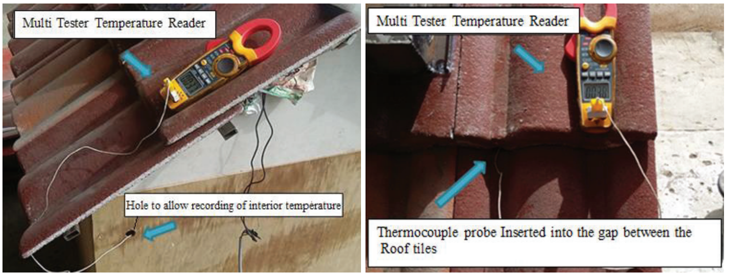


Figure 2: Experiment setup

The interior temperature of the model house is raised with the help of an air heater. After that, the fan is turned on in order to observe its effect on the interior temperatures of the house. This observation is carried out by measuring the temperatures of the air within the spaces as described earlier. There are also control runs where the temperatures are measured without the fan in use, so that the effect of the fan is more observable. The temperature of the interior of the model plywood house was measured using a CEM multi tester model DMM DT 3343 1000A AC DC clamp – table meter device. The device is henceforth referred to as the "Multi-Tester", for convenience. A 100 watt polycrystalline solar panel with a 3A solar charge controller was used to produce electricity, which was regulated with an 18 Ah, 12 V sealed lead acid battery and a smart inverter with ratings of 12 VDC to 230 VAC and 500 watt.

2.3 Temperature Measurement

Figure 3 shows how the temperature readings of the model room environment and model attic environment were taken, respectively. The model interior temperature was measured by inserting a thermocouple probe from the Multi-Tester into a small hole in the upper part of the plywood house. The model attic temperature was measured by inserting another thermocouple probe between the gaps of the roof tiles. In the experiments, the interior temperature of the model would be raised to significant levels before the heater is turned off. The fan which is being tested would be used to ventilate the interior. This is done for each fan type. The temperature changes would be recorded in intervals of one minute for a total of 30 minutes.



(a) (b)

Figure 3: Measuring model temperature (a) interior, (b) attic

2.4 Power Requirement

To satisfy the power requirement of both fan types, calculations were performed to determine the nominal power output rating of the solar panel that is to be used [15]. To determine the actual power used by the fan, Pactual, the equation (1) is used.

$$P_{actual} = P_{fan} / \mathcal{E}_{inverter} \tag{1}$$

Where,

P_{fan} is the nominal power consumed by a fan

$\mathcal{E}_{inverter}$ is the efficiency of the inverter, which is nominally 85%.

The equation for the nominal solar power that is needed for the fan, P_{solar}, is as in equation (2).

$$P_{solar} = P_{actual} \times T_{factor} \tag{2}$$

Where,

T_{factor} is the factor of account for loss. A factor of 1.4 has been used.

The results of the calculations of the variables for both fan types are shown in Table 1. It is notable that the nominal solar power that is needed for either fan design is under the nominal power rating of the solar panel, which is 100 watt as mentioned earlier in section 2.2.

Table 1: Minimum power requirement for the solar power system

	Minimum requirement	
	Centrifugal fan	Axial fan
Nominal fan power	58 W	32 W
Actual power used	68.3 W	37.7 W
Nominal solar power needed	95.6 W	52.78 W

2.5 Testing the Model House

Before the experiments are conducted, the model house was tested to check whether it can simulate a residential house. The criteria for the simulation are as follows:

a) The ambient temperature may change over time due to external factors, e.g. wind, but the interior and attic temperatures are expected to be more stable than ambient temperature due to the insulation provided by the plywood. This is consistent with the expectations for insulation in real residential buildings.
b) The attic temperature is expected to be higher than the interior temperature, as a consequence of trapping heat from sunlight.

To test for these criteria, the interior and attic temperatures of the model house were measured over several minutes under a sun-lit and open area. The fan is not turned on during this test. This test conducted at 12 pm on 19 December 2014 at Taman Merdeka, Melaka. Figure 4 shows that the interior temperature lags behind the ambient temperature in its response to changing temperature conditions. Meanwhile, the attic temperature remains the highest of the three, thus suggesting that the attic of the model house does trap heat.

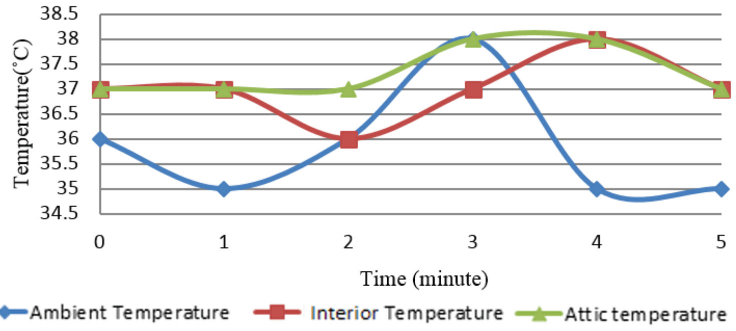


Figure 4: House temperature vs. time after exposure to sunlight, without fan

Next, the response of the model house to any ventilation would be tested. This test immediately occurs after the previous one. For this purpose, the fan would be used to provide the ventilation. In the case of the following results, the centrifugal fan was used. (Note that which type was used is not a concern; there has to be a reminder that the model house is to be tested to check whether it responds to ventilation).

Figure 5 shows that after 3 minutes, the attic and interior temperatures approached the ambient temperature. More importantly, they remained stable. This is to be expected from adequate ventilation, so the model house and the set-up of the experiment should suffice as satisfactory conditions.

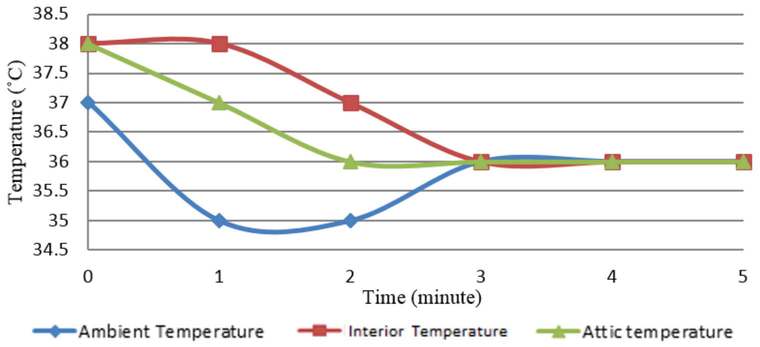


Figure 5: House temperature vs. time after exposure to sunlight, with fan

2.6 Stability of Temperature without External Factors

Before the experiments, the ambient, model interior and model attic temperatures were measured for a period of 10 minutes, without the use of any fans and without exposure to any heat source. This is to check for any unexpected fluctuations of temperatures. The results are shown in Table 2. Since the fluctuations are within 1 °C, there are no abnormalities within the model house.

Table2: Ambient, interior and attic temperature – before experiments

Test area	Time (minute)						Average Temperature
Temperature (˚C)	0	2	4	6	8	10	(˚C)
Ambient	34	34	35	35	34	35	34.4
Model Interior	35	36	35	36	35	36	35.6
Model Attic	37	38	37	37	37	38	37.4

3.0 RESULTS AND DISCUSSION

Figure 6 shows the results of the experiment which used the centrifugal fan type, whereas Figure 7 shows the results for the one with the axial fan. Both results show that the interior temperature of the plywood house model started out higher than the ambient temperature, and eventually cooled to the level of the latter, which is expected. For both fan types, the interior temperature drops faster with the use of either fan than without its use. The main difference between the fans is the rate of the temperature drop when either is in use.

The room temperature was raised to 65 ˚C for the experiment with the centrifugal fan and 60 ˚C for the one with the axial fan design. In the experiment with the centrifugal fan, the interior temperature drops to the ambient temperature in less than 10 minutes. In the experiment with the axial fan, the temperature drops to the ambient temperature between 10 and 15 minutes. The centrifugal fan reached the expected outcome (i.e. the interior temperature dropping to the level of the ambient temperature) in a shorter time, despite having a higher starting temperature for the interior.

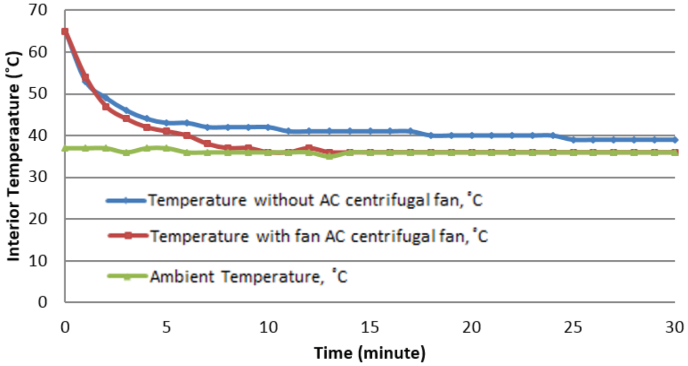


Figure 6: Interior temperature vs. time for AC backward curved centrifugal fan

Figure 6 and Figure 7 show that the interior temperature eventually reaches the ambient temperature and becomes stable. This means that both fan types succeed at one of the purposes of ventilation, which is to regulate the temperature of the interior of a building against its exterior surroundings

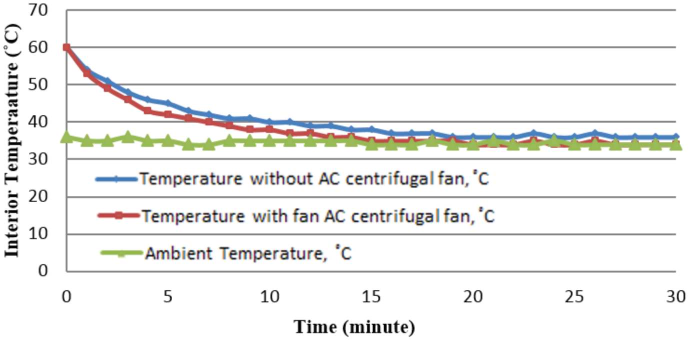


Figure 7: Interior temperature vs. time for AC cooling blower axial fan

The centrifugal fan design that is used in this experiment has a speed of 2500 RPM, compared to that of the axial fan design, which is 2800 RPM. Despite the difference in speed, this experiment has shown that the centrifugal fan design has the interior temperature approaching equilibrium faster than the axial fan design, and also despite the difference in starting temperatures. Therefore, there is the inference that the centrifugal fan design works more effectively than the axial fan design, though this came at a cost of higher power requirement, as noted in section 2.4.

By extrapolating from the size of the model house as described in section 2.2, it can be estimated that 11 units of exhaust fans are needed for a 15 m × 15 m × 7 m house in order to provide ventilation. This would mean introducing a considerable number of openings in a house, which can in turn lead to problems which are associated with such openings. However, the benefits may outweigh costs, though this is a topic for other research work. Observations during this work also determined that the warm air which is trapped in the attic of a house can be ventilated such that it achieves equilibrium temperature with the rest of the house.

4.0 CONCLUSION

The fan designs which are conceived in this work are successful at providing ventilation. In particular, the centrifugal fan is found to be able to achieve equilibrium temperatures faster than the axial fan. Furthermore, by installing ventilation on the roof of a house, the temperatures of sections of the house, which include the attic, can be regulated such that they reach a common equilibrium. These benefits can be achieved with modular fan designs which make for easy installation and maintenance.

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