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ORIGINAL ARTICLE

Experimental Study on the Performance of Small Solar Updraft Tower in the Climate Region

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ABSTRACT – Solar updraft tower (SUT) power plant is a unique system using solar energy, which consists of three main parts: the chimney, turbine, and collector. In tropical climate conditions, especially in Malaysia, the application of solar chimney can be deemed more competitive compared to other renewable energy systems. In this study, one prototype with a dimension of 3.5 m in diameter for the collector and 5 m height for the chimney, was built in Melaka, Malaysia. Vital parameters such as temperature field, pressure, humidity, and air movement were measured using data logger and stored using non-volatile memory. The most exciting finding was that the temperature and pressure difference was significantly seen during the experiment along the day. There was a significant surge for the humidity in the morning with an average of above 95% and the ambient temperature was approximately 35 °C due to low solar radiation. The humidity kept decreasing after sunrise due to the greenhouse effect produced in the solar collector. With the collection of these critical parameters, a solar chimney power plant was adequate to function and generate power from solar radiation in a country such as Malaysia, which is based in the equatorial region. These studies are limited as the analysis focused mainly for high radiation and did not investigate efficiency during low solar radiation. The addition of heat storage underneath the collector with current techniques is another direction of research for continuous system operation, particularly during low solar radiation. It is proposed that the synthesis of these factors should be extensively explored in future studies coupled with the application of heat storage.

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INTRODUCTION

One of the most significant current discussions is the increasing concern that nonrenewable energy, such as oil or coal, is damaging our environment. At the same time, exposure to radiation from nuclear power stations is related to adverse effects [1]. Recent developments in renewable energy sources have intensified the need for sustainable growth in the global economy. Renewable energy is produced from natural and persistent flows of energy occurring in the immediate environment instead of nonrenewable sources, which are nearly depleted. Apparent examples of renewable energy are solar energy, wind energy, biomass energy, and water which repetitively refer to the 24-hour significant period. Throughout the last century, there was a dramatic increase in interest in the electricity generation potential of solar energy. Solar energy is clean and one of the renewable energy resources available around the world. The solar updraft tower (SUT) is a special solar-powered structure composed of three main components: a chimney, a turbine generator and a collector. The operating theory of SUT begins by receiving exposure from solar radiation in order to increase the temperature of the ambient air under a low, transparent circular or translucent collector due to the greenhouse effect. The height between the collector and the ground below will slightly increase to allow the hot air to go up and narrow to the centre of the collector as hot air is lighter than cold air. Kinetic energy is produced due to the different air temperatures inside the collector and chimney, and it is used to move the turbine to generate electricity by using a small power converter unit (PCU). The concept of the solar chimney power plant is clearly shown in Figure 1. The discovery of the first pilot SUT in Manzanares, Spain in 1982 triggered a huge amount of innovative scientific inquiry after the first concept of the solar chimney was proposed by Hanns Gunther in 1931 [2]. This prototype was successfully set up by Schlaich together with his colleagues and operated for seven years from 1983 to 1989 to demonstrate the feasibility and reliability of the SUT technology for power generation using renewable energy. With no-load condition, the plant produced approximately 15 m/s and 41 kW for the upwind velocity and maximum power output, respectively, from July to September in 1982 [3]. The first attempt to analyse the performance of the Manzanares pilot results was brought out by Haaf et al. [4].

In 1983, a 10 W power solar chimney plant with a chimney height of 10 m and a diameter of 6 m for the collector was built by Krisst [5]. Several years later, a small scale model of the solar chimney was set up by Kulunk [6] with a 9 m^2 collector area while the chimney was 7 cm in diameter and 2 m in height. To determine the effect of the solar chimney system, Pasurmarthi and Sherif [7] analysed a temperature field by extending the collector and making an intermediate absorber to enhance the power output with their solar chimney power plant. The effect of the chimney's characteristics on its thermodynamic features including total height, different area, additional losses, wall friction, and internal drag was investigated by Gannon von and Backstro¨m in 2000 using a one-dimensional compressible flow approach [8]. They also investigated the solar chimney's turbine performance three years later [9].

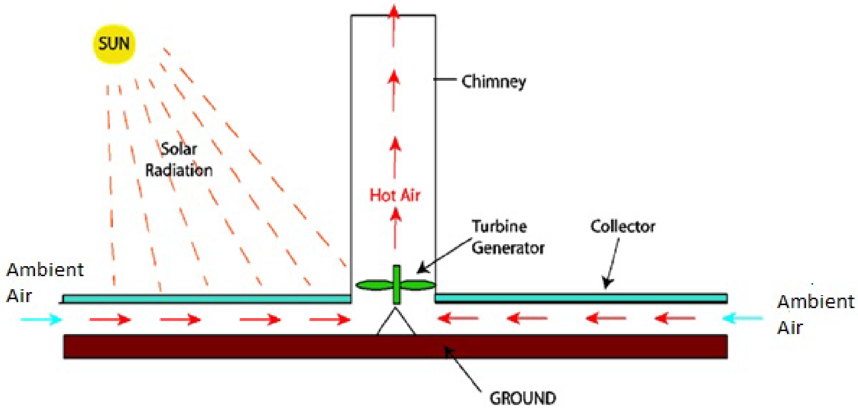


Figure 1. Solar updraft tower concept.

In 2003, a technical analysis, especially for thermal behaviour regarding solar chimney power system, was explored by Bernardes et al. [10]. For some physical performance, Bernardes studied the effect of soil thermal properties on the heat storage performance of the SUT collectors [11]. Ming et al. examined the outcome of using additional blockage installed around the circumference a few metres away from the collector entrance by taking into consideration the ambient crosswind effect on the SUT performance [12]. In 2016, Ming et al. [13] introduced a black tube as the solar collector into the solar chimney power plant design. The advantage of this invention is that it can extract fresh water from the air and produce power.

