

# Finite element analysis of the thermal response test for road thermoelectric energy harvesting system (RTEHs)

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**Keywords:** Thermoelectric, FEA, RTEHs

**ABSTRACT** – This paper investigates the thermal response for the road thermoelectric energy harvesting system (RTEHs) application where the finite element analysis (FEA) is used to predict the real condition for the RTEHs. The findings for both FEA and in-lab experiment able to gives less than 1.5 % for the structure of rod and 6.6% for the flat bar of the percentage of difference. Both findings able to gives a similar maximum temperature at the top plate used as the heat collector at 43°C for the flat bar and 48°C for the rod. This proved the greater the thermal diffusivity, the more reliable the materials able to conducts heat more rapidly than the flat bar.

## 1. INTRODUCTION

A proliferation of studies in energy harvesting has risen tremendously for the past decades in solar, wind, piezoelectric and thermoelectric. The Technology Readiness Level (TRL) which originally conceived from NASA since the 1980s based on a nine-level scale was used to categorize the readiness level of one's technology [1]. The solar and wind can be label as matured technology with TRL level approaching 9 where the system has been tested, launched and operated for a considerable amount of time.

In Thermoelectric Technology used to harvests the energy from road pavement, TRL level only reached up to 6. There are numerous designs for the road thermoelectric energy harvesting system (RTEHs) that aims to achieve the most optimum temperature difference from the cooling method of the RTEHs use [2]. Therefore, this study seeks to obtain findings which will help to address these research gaps on the most efficient cooling method that able to provide the maximum voltage-generated of the RTEHs through finite element analysis (FEA) simulation.

## 2. METHODOLOGY

FEA simulation was conducted using COMSOL Multiphysics where it able to predicts the thermal response in certain conditions and different geometry for our RTEHs before commencing into an actual experiment. Our RTEHs uses a subterranean cooling method where the cooling element will be installed under the asphalt and submerge into the soil as depicted in Figure 1 and the dimensions are given in Table 1.

In this FEA simulation, the aluminium plates are placed in between two cascaded thermoelectric modules

(TEM), APH-127-10-25-S as discussed in [3]. The top plate will perform as the heat collector for the system. The bottom plate of the aluminium is bond to the cooling element which is either rod or flat bar. This FEA simulation will determine which of this cooling element structure able to provide the best thermal response since the temperature difference,  $\Delta T$  between the hot and cold side of the TEM are highly influencing the output voltage.

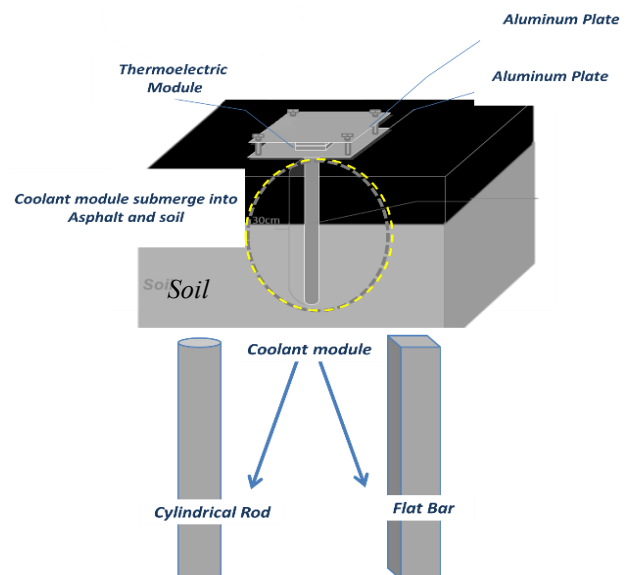


Figure 1 Illustration of the experimental setup.

Table 1 Size and Properties on experimental setup.

Type	Dimension (mm)	Material	Thermal Cond. (W/mK)	Density (kg/m <sup>3</sup> )
Flat Bar	25.4 X 50.8 X 300	Aluminum 6061	187	2712.51
Rod	Diameter (25.4), Length (300)	Aluminum 6061	187	2631.37
Plate	Aluminium SIC 0.128	60 X 100 X 3	222	2.71
Asphalt box	Plywood	Base (320 X 320)	-	-

In every material, the properties parameters such the thermal conductivity,  $k$ , density,  $\rho$ , and specific heat,  $C_p$  are following the standard parameters given by the manufacturer or it can easily refer to the handbook [4]. As the heat runs through the material, thermal diffusivity,  $\alpha$  control the time speed of the temperature's fluctuation where when  $\alpha$  is high, the quicker the temperature disperses out.

$$\alpha = \frac{k}{C_p \rho} \quad (2)$$

### 3. RESULTS AND DISCUSSION

The solar irradiance's value used in this FEA simulation is based from the halogen lamp used in the lab which is 75 W with the square area of 0.11-meter square. Both FEA and in-lab experiment are tested for the durations of 2 hours.

Depicted in Figure 2 and Figure 3, the thermal response in structure using rod is much higher than the structure using a flat bar which proven the  $\alpha$  of the rod was higher than the flat bar since the heat flows quickly through the material where it able to conducts heat more rapidly compared to its volumetric heat capacity.

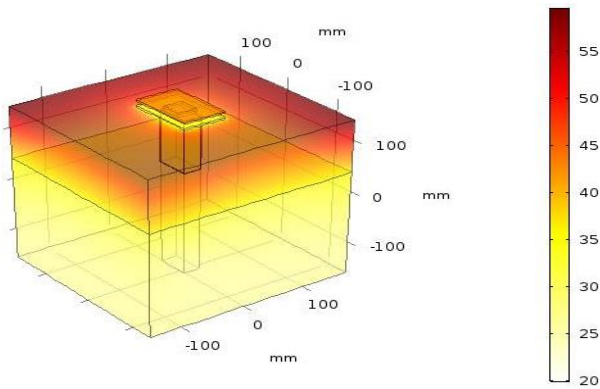


Figure 2 Temperature distributions for the cooling elements of flat bar.