Some modification was proposed by Bilgen and Rheault to improve the solar collector efficiency by making a collector component in a sloppy and tapered section [14]. In 2014, Khanel and Lei [15] examined experimentally on an inclined passive wall solar chimney. From their investigation, the air movement inside the chimney changed due to the inclination angle modification. A model with a 10 m collector diameter and 12 m chimney height was built by Kasaeian et al. [16], and they found that a smaller entrance size for the collector will give a positive impact for system efficiency. From the numerical aspect, Kasaeian et al. [17] conducted geometric optimisation to analyse the solar chimney performance. The result was validated based on their prototype experimental data with a dimension of 2 m chimney height. Besides that, they investigated the effect of temperature distribution and the velocity of solar chimney air on the campus of the University of Tehran. From their findings, the system's geometric mainly gave impact to the air inversion phenomenon [18]. Nasirivatan et al. [19] investigated the effect of the corona wind on the thermal performance of solar chimney absorber to increase the solar chimney's efficiency. According to Yuji [20], thermal updraft velocity is proportional to the square root of the tower height and/or temperature difference. They found that the optimal shape of 4° semi-open for diffuser tower produced the fastest updraft at each temperature difference through experimental and numerical analyses.

In Malaysia, Al-Azawie et al. [21] studied different materials as absorber under the collector by numerically and validated them with experiments. These materials were used to convert solar radiation to kinetic energy, which consisted of sawdust, blackstone, ceramic, pebble, sand, and dark green painted wood. In their investigation, ceramic shows the best material with the highest efficiency at night. Another investigation using various types of absorber materials has conducted by Mehla [22], and he found that the maximum average collector efficiency, the collector exercise efficiency and the overall efficiency of the SUT were achieved with the small stone pieces. The experiment was supposed to store the solar intensity and exchange it for the air being heated by using four separate absorbers equipped with the convergent chimney. In a study which set out to determine the best geometric for the solar chimney through simulation, Asril et al. [23] found that 0 degree of slope collector and 0.05 m for the entrance gap of the collector helped to improve the system power output. Significant analysis and discussion on the optimum performance were presented by Cottam [24]. In his fascinating study, the power output rises quadratically with the chimney height, confirming the need to design high chimney plants. He concluded that the optimisation of the power output using the thermodynamic model combined with the cost model suggested that multiple smaller plants with a collector radius of approximately 3000 m could be preferable over one larger power plant. More recently, numerous attempts have been made to approximate power output on the basis of a list of household power equipment. Ramakrishna is primarily described in the overall productivity of the power plant [25]. The tests were carried out over a period of 10 days, and the findings of one such day were presented. The theoretical and real outputs were 1.37 and 0.82 W respectively, while the chimney and average plant productivity were 0.0187% and 0.0128% respectively.

A country like Malaysia generally experiences season weather throughout the year with an average temperature between 26 °C and 29 °C. In addition, the average relative humidity and rainfall per year in this country are normally from 70% to 80% and 250 cm, respectively [26]. Under these tropical climate conditions, the application of solar chimney becomes more competitive compared to other renewable energy systems if the system can be improved, especially in Malaysia. More analyses regarding the efficiency and performance that are critical for review include the temperature field, humidity, and pressure of the system. As explained in the introduction, it is clear that many articles generally focus on the structure models, the effectiveness of the system and other related problems for solar chimney power technology. However, a comprehensive study regarding temperature distribution for solar chimney power systems, especially in the tropical climate region with high-density humidity area has never been reported. Therefore, the objective of this paper is to exclusively conduct a detailed analysis through experiments on the temperature field, humidity and pressure in the system itself under the extreme tropical weather.

EXPERIMENTAL SETUP

A prototype solar chimney power plant of 5 m height and 3.5 m collector diameter was constructed in Melaka, Malaysia. The chimney was built from polyvinyl chloride (PVC) pipe (82 mm in diameter and 3 mm in thickness) as shown in Figure 2. For a prototype, it is crucial to identify a material with the following essential characteristics, such as lightweight, high wind resistance, moisture resistance and impact resistance [31]. In this study, the PVC pipe is chosen due to market availability, strength, excellent thermal resistance, weight reduction and the suitability during setup arrangement. Due to the extreme weather and high wind resistance in this region, the diameter of the chimney should be small, and the height should not be too high to make the chimney structure is resilient for long term usage.

The framework of the collector with 3.5 m diameter was constructed using hollow bar iron in order to hold out against strong winds and heavy rain. The collector base structure profiles were welded firmly to support the collector roof, as shown in Figure 3. Some essential material characteristics for the collector should be considered especially the reflection and absorption aspect should be as low as possible. To increase the greenhouse effect in the system, the heat transfer through the collector material should be as high as possible with high temperature and UV tolerance and excellent impact resistance, particularly during heavy rainfall.

From the above discussion, the collector roof part was made by using clear acrylic with 2 mm thickness. The acrylic panel is most suitable as it is readily available, and the percentage of transparency is higher than other materials. According to Chappell [24], the acrylic panel is the most transparent compared to others, as shown in Table 1. An adequate distance between the ground and the collector edge was determined with 10 cm to allow the potentiality of the ambient air into the collector. Table 2 indicates the fundamental geometrical parameters for the solar chimney prototype setup.

Table 1. Summary of collector materials considered for the collector roof [27].

Product	Material	Transparency (%)
Greenhouse sheeting	Polyethylene	94.6
Common Vapor barrier	Polyethylene	76.1
Acrylic Panel	Acrylic	95.8
Glass Panel	Glass	84.6

Table 2. Solar chimney parameters.

Name of component	Parameters
Updraft tower height	5.0 meters
Updraft tower diameter	0.082 meter
Solar collector diameter	3.5 meters
Solar collector entrance height	0.15 meter

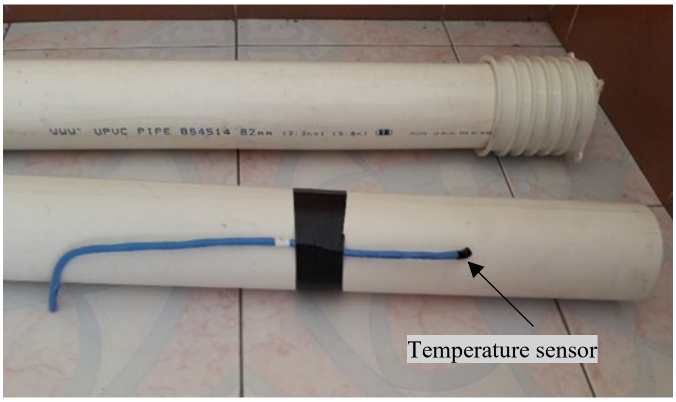


Figure 2. Chimney setup with a temperature sensor.

Figure 3. Collector structure using steel with clear acrylic as a collector.

Measurement and Sensors

In this study, the experiments run using data logger for continuous measurements. Vital parameters such as temperature field, pressure, humidity, and air movement were collected every single minute into a data logger device for the whole day. The temperature profile was collected using seven calibrated sensors to visualise the temperature distribution in the solar chimney using digital sensors type DS18B20. The sensors are also suitable for measuring the temperature of conductor and ambient air in the dynamic capacity increase and help to improve the accuracy of the calculation of the increase in capacity [28]. Since DS18B20 has excellent stability with one-wire bus capability through parasite power, these digital sensors have an accuracy of ±0.5°C, which is suggested by ASHRAE Standard 93-86 [29]. Thus, it is simple to use one microprocessor to control many DS18B20 distributed over a large area. These seven digital sensors are connected through one wire connection using unshielded twisted pair (UTP) type CAT 6 network cable. A micro-SD memory card is needed to record data securely by using Arduino microcontroller. This is further supported with a nonvolatile memory type as media storage gives an absolute solution to collect data securely throughout the duration of the experiment without having to be present at the site. Two sensors were mounted along with the chimney, while three other sensors were assigned to the air temperature measurement under the collector. Another two temperature sensors have been configured for the ambient air and power converter unit. For the temperature distribution under the collector, the sensors were divided into three positions with 0.5 m distance in between. In each position, the temperature along the collector was measured. To increase the reliability of measures, one digital sensor was located approximately 1.25 m above the ground to measure the ambient temperature, as recommended by ASHRAE Standard 93-86 [26]. The complete set of power converter unit which consists of temperature, pressure, humidity sensors and small generator before assembly with the collector base and the chimney is shown in Figure 4.

Figure 4. Power converter unit complete set.

All the work on the prototype was carried out with a small scale turbine. A removable cylinder with a flange and multiple-blade fan was installed at the chimney inlet, as shown in Figure 5. The wind rotor which acted as a low-speed generator was installed in the chimney. To assess whether air velocity was produced, the brushless pc fan was an ideal choice as a power conversion unit and measurement. The reliability, power efficiency, and the capability for revolution per minute (rpm) feedback are the main factors for choosing the brushless pc fan. The magnetic bars around the perimeter of the pc fan is not required. Without these magnetic bars, the rotor becomes lighter, and the movement is easier and smooth without any magnetic field. The fan dimensions are 80 mm in diameter with 7 flat plate airfoil blades. The fan frame, also more professionally called the stator, is the, well, fan frame that helps hold the entire thing together and make it mountable in the chimney diameter. In order to identify air velocity inside the chimney, the rotor speed was measured in rpm. A 10 K pull-up resistor was connected between the sensor wire and the 5 V from voltage supply. As the fan turns, a pulse can be read from between the ground and the signal wire, which is to receive a pulse from a hall effect sensor. Solar radiation was recorded by using a mini solar panel through an analogue input to measure the vertical solar radiation.

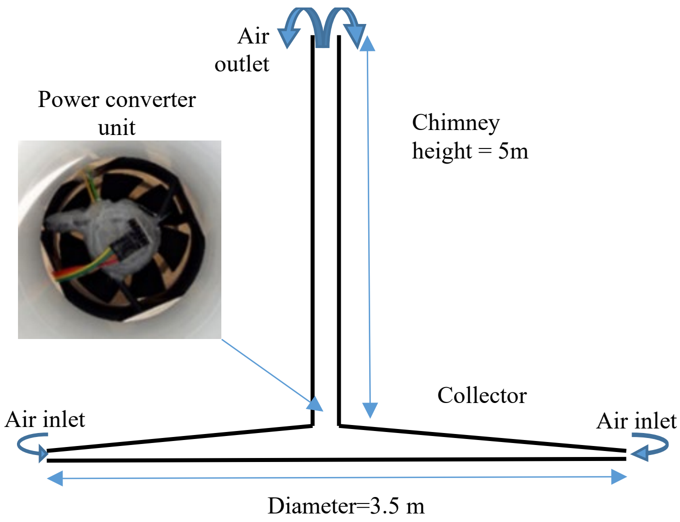


Figure 5. Schematic of solar chimney set up.

In order to verify the accuracy of the thermal sensors, a series of calibration was performed using a digital multimeter. The distribution of temperature reading inside the system and the ambient temperature was monitored to compare with the digital multimeter. From the observation, the temperature reading showed a good agreement with the temperature measurement, which was obtained by the sensors. The reliability of the pc fan was verified by using a portable tachometer before installation to ensure that the pulse reading from the hall effect sensor is accurate.

Power Converter Unit Sensor Measurement

To enable the condition inside the chimney to be seen clearly, the PCU was embedded with the BME280 sensor, as shown in Figure 6. The PCU is not attached with a load to produce power for this analysis. It is to visualise the operation of the turbine spinning due to the buoyancy effect. Data for pressure and humidity were collected from this sensor simultaneously during experiment activities. The pressure difference initially indicated the ability of air underneath the collector to move towards the chimney inlet and then through beyond the outlet. The advantages of BME280 from Bosch are its capability of measuring, which include barometric pressure, altitude, temperature and relative humidity (RH) with a fast response time, as shown in Table 3. The outstanding relative accuracy of ±0.12 hPa makes this sensor greatly suitable in this application for pressure measurement. This sensor is connected with the microcontroller through the Inter-Integrated Circuit (I2C) interface for communication.

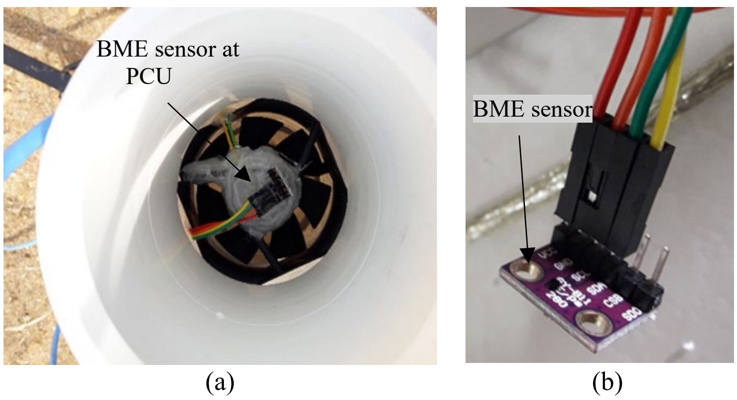


Figure 6. Power converter unit (a) and Bosch BME280 sensor (b).

Table 1. BME280 sensor technical specification.

Specification	Parameters
Temperature range	-40 to +85 °C
Pressure range	300 – 1100 hPa
Humidity accuracy tolerance	±3 % relative humidity
Humidity response time	1 s

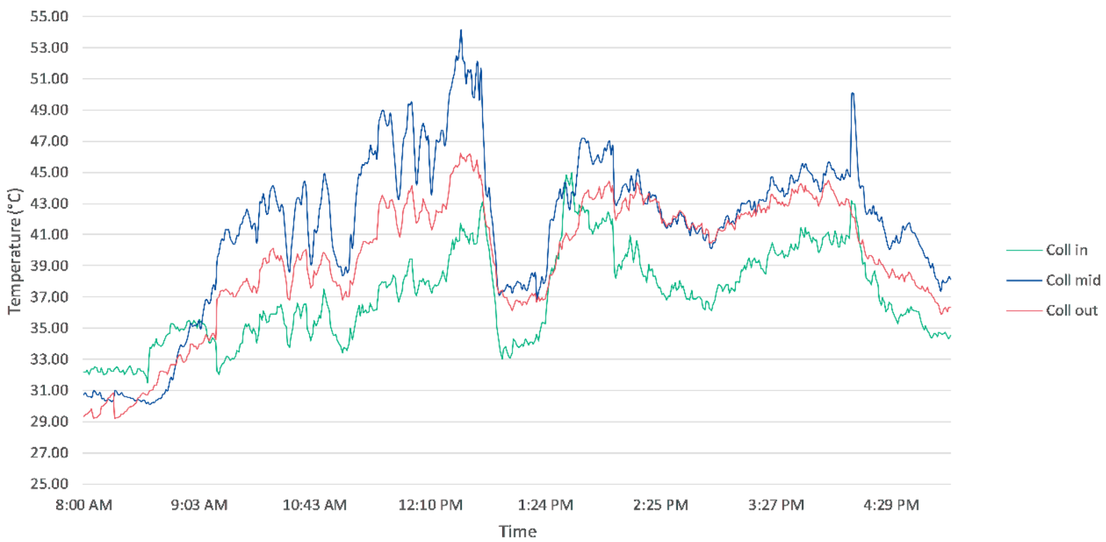
RESULTS AND DISCUSSION

This study set out with the aim of assessing the performance of the solar tower with several parameters. For this purpose, four parameters are presented and carried out under ASHRAE standard during daytime from 8.00 am to 5.00 pm with one-minute intervals. The parameters involved are temperature, pressure, humidity, and air velocity. The activities were conducted over several days, but the results were considered acceptable only on days with clear weather. The present study was designed to run from April 2018 to September 2018 due to clear and dry weather conditions in Melaka.

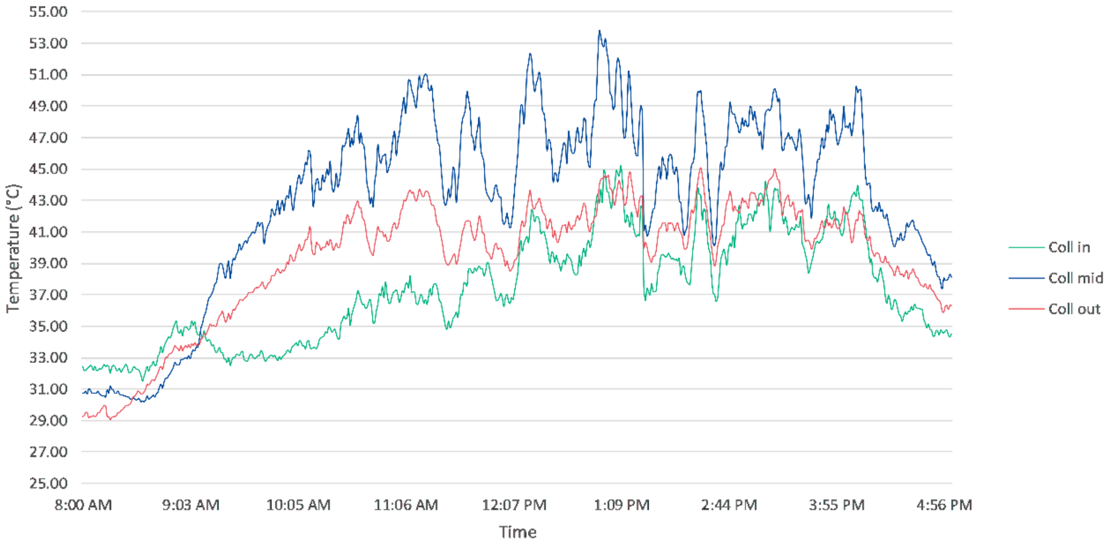
The results in this subchapter will indicate and deeply elaborate the temperature distribution and humidity relationship. The next subchapter, therefore, moves on to discuss the pressure and air movement inside the system. In order to present the results obtained from the experiment activities, the comparison is made for two different days; Day 1 (10th July 2018) and Day 2 (22nd July 2018). From this, the correlation between all parameters and how the system was affected can be significantly observed.

Temperature Field

The distribution of air temperature in the system was measured along with the collector point: inlet, middle, and an outlet for every single minute from 8.00 am to 5.00 pm. In the case of rainy and unpredictable weather conditions and for a predefined duration, the best two days are chosen for this analysis to assess the effectiveness of the system. The experimental results collected for two days are seen in Figure 7(a) and 7(b). From both charts, it can be seen that by far, the highest average temperatures for all points are experienced mostly from 12.30 to 1.00 pm, where the solar radiation becomes intense after sunrise. These results pattern is in agreement with Zhou's [10] findings which showed a maximum value for air temperature in the collector at 1.00 pm before it starts to decrease until evening due to low solar radiation reception around the collector. This phenomenon makes the air temperatures in both collector and chimney rapidly grow until reaching the maximum point in the afternoon. On Day 1, the graphs of the temperatures had very strong erratic patterns: all graphs start from their peak at 12.30 pm with average 54 °C, 46 °C, and 42 °C for inlet, middle, and outlet, respectively. However, the temperatures drop and reach their bottom levels at 1.00 pm. It is interesting to note that the temperature goes upward at the end of the day and rises about 10 °C for each point. It is also quite concerning to note that the temperature has declined in the middle of Day 1 due to the unexpected weather after it had turned cloudy. This temperature measuring pattern is unlikely to be the same as on Day 2. On the other hand, temperatures on Day 2 displayed fluctuation, starting from their lowest levels at 8.15 am. It is apparent from Figure 7(b) that there is a steady increase until it reaches a peak with over 53°C for middle and 45°C for both inlet and outlet. Then the temperatures decrease steadily after 4.30 pm. These relationships may partly be explained where the absorber was heated after sunrise by solar radiation and a large quantity of heat was stored before it began to release the heat during low solar reception in the afternoon by convection. Comparative results between two days are shown that the temperature get lower at the middle and the outlet of the chimney. This indicates that the hot air at the entrance of the collector cooled down by the turbine and also that the material used, such as PVC, is excellent for heat insulation. The temperature outside is not supposed to affect the temperature of the air inside the chimney.



(a) Day 1

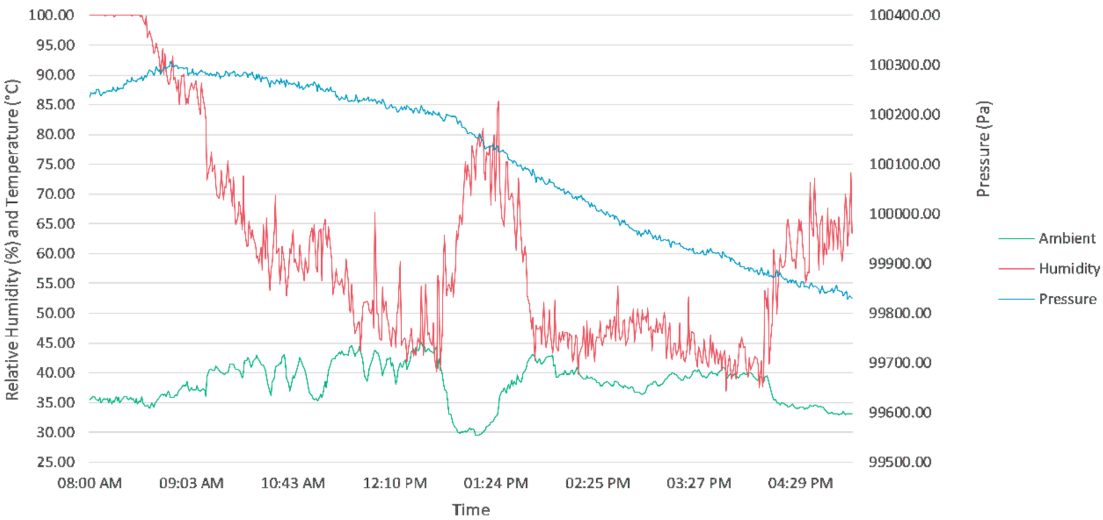


(b) Day 2

Figure 7. Temperature at a different location under the collector area.

Relative Humidity Distribution

The conditions, along with the chimney, especially inside the power converter unit, were thoroughly measured. Figure 8(a) and 8(b) illustrate the intercorrelations among the three measurements of ambient temperature, humidity, and pressure inside the chimney. From both charts, it is noticeable that the pressure distributions in the chimney for both days show the same trends which are higher at the early stage and then decreases slowly until 4.00 pm. The pressure inside the chimney is the highest from 10.00 to 11.00 am and starts to drop drastically in the evening. In this investigation, the relative humidity inside the solar chimney was also measured. As can be seen from both days, the results are quite revealing of the theory that temperature behaviour is opposite to the relative humidity behaviour. There was a significant surge for the humidity in the morning with an average of above 95% and the ambient temperature was approximately 35 °C due to low solar radiation. This correlation between ambient temperature and relative humidity is interesting because as temperature increases, the humidity percentage drops, indicative of dryness of the air. The effect of the storage and absorption process on the absorber was the leading cause during sunrise that made the temperature and humidity collapse and peak, respectively.



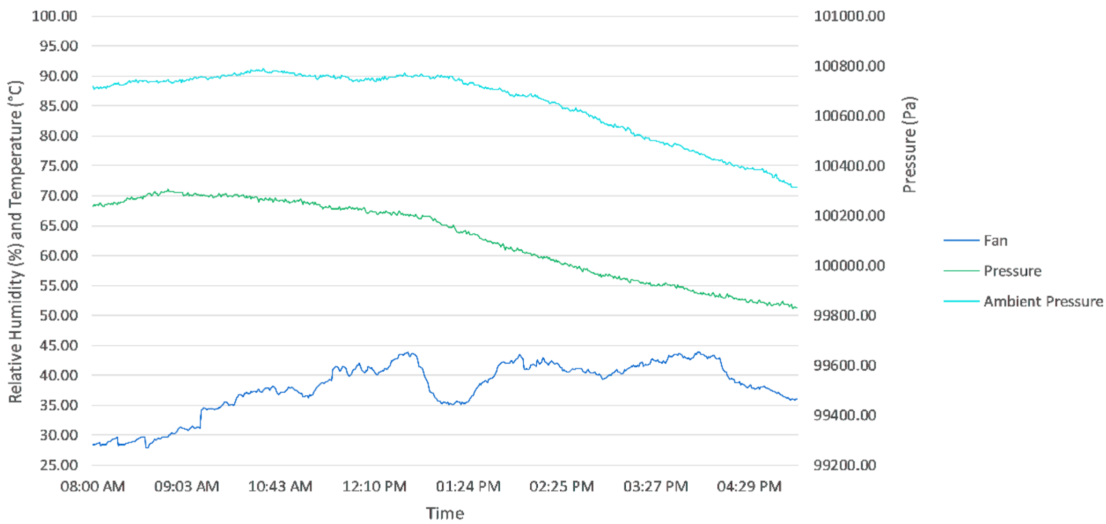
(a) Day 1

(b) Day 2

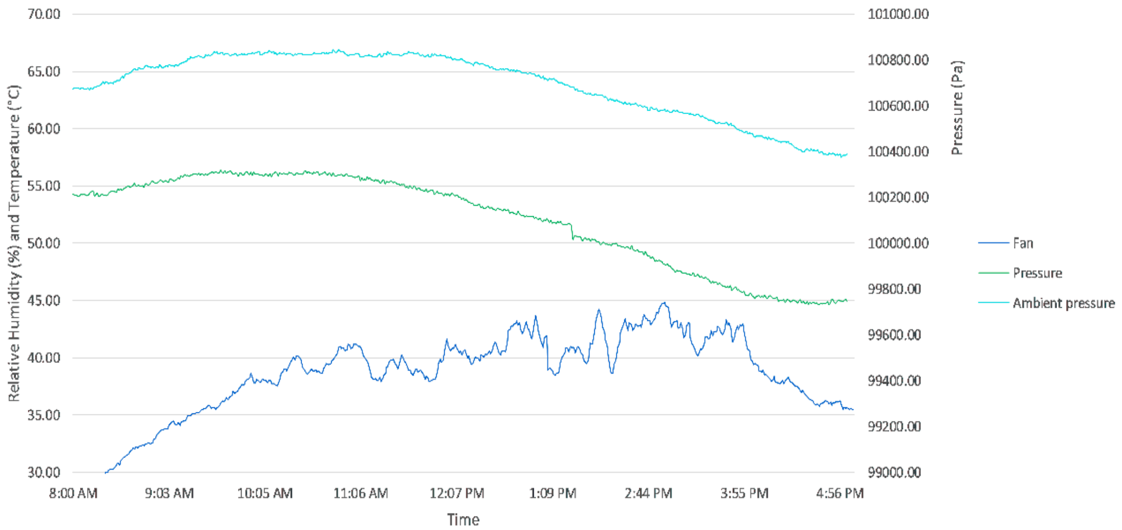
Figure 8. Pressure, relative humidity (RH) distribution at power converter unit (PCU) and along with the ambient temperature.

Pressure Difference

The correlation between ambient pressure and internal pressure was measured in these activities. The results obtained for two days of analyses of pressure difference can be compared in Figure 9(a) and 9(b). What is interesting in this data is that both days showed the same pattern either for ambient pressure or internal pressure. For Figure 9(a), it is apparent that the ambient pressure and internal pressure is maximum in the early morning, which is recorded at 100.8 kPa and 100.2 kPa, respectively. For Day 2, the measurement followed a similar pattern throughout until evening for both pressures with a slightly high reading of around 0.1 kPa, compared to Day 1. The most striking result to emerge from both days is that the difference in the value between the ambient pressure and internal pressure almost reached 0.6 kPa in the afternoon. Together, these results provide valuable insights into creating updraft air through the chimney. It seems possible that these results are due to the greenhouse effect occurring in the collector with enough air intake from the outside. However, with a small pressure difference, caution must be applied, as the findings might not be able to compensate the turbine resistance to produce electricity.



(a) Day 1

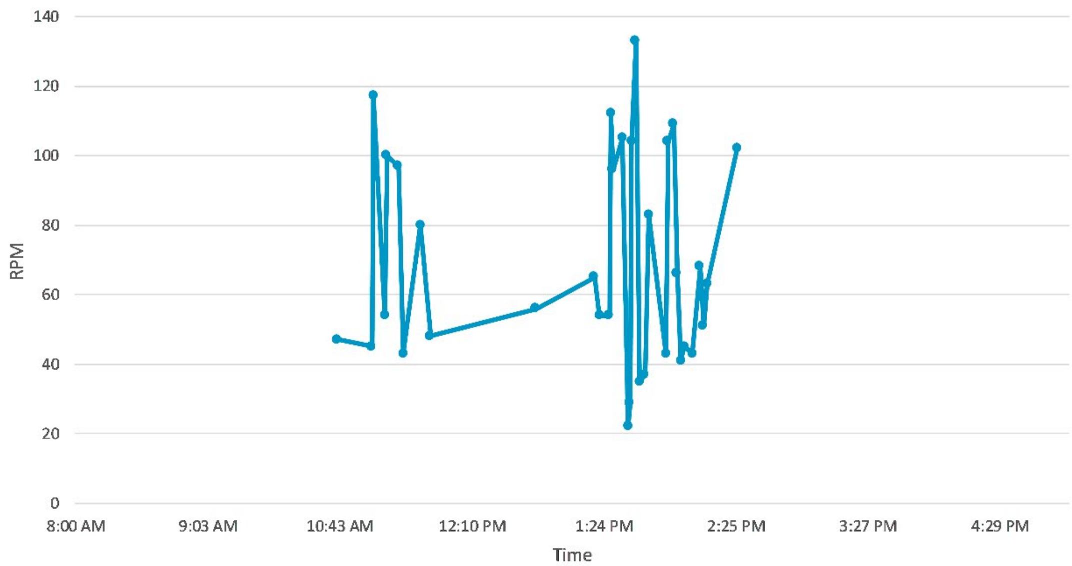


(b) Day 2

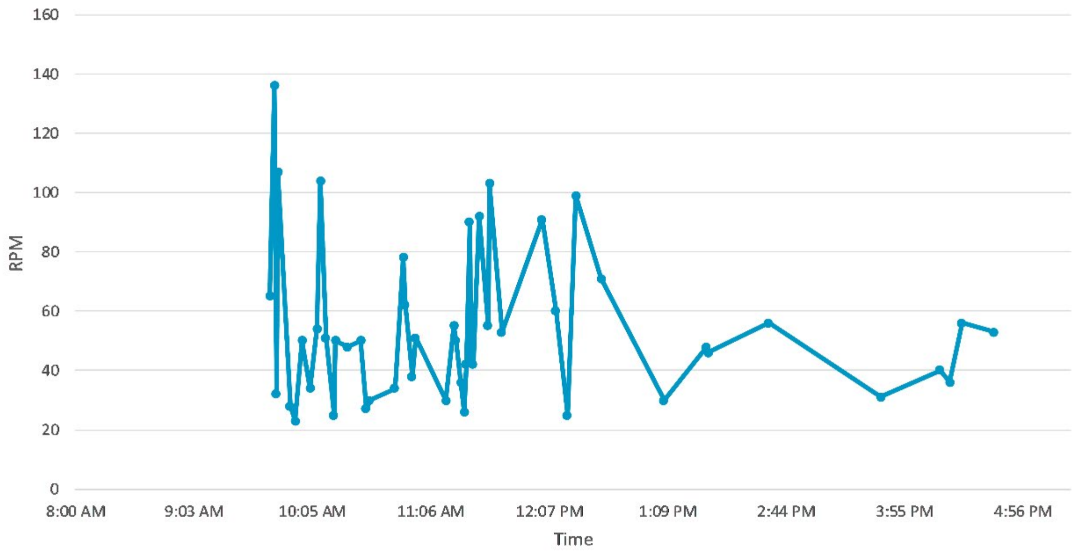
Figure 9. Pressure, relative humidity (RH) distribution at power converter unit (PCU) and along with ambient pressure.

Air Velocity

The movement of the fluid inside the chimney was measured using a small pc fan which was placed at the collector outlet. The application of ball bearings and the low spinning resistance of pc fan made the blades rotate smoothly. Figure 10(a) and 10(b) illustrate the average of two kinds of rotational speed measured inside the chimney for two days. The speed is measured in revolution per minute (rpm). Overall, the maximum and minimum speed for two days indicated the same average value: 135 rpm and 20 rpm, respectively. The highest speed for Day 1 was recorded at 1.30 pm while the speed for Day 2 spiked at 10.00 am. The findings obtained on Day 2 are marginally higher at an early stage, mostly due to the addition of windy condition from the surrounding. In principle, this can give addition air movement at the chimney entrance. From both graphs, the reading frequencies are high after 1.00 pm, but another day, the frequencies were more active in the morning. In the beginning, there was no reading from 8.00 to 10.00 am for both days, which indicated that the air inside the system was insufficient to create a natural draft due to cold air. This process was observed where no reading was recorded on Day 1 after 3.00 pm as the pressure within the system became constant until the end of the measurement time. In the other hand, as solar radiation started to decrease after 3.00 pm, the airspeed level for the curve on Day 2 decreased and stayed unchanged until the evening with an average reading of 50 rpm. Looking at these conditions, it was found that there is inconsistency in the rotation of the turbine, particularly during low solar radiation. It also could be due to a number of factors including the air hardly moved out from the chimney outlet due to the small driving force generated and the effect of the wind from the surroundings at the chimney tip. In the context of chimney geometry, this could have been limited to the airflow from the inlet to the outlet. This could be related to a reduction in buoyancy, as shown in previous studies [30], where the backflow happens, and the vortex is created.



(a) Day 1

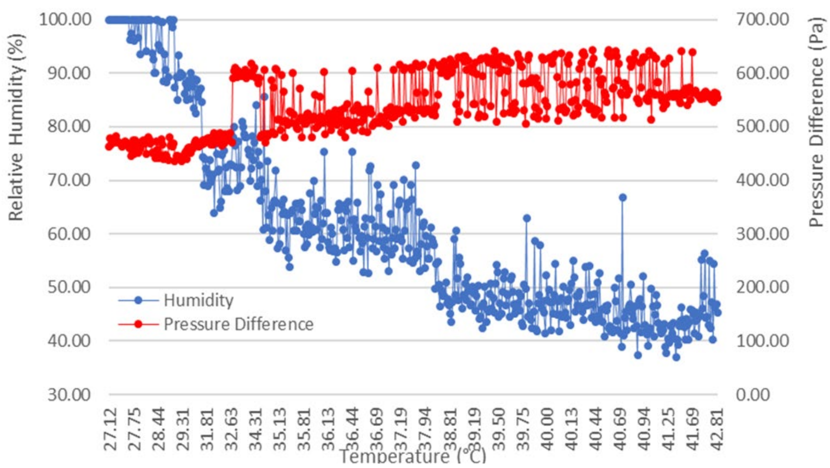


(b) Day 2

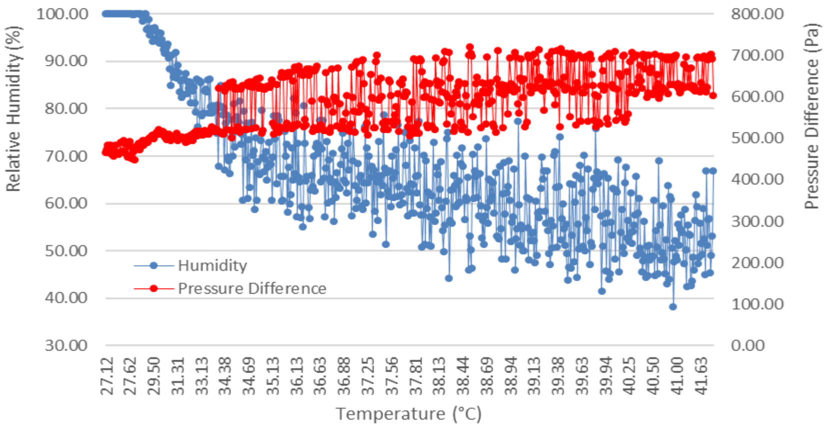
Figure 10. Speed reading.

Effect of Air Temperature on Pressure and Humidity

As previously presented, the pressure difference seems to have a significant effect on the forming of updraft air due to the buoyancy effect inside the chimney. This phenomenon was demonstrated by the assessment of the air velocity. In addition, the effect of humidity on the operating potential and performance of the solar updraft tower is also discussed. The humidity plays a vital role, especially in places where the atmosphere contains much moisture, which dictates the possibility of condensation. This finding is further analysed by the incorporation of the relationship between vital parameters temperature, humidity and pressure difference. The variation of humidity and pressure difference is plotted as a function of air temperature. Figure 11(a) and 11(b) demonstrate the effect of temperature on pressure and humidity. The pressure difference is calculated between the inlet chimney and ambient pressure. The temperature of the power converter unit is chosen based on a crucial condition for determining the performance of the system. These two charts indicate the same patterns as the humidity is inverted in relation to the air temperature. In the early morning, the low temperature of the air coupled with high humidity was observed, which creates a minor change in pressure. At noon, the reverse effect occurs as temperature increases resulting in low humidity, and at the same time, there is a growing disparity in pressure. The same amounts of a pressure difference for an average value of 650 to 710 Pa were recorded as the temperature increases for Day 1 and Day 2. The lowest moisture value of 39% RH is reported when the temperature had reaches 40 °C. This value means that the air becomes dry and that the lower density of the air makes it much easier to flow upwards. In addition, the pressure difference has become more consistent as the temperature increases leading to decreased humidity. As a result, humidity plays an unfavourable role in the creation of performance for solar chimney power plant, as a minor pressure differential is created, resulting in a small buoyancy effect [32]. These results may be a direct consequence of the presence of humidity in the air going to slow down the adiabatic thermodynamic process, which decreases the temperature and enhances the reduction of the updraft air density. Air density is critical as the system relies heavily on its natural effect. The higher air temperature can be reached; the lower that air density is made to generate more pressure difference, thus, towards more updraft air inside the system.



(a) Day 1



(b) Day 2

Figure 11. Variation of humidity and pressure difference as function as temperature.

CONCLUSION

An experimental pilot plant was successfully installed in Melaka, Malaysia, in a tropical climate where no investigation of the SUT power plant had been conducted before. This study set out to examine the critical parameters that influence SUT performance, including the temperature field, pressure, humidity distribution and air velocity inside the solar chimney power system. This study has examined the factors which are thought to contribute to enhancing the system efficiencies. The experimental results show that the system can generate a driving force due to turbine spinning observation. This driving force is closely related to temperature and pressure differences, while humidity has an indirect effect on these two vital parameters in the system. Current findings show that the greenhouse effect occurred underneath the solar collector due to temperature and pressure difference. From observation, the highest temperature differences are approximately 15 °C, and the pressure difference of approximately 0.6 kPa was recorded for two days. These two significant findings demonstrate the adequacy of the system to produce a buoyancy effect in the chimney hence creating an updraft air as expected. These are evaluated by relating to the faster the blade could turn inside the unit, representing higher air velocity, and more updraft air produced. However, even better results are obtained with this arrangement, the inconsistency of the rotation of the turbine, particularly during low solar radiation and the effect of the wind from the surroundings, the design may be improved to provide additional functionality by employing different measurements method for air velocity and utilising thermal energy storage technique. In future work, it may be helpful to investigate different aspects of relationships with a different type of absorber and thermal energy storage to sustain the output.

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