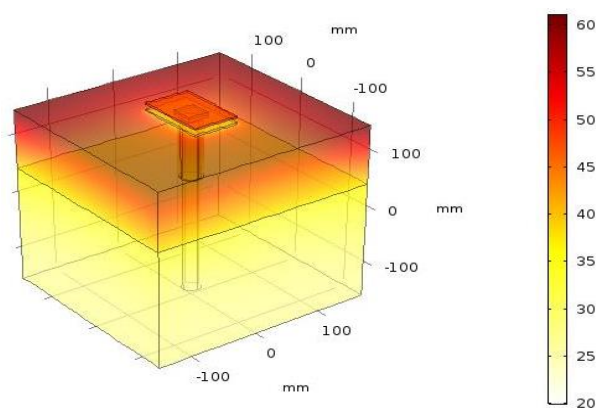


Figure 3 Temperature distributions for the cooling elements of rod.

From Figure 4, the simulation and the experiment's temperatures for the top plate are similar to each other with the percentage difference of 1%. While the bottom plate's temperature between simulation and experiments are varied by 6.6% of differences. The unknown properties for the material used in the FEA simulation may have contributed in the

larger discrepancy in the percentage difference.

However, in Figure 5, the percentage of differences between simulation and experiment was less than 1.5%. This proved when  $\alpha$  is high, the more reliable the material able to conducts heat more rapidly than the flat bar.

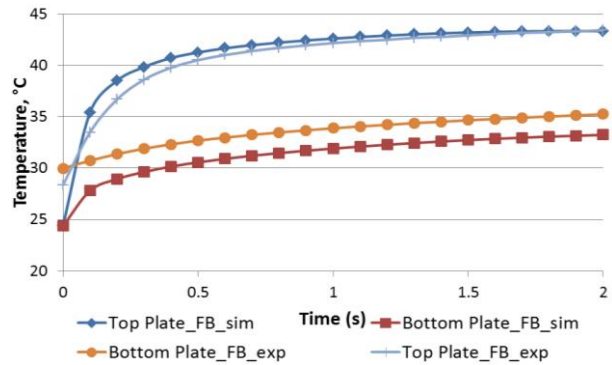


Figure 4 Temperature behaviors of flat bar for simulation vs experiment.

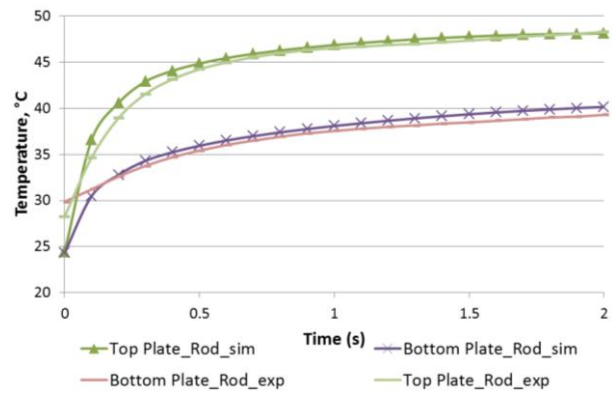


Figure 5 Temperature behaviors of rod for simulation vs experiment.

### 4. CONCLUSION

As the conclusion, the finite element analysis showed the cooling element of the rod has a higher thermal response than a flat bar where the percentage of differences between simulation and in-lab experiment is less than 1.5%. Both findings able to gives a similar maximum temperature at the top plate used as the heat collector at 43°C for the flat bar and 48°C for the rod.

### ACKNOWLEDGEMENT

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# Determination of solar panel maximum output power using predictor variables method

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**Keywords:** Solar Power forecasting; statistical analysis; correlation

**ABSTRACT** – The optimization of the output of solar photovoltaic (PV) system is highly important to harness its maximum potential as the alternative energy source. This paper identifies the importance of the PV system variables on solar power output and enables the predictor variables identification using statistical analysis. This technique analyses the significant correlation between the variables and solar output power. The correlation attributes are used as a guideline in identifying the most influential variables towards the prediction of solar power output. The simulation results showed the variables can be evaluated based on the correlation between the predictor variables and the solar output power.

## 1. INTRODUCTION

The demand for electrical energy nowadays has substantially increased as the electronics and high-powered machines are immensely introduced and used worldwide. Malaysia that is located near the equator typically receives solar power between 4,000 to 5,000 Wh per square meter per day.

Under the encouragement of Malaysia Tenth Plan, the government of Malaysia aimed to contribute 5.5% of total electrical generation in Malaysia from renewable energy [1]. Aligned with this aim, the installation of photovoltaic (PV) system around the Malaysia area has to show an increasing trend, where it used as a heating purpose and also electrical generation [2].

Solar forecasting based on the prediction model have been implemented either with the statistical or physical method or the combination of both with the help of artificial intelligence and neural network [3,4]. The computation and training of weather data are carried out to predict the future solar output generation. However, the time sensitivity must be considered in actual practice and it is necessary to update the data in real time [5]. The inconsistent of outcome due to the weather change in four season countries also an important consideration for the forecasting of solar output [6]. These research gaps show that forecasting should be simpler and considers external factors such as temperature and humidity.

According to the statistical survey in 2012, the solar radiation received by northern area of Malaysia such as Kedah, Penang, and Sabah are the highest while the

southern area of Malaysia like Johor received the least of solar radiation among the other states of Malaysia as shown in Figure 1.

Thus, the main objective of this study is to propose an investigation of solar maximum output panel using the correlation and coefficient analysis using PV variables and weather data. Initially, PV variables were acquired from Mono solar panel in the Faculty of Electrical Engineering (FKE), Universiti Teknikal Malaysia Melaka (UTeM). The five variables are global tilted irradiance (GTI), global horizontal irradiance (GHI), temperature, humidity, and panel temperature. They were used as an input predictor variable, while the power output from the panel is the output. Using the correlation and coefficient analysis in the SPSS software (SPSS Inc. 2007), the most influential variable towards the solar output power can be identified. Thus, the general equation of the solar panel system can be formulated.

## 2. Impact of PV Parameter to Solar Power Output

The main objective of this study is to find out the predictor variables and parameters that affect the solar output generation the most. In order to achieve this objective, multi-regression method is utilized to show the influence of the variables to the solar output. The implementation steps are described in the flow chart in Figure 2.

Samples were taken from the Mono solar panel in the Faculty of Electrical Engineering (FKE), Universiti Teknikal Malaysia Melaka (UTeM) in the year 2015. A total of 52,347 instances of PV system variables were taken every 5 minutes' interval from 7.25 am to 7.25 pm every day. There were 24 units of solar panel that contributed to this data.

### 3.1 Performance of Each Predictor Using Linear Regression Analysis

In order to determine the importance of each parameter toward the solar output, the correlation between the dependent variable and the independent variable is the key. The coefficient of determination,  $R^2$ , is the measure of the correlation between the dependent and independent variable. If the value is closer to 1, it means that there is a strong correlation between the variables.

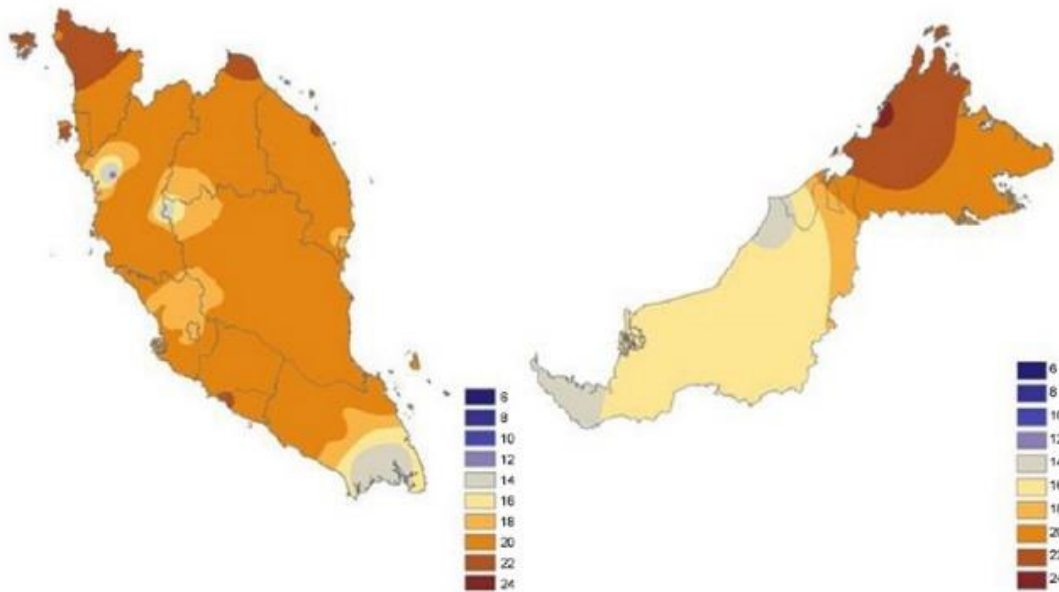


Figure 1 Average daily solar radiation (MJ per sq. m) across Malaysia [7].

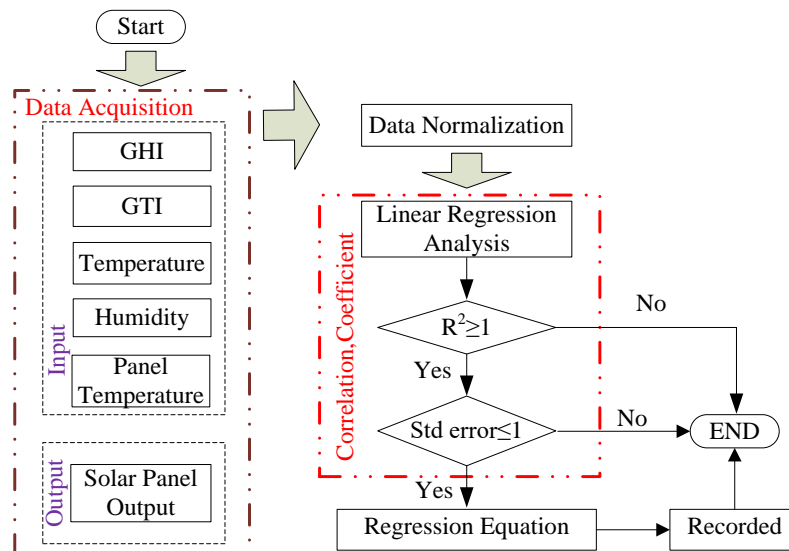


Figure 2 Summary of the proposed technique.

The result obtained in Table 1 showed that the global tilted irradiance (GTI) has the highest  $R^2$  value. This result indicates that it has the strongest correlation which has the highest impact on the solar output. Meanwhile, the temperature variable has the lowest value of  $R^2$  which is only 0.201.

The standard error of the estimate measures the accuracy of the prediction. The lower the value the higher the prediction accuracy. GTI has the highest value of  $R^2$ , and the lowest standard error of the estimation among all the predictors as tabulated in Table 1. On the other hand, temperature has the lowest correlation and has highest value of the standard error of the estimation. Thus, it is evident that the GTI has a good correlation in predicting the solar power output rather than the temperature.

Table 1 Model summary for each predictor.

Model	R	$R^2$	Standard error estimation
GHI	.900 <sup>a</sup>	.811	.10959
GTI	.920 <sup>a</sup>	.847	.09864
Temperature	.448 <sup>a</sup>	.201	.22522
Humidity	.477 <sup>a</sup>	.227	.22147
Panel temperature	.813 <sup>a</sup>	.660	.14686

<sup>a</sup>Predictors: (Constant), Panel Temperature, Humidity, GTI, Temperature, GHI.

### 3.2 Performance of Five Predictors with the Output

The performance of the five predictors with the output is then simulated in order to evaluate the coefficients of the predictor variables. These coefficients (shown in Table 2) were evaluated and analysed in order to find the regression equation in estimating the solar power output. It is evident in Table 2 that the evaluation of all parameters is at  $P < 0.05$ , which concludes that all the parameters are statistically significant. Hence the findings found in this study is likely to generalize to the broader population of PV system across Malaysia. Therefore, an estimated solar output power using regression equation can be formulated by Equation (1).

$$P_{out} = 0.95(GTI) + 4.752(PanelTemperature) + 0.021(Humidity) - 0.061(Temperature) - 0.057(GHI) - 0.012 \quad (1)$$

Table 2 Coefficients of all predictor variables.

Model	Unstandardized coefficients		Standardized coefficients		Sig.
	<i>B</i>	Std error	Beta	<i>t</i>	
Constant	-.012	.005		-2.677	.007
GHI	-.057	.011	-.055	-5.384	.000
GTI	.950	.011	.879	86.817	.000
Temperature	-.061	.007	-.043	-9.239	.000
Humidity	.021	.003	.020	5.881	.000
Panel temperature	4.752	.191	.145	24.879	.000

<sup>a</sup>Dependent variable:  $P_{out}$ .

This regression equation summarizes that GTI has the highest influence on the output with a positive coefficient of 0.95 and the GHI has the least influence on the solar output when all the variables are used together to predict the output.

### 3. SUMMARY

This paper proposed the solar output forecasting by using predictive model based on the predictive variables. The advantage proposed method is that it does not require a complicated calculation and mathematical model with only historical weather data. The forecasting of solar output based on the predictive model can be made by determining the correlation of the attributes. Based on these findings, the future work of the authors will include the development of modelling the predictor variables using a machine learning technique.

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# An experimental study of the cooking stove waste heat energy conversion using thermoelectric generator for night market application

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**Keywords:** Night market; energy conversion; thermoelectric generator

**ABSTRACT** – Electrical power requirement used to power up electrical appliances at night market usually provided by a petrol-electric generator which also contribute to air and noise pollution. Quite a few stalls at night market are involved with cooking activities and therefore produced waste heat which can be converted to electrical energy using a thermoelectric generator (TEG). The experimental work conducted managed to convert a maximum of 46.8 mW electrical power with the usage of five units TEG. However, the remaining heat energy is still high and therefore the power generated can further enhanced by increasing the total number of TEG used.

## 1. INTRODUCTION

Night markets usually operate from late in the evening and continue could be up to midnight, hence requires light source which normally using either fluorescent or LED type. Power consumed ranging between 50-100 W/hr per night for each stall, the light normally powered by gasoline electrical generator which consumed an average of RM2 to RM4 [1]. Additional cost for generator set maintenance will further increase the overhead cost. On top of that, the usage of the generator set also contributes to noise and air pollution which can affect the quality of food as well as disturbing the customers.

Cooking activity is one of the major activities at the night market which can cover up to 25% of the total available stalls [2]. This activity produces a huge amount of waste heat energy which normally can be seen by the coverage set up by the stall operator used to reduce the heat effect towards the customers. This excess heat has the potential to be converted into electrical power using a thermoelectric generator (TEG) and further used to power up the night market stall.

Worked based on the principle of Seebeck effect where the temperature difference ( $\Delta T$ ) and therefore the heat or thermal energy acts as a replacement of input or supply electrical voltage as the driving force of the electron's movement or the electrical current in the circuit [3]. The electrical energy produced is proportionate to the temperature difference between the two sides of TEG [4] as follows:

$$V_0 = \alpha_{TEG}(T_H - T_C) = \alpha_{TEG}\Delta T \quad (1)$$

Where  $V_0$  is voltage output,  $\alpha_{TEG}$  is Seebeck coefficient,

while  $T_H$  and  $T_C$  are the temperature at hot the and cold side of the TEG respectively. Seebeck coefficient is very much depends on the individual element used in constructing the TEG which is based on the concept of the semiconductor.

This project interest is to generate electricity using excess heat from the cooking activity at night marking with the intention to power up lights at their stall.

## 2. METHODOLOGY

A set of five TEG units modeled SP1848-27145 and connected in series were used during the experimental process. The modules were arranged next to each other to minimize the length of wiring and hence the potential current loss due to wiring. The terminals of the modules are then connected to load, rated 2 Volts. The hot side of the TEGs was attached to a 0.5 mm thick copper plate which will be heated at one end using butane gas stove. Figure 1 shows the schematic diagram of the TEG arrangement.

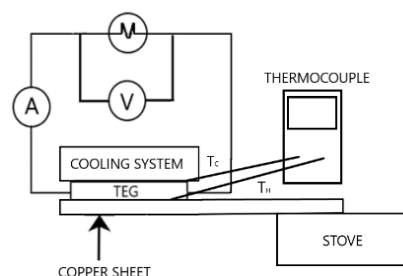


Figure 1 TEG's schematic diagram.

Four sets of parameter were measured for 200 seconds namely voltage and current; measured using multi-meter, while the temperature at both the hot and cold side; measured using dual channel thermocouple. The power output was then calculated as follows:

$$P_{TEG} = V_0 I_0 \quad (2)$$

## 3. RESULTS AND DISCUSSION

The output value of voltage  $V_0$ , current  $I_0$ , and power  $P_0$  had increased uniformly over time as shown in Figure 2 during the pre-heating period before became stable at 72 seconds. Time taken for the pre-heating process is very much depends on the amount of heat produced. The output values further slowly drop over



time during a constant temperature range, after achieved the maximum values at 90 sec heating time, similar to the one reported in [5]. Since TEG is a semiconductor type which made of two materials which highly govern the Seebeck coefficient and thus therefore the voltage output.

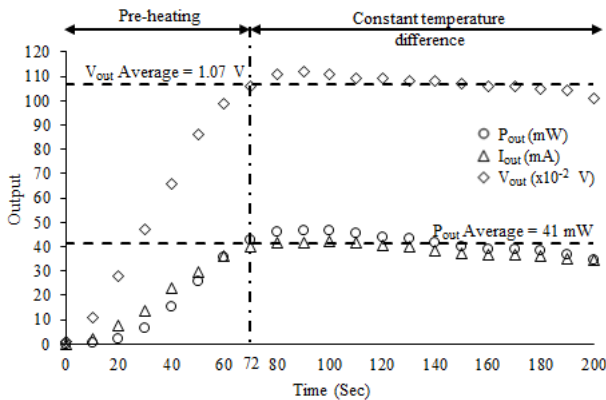


Figure 2 Voltage output against heating time.

The amount of current produce relatively very low and so for the power produced. Apartet et al. [6] have solved the numerical solution for TEG power output also found a similar pattern of power dropped. Table 1 shows the average and maximum value for every output.

Table 1 Output's average and maximum values.

Output values	Average values	Maximum values
Voltage (V)	1.07	1.12
Current (mA)	38.6	42.1
Power (mW)	41.3	46.8

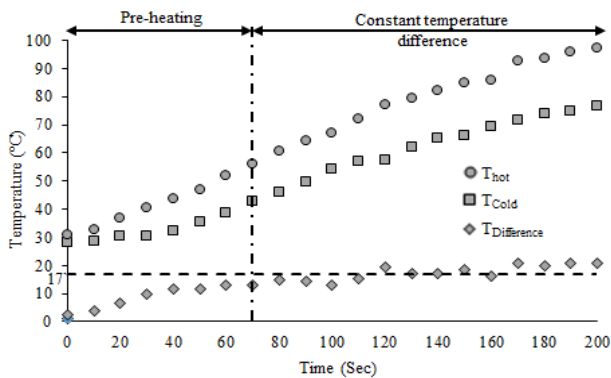


Figure 3 Temperature comparison over heating time.

Figure 3 shows the temperature at the hot and cold side, as well as the difference. Temperatures at both sides of the TEG modules increases exponentially from the moment copper plate been heated and keep increasing after 200 seconds. This showed that the amount of heat been transferred to the copper plate still not yet achieve the maximum level. However, the calculated temperature difference showed almost constant at an average value of 17°C after the pre-heating range which is similar to the one recorded in [5]. This constant in temperature difference had resulted in the constant output values, but rather lower relative to the heat input. Further,

the continuous temperature increment at the hot side shows that the TEG capable of producing higher output values, considering the cold side temperature can further be reduced with cooling mechanisms [4].

After the excess heat been converted using only five sets of TEG, it is assured there is still abundant of heat been released by the stove. A series of TEG modules fitted along the heat flux mechanism will receive the same amount of average heat energy in terms of the temperature difference and thus will produce the same amount of power output [7]. Therefore, additional TEG modules with the proper arrangement on heat transfer mechanism will further increase the power output.

#### 4. CONCLUSION

This study showed the application of thermoelectric generator used to harvest waste heat from cooking activities at night market and further converts into electrical energy used to power up their electrical appliances. Even though the output power produced relatively low (maximum of 46.8 mW) as compared to the waste heat input, but it is evident that it can be further improved by increasing the number of TEG used and incorporating a cooling mechanism.

#### ACKNOWLEDGEMENT

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# Current Consumption and welding force measurement of bobbin friction stir welding on 6 mm thick AA1100

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**Keywords:** Bobbin friction stir welding; current consumption; force measurement

**ABSTRACT** – The weld formation of bobbin friction stir welding (BFSW) process is hardly to observe. The interaction of the bobbin tool that used to generate frictional heat and enhance the material flow to form a weld joint require a comprehensive understanding. One of the ways is by measuring the signal processing to explain how much energy demand needed by the BFSW process to form the weld joint. This study investigates the phenomenon of weld formation of bobbin friction stir welded AA1100 through measurement of the current consumption and welding forces.

## 1. INTRODUCTION

The weld formation produced by bobbin friction stir welding (BFSW) is one of the crucial thing to be observed. Although various researchers attempt to discover the material flow in BFSW [1-2], however less documentation on signal processing measurement of the bobbin tool interacts with material to form a weld joint. This is important as to give an information that may help to point out the reason of the uncertainty phenomenon like tool breakage and incomplete weld joint. Also, it helps to sustain the BFSW by improving the tool features development and combination of parameters used. Therefore, in this study, the current consumption and welding forces measurement of BFSW was recorded and analyzed in order to investigate the interaction of bobbin tool to form the weld joint on AA1100 plates.

## 2. METHODOLOGY

The base material used for this investigation was 6 mm thick of aluminium alloy (AA) 1100 which were cut into plates with dimension of 140 mm long by 140 mm wide. This plates were butt joined parallel to the rolling direction via CNC milling machine and a fixed gap bobbin tool. The fixed gap bobbin tool was made from H13 tool steel consists of three main components which are the upper shoulder, tool pin and lower shoulder. The upper and lower shoulders having the same diameter of 25 mm and only lower shoulder having the taper of 5° feature. The tool pin has the diameter of 10 mm with three flats feature on the smooth cylindrical feature.

Before welding, the UNI-T232 clamp current meter with USB connection was placed at the spindle motor of the CNC milling machine and Kristler dynamometer were clamped underneath the jig for measuring the current and welding force, respectively. For welding trials, the spindle speed was varied from 750 to 950 rpm

at fixed welding speed of 150 mm/min. Figure 1 displays the experimental setup for this investigation.

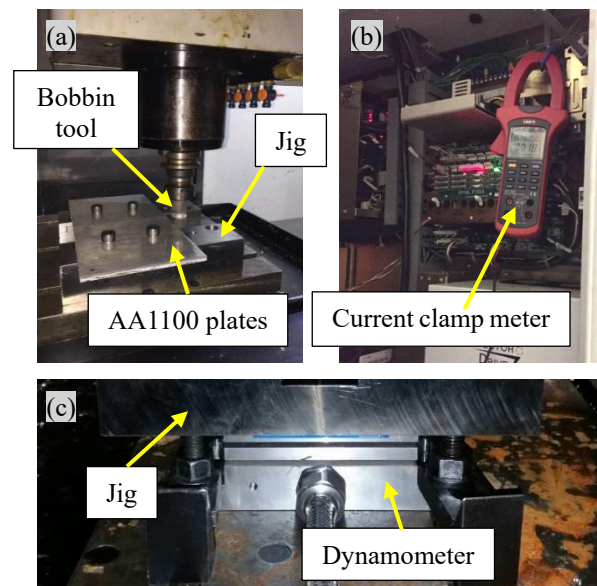


Figure 1 Experimental setup of the (a) welding work, (b) placement of current clamp meter and (c) dynamometer.

## 3. RESULTS AND DISCUSSION

Figure 2 vividly reveals the result of the current-time and force-time plots. Noted that the variation of the plot curves in Figure 2(a) for all of the welding trials were similar to the defined phases namely milling current, tool entry, weld phase and tool exit. On the other hand, the force-time plot in Figure 2(b) was recorded at spindle speed of 950 rpm and welding speed of 150 mm/min indicated three welding forces which were the travel force (force in y direction,  $F_y$ ), transverse force (force in x direction,  $F_x$ ) and axial force (force in z direction,  $F_z$ ).

Referring to Figure 2(a), the milling current phase is the current that consumed by the CNC milling machine to operate the bobbin tool without any welding work taken into action. For this investigation, the average current was consumed about 1.6 A. On the contrary, the forces of all directions found to be zero value as no welding was conducted.

When the bobbin tool started to touch the edge of the AA1100 plates, the current increase remarkably with the average value of 11.9 A. Similar pattern was found in force-time plot whereby the force in  $F_x$  and  $F_y$  showing

sudden increase with average value of 5 kN and 3 kN, respectively, while the force in Fz was nearly to zero. The increase of both current and force reading were due to the bobbin tool begun to stir the material from the retreating side (RS) of the weld and around the back of the bobbin tool and then transferred the material on the advancing side (AS) of the weld. As the bobbin tool rotated and traversed slightly, the peak current and all the forces values were slightly drop which believed that the AA1100 plates started to soften resulting from the frictional heat generated by bobbin tool to form the weld [3].

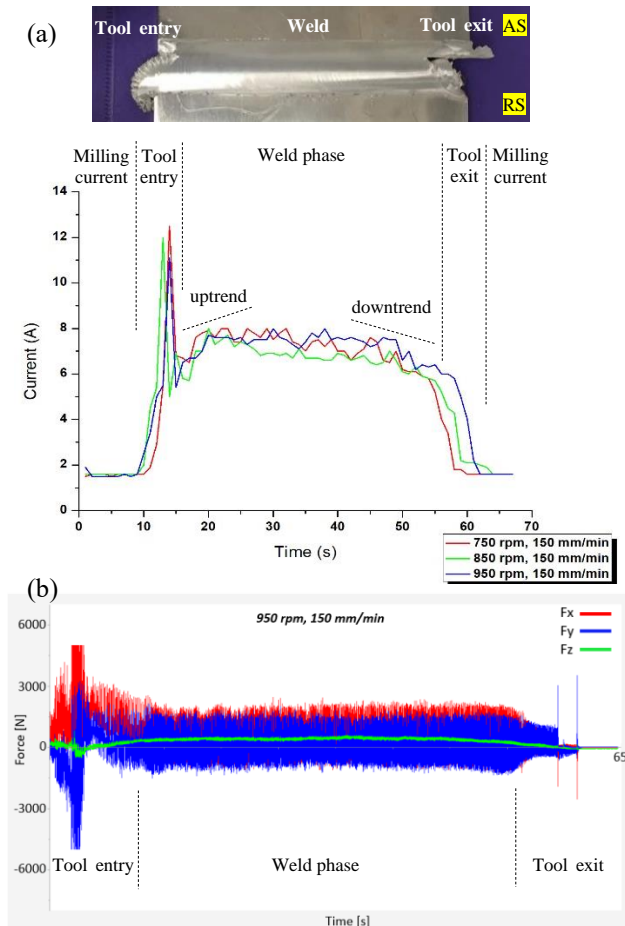


Figure 2 (a) Current-time plot and (b) force-time plot.

Entering the weld phase, there was two noticeable graph trend as depicted in Figure 2(a) which are the uptrend and downtrend. The uptrend was due to the load of the bobbin tool produced by the opposing shoulders as well as the material flow behind the bobbin tool to form the weld joint [4]. As the bobbin travels forward, the current became stable with the average value of 7.1 A. The downtrend indicated that the temperature of the material near the tool was increased causing the bobbin tool to have less effort to generate the frictional heat as the material was already softened.

On the other hand, as highlighted in Figure 2 (b) the forces in Fx and Fy display a stable trend with average peak value of 2 and 1.5 kN, respectively. The axial force in Fz direction was minimal compared to the force in Fx and Fy direction. Unlike the convention friction stir welding process, the axial force of BFSW is minimal and

absence due to the BFSW process started to penetrate the tool from the edge of the material which consequently influence the force in Fx and Fy more than the Fz. This result match with the finding found in [5-6].

Entering to the tool exit phase, the current reading of all the weld had sudden decrease before reaching the average value of 1.6 A at the milling phase current. In the same way, the force measurement in all direction shows that the peak force value started to drop reaching to the value of zero. The reason is that there was a disruption that stop the softened material to circulate from AS to RS of the weld which consequently due to insufficient material to stir [7] that resulting the bobbin tool released out from the material.

#### 4. CONCLUSION

As conclusion, throughout experimental work, the current consumption and force measurement of the BFSW on AA1100 was discovered and presented. Both signal processing measurements increased remarkably at tool entry as the bobbin start to build a weld. When the tool enters the weld phase, both measurements depicted stable data. Sudden decrease in both measurements found at the tool exit.

#### ACKNOWLEDGEMENT

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# Barriers and motivation of the solid waste management among manufacturing companies in Malaysia

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**Keywords:** Waste management; manufacturing

**ABSTRACT** – Solid waste management refers to the process of production, storage, source separation, collection, transportation, processing, recycling and disposal of solid waste. The objective of this study are to analyze the practice of solid waste management by manufacturing company, to investigate the barriers in manufacturing company and to identify a factor that can be the catalyst to execution solid waste management in manufacturing company. This paper is using qualitative method through semi-structured interview with five respondents in Malaysia. It was found there were six factor of barriers of the solid waste management, size is an important factor on solid waste management and maintenance the barriers to manufacturing company to implement solid waste management. This paper recommends to explore the solution of the awareness problem in the society about environmental issue.

## 1. INTRODUCTION

The increase of solid waste is a big problem faced by global. This was due because of the increase in the population of Malaysia at the rate of 2.4% or 600, 000 people on yearly basis. This has also led to an increase in Malaysia industry to fulfil need and waste of the Malaysia population. According to Jalil [1], solid waste produced from both industrial and household sector in the capital of Malaysia was 3500 metric tons each day [2]. Solid waste can be split into eight categories which are imported solid waste, commercial waste, garden waste, construction and demolition waste, household waste, industrial waste, institutional solid waste and public solid waste [3]. This proves that the industry is also one of the major contributor to increasing of solid waste in Malaysia. The quantities and type of industrial waste usually depend on the characteristic of industrial activity.

This problem will be worsened if solid waste management is not well-managed because it can cause pollution, resource degradation and health problem for humans and animals [3]. Example of environmental impacts is the loss of recreational facilities, damage or loss of biodiversity, air, water, land and noise pollution, loss of aesthetic landscapes and scenery and burst hazards [3]. To solve this problem, the government implement a landfill and recycling method of solid waste

generated. However, the landfill method also has problems and weakness such as difficult to implement and cause environmental pollution. Meanwhile, recycling method is difficult to implement because not all waste can be recycled. This problem has led into the implementation of solid waste management in manufacturing companies to help the government effort to reduce industrial solid waste. This is because effective waste management within the company can contribute to minimize and control the solid waste generated by manufacturing companies

## 2. METHODOLOGY

The qualitative research is often associated with an interpretive philosophy. It is interpretive because researchers need to make sense of the subjective and socially constructed meanings expressed about phenomena being studied. The needs to understand deeply about this study and the gaining accurate and strong data. Moreover, the researcher will give respondent some opportunity to discuss this topic in depth. Therefore qualitative method has been chosen, besides the researcher also can increase understanding of this topic.

In the study, interviewed with top-level managers and middle level managers. This is because top-level managers have a vast of the experience for managing solid waste in their company. In addition, the respondent is also in charge of decision making in managing the company solid waste. Meanwhile, the middle-level managers are responsible for implementing solid waste management and have extensive knowledge of the company solid waste. The respondent will create the objective of department to achieve a vision that has been set by top-level managers.

Thematic Analysis is a type of the qualitative research method. It is used to analyse categorizations and present themes (patterns) that relate to the data. According to Ibrahim [4], it illustrates the data in great detail and deals with various subjects via interpretations. Thematic analysis is considered the most suitable for any study that seeks to discover using interpretations [4]. Other than that, thematic analysis gives a systematic element to data analysis [4]. The researcher develops case

studies and need to use the interview method to gain a clear view and also get more detail data to improve the understanding of the research

### 3. RESULTS AND DISCUSSION

In conclusion, this research is about barriers and motivation of the solid waste management among manufacturing company in Malaysia. Overall, all the research objectives were achieved which is barriers of the implementation solid waste management, motivation of the implementation solid waste management solid waste management and the most influenced barriers of the manufacturing company to implement solid waste management. From Figure 1, it was found that six barriers to the implementation of the solid waste management among manufacturing company and six motivation implementation of solid waste management of solid waste management among manufacturing company. This research using the various method in finding answer objective of the research such as interview method and observation method. Other than that, the researcher found that maintenance factor is the factor that prevents the manufacturing company to implement solid waste management. This factor was never mentioned in any past study about barriers of the solid waste management. The researcher also found that the size of the company is playing the main role in this implementing the solid waste management. This is because the implementation of solid waste involves cost and procedures which the small size company mostly does not have the capability in terms of money and skills.

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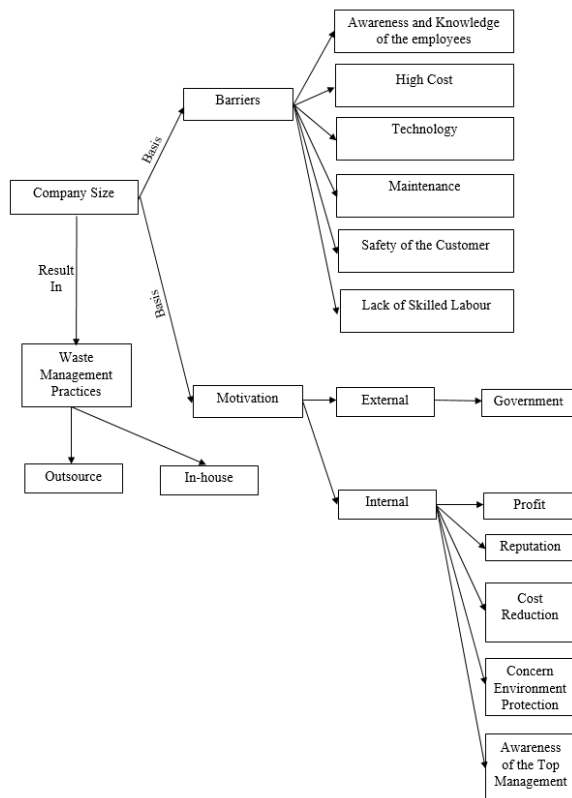


Figure 1 Result of the interview.

# Methodological hardware design and development of health monitoring

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**Keywords:** Health monitoring system; data acquisition system; internet of things

**ABSTRACT** – This paper presents the hardware methodological design and development of health monitoring system for an individual solar module. The proposed system comprises of four units of Thermocouple Sensors – MAX31855 Amplifiers, one INA 219 DC Voltage/Current Sensor, Raspberry Pi Zero Wireless, 16GB Micro SD CARD. The design and development of the proposed system is explained chronologically till preliminary system operation is achieved. Preliminary system operation findings for Thermocouple – MAX31855 Amplifier Sensors for Temperature and INA 219 DC Current/Voltage Sensor for current and voltage results are observed, recorded and analyzed. And, overall system integration is also validated based on the preliminary obtained results.

## 1. INTRODUCTION

Several solar module forecasting methods can be found in the specific literature [1-7]. All these systems are developed to sense and measure the solar module output based on the real-time condition. Therefore, real-time temperature, current and voltage parameters monitoring allows to predict the health of solar module. Moreover, real-time temperature, current and voltage parameters [8] monitoring provides real local information of an individual solar module and ensure the output reliability of an individual solar module [9].

This paper methodologically explains about the hardware design and development of health monitoring system for an individual solar module. The proposed system comprises of four (4) thermocouple sensors each integrated with a MAX31855 amplifier, an INA 219 DC Current/Voltage Sensor and Raspberry Pi Zero Wireless system board to integrate all the thermocouple sensors and INA 219 DC Current/Voltage Sensor. The thermocouple sensors integrated with MAX31855 amplifier is embedded at the back of the solar module to detect the solar module temperature which can be used to analyses the solar module performances when the temperature fluctuate. Meantime, INA 219 DC Current/Voltage Sensor is connected to the positive solar module wire to sense and measure the output voltage and current of the solar module.

## 2. METHODOLOGY

The proposed health monitoring system section shows the conceptual block design of the proposed health monitoring system in Figure 1 before the actual hardware shown in Figure 2 is developed after reviewing the previously developed system. General architecture

shown in Figure 2 explain about the proposed hardware development of health monitoring system for individual solar module.

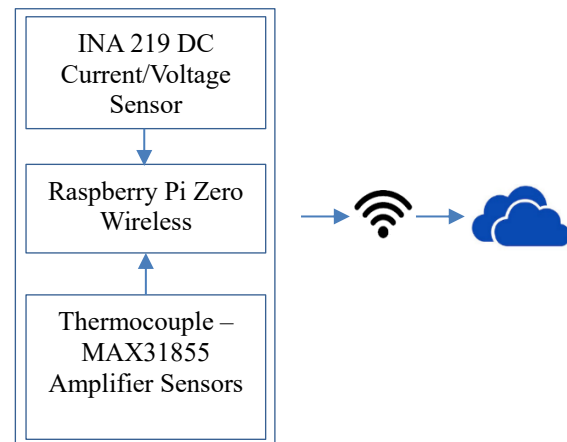


Figure 1 Block Diagram of solar health monitoring system.

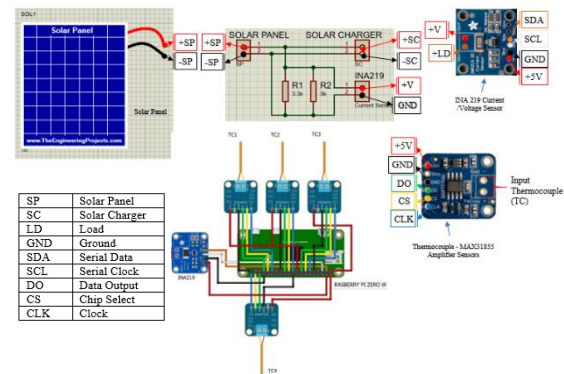


Figure 2 Proposed hardware system design – solar health monitoring system.

Figure 2 shows the proposed hardware system design for the solar module health monitoring system. Referring to the conceptual design in Figure 1, the components mentioned in Figure 1 is used to design the layout shown in Figure 2. Some other additional components such as the solar module and current divider is also used in the layout. The solar module is connected to the current divider to limit the output current before entering the INA 219 DC Current/Voltage Sensor. The high output current from solar module is stepped down to support the characteristic of INA 219 DC Current/Voltage Sensor. This also to allow the INA 219 DC



Current/Voltage Sensor to perform the real-time voltage and current sensing and measurement.

### 3. HARDWARE SYSTEM DEVELOPMENT

The +SP and -SP is connectivity of solar module to the current divider. The +SC and -SC is the connectivity to the charge controller and +V at current divider connects +V at the INA 219 DC Current/Voltage Sensor, whereas the GND at the current divider connects to the GND at the INA 219 DC Current/Voltage Sensor. The INA 219 DC Current/Voltage Sensor is powered using +5V. The SDA and SCL connected to the SDA and SCL of the Raspberry Pi Zero Wireless. The MAX31855 Amplifier Sensor is powered using +5V, and the DO, CS and CLK is connected to the Raspberry Pi Zero Wireless.

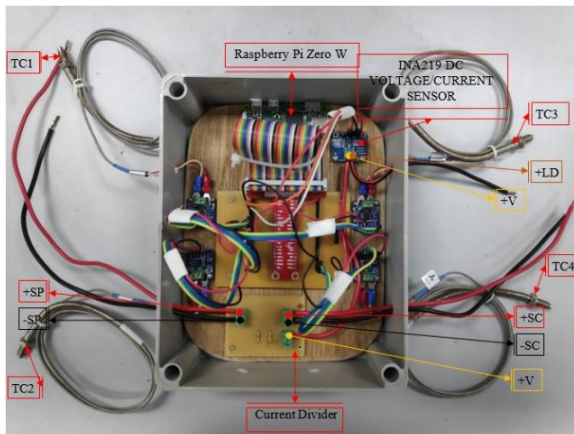


Figure 3 Developed health monitoring system – integrated with thermocouple MAX31855, INA219 DC voltage/current sensor, raspberry pi zero wireless.

### 4. RESULTS AND DISCUSSION

Figures 4 and 5 presents the preliminary results of current, voltage, power and temperature obtained from the installed INA 219 DC Current/Voltage Sensor and Thermocouple – MAX31855 Amplifier Sensors.

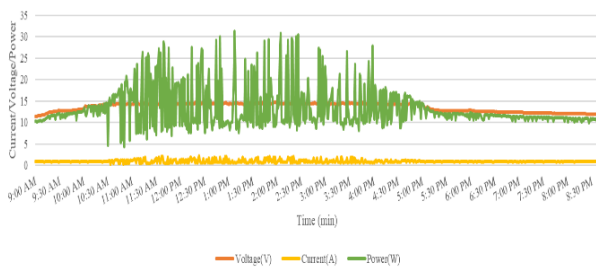


Figure 4 Measured current, voltage and calculated power.

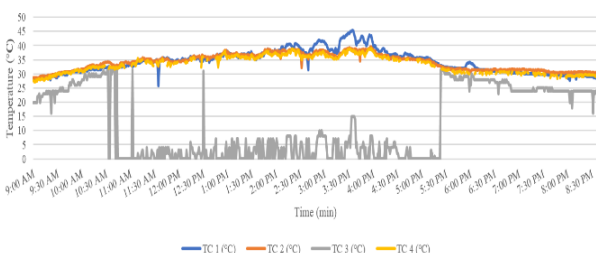


Figure 5 Sensed and measured solar module temperature.

### 5. CONCLUSION

The proposed methodology shown in Figure 2 is used to develop the system shown in Figure 3. Thus, the proposed methodology is validated by obtaining the results presented in Figures 4 and 5. The obtained results in Figures 4 and 5 explained the successfulness of the proposed hardware system operation and functionality to achieve the objective to monitor the health of an individual solar module.

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# Measurement and analysis of energy consumption in a university building

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**Keywords:** Energy consumption; educational building; energy audit

**ABSTRACT** – In this paper, proposed a measure and evaluate existing internal parameters, which focused on the Language and Human Development Centre (PBPI) building at the Universiti Teknikal Malaysia Melaka (UTeM) main campus. Physical parameter requirements compared to current Malaysian Standards (MS 1525:2014). The paper also analyses the effects of indoor parameters at the comfort level of the occupants and investigates the impact of lighting changes as well as to evaluate energy consumption. The air-conditioning recorded the highest rate consumption that was 72% of electricity usage in the building, followed by the consumption of lighting at 18% and other equipment 10%. Finally, economic analysis is accompanied by potential alternative measures to achieve optimum building energy utilization.

## 1. INTRODUCTION

Nowadays, sustainability and environmental issues has great attention in relevant policies and strategies for developing countries [1]. The growing number of commercial premises and development projects for a residential and non-residential buildings impact the demand of energy in the country. Therefore, relevant policies and strategies are adopted to preserve and sustain the environment [2,3]. It is evident that electrical energy utilized in buildings continues to increase and will continue to grow in demand [4], utilized by the advanced technology used in electrical equipment [5]. An energy audit is crucial to obtain an optimal energy performance by reducing the energy waste and improve the efficiency of air-conditioning and lighting systems [6,7].

In this present work, a Detailed Energy Audit has been conducted at the selected building and all related data about that building was collected in order to get overall picture of the building energy consumption. Energy saving measures that can be implemented in the building are discussed.

## 2. EVALUATION STRATEGIES

The methods applied in this study, included gathering field data by doing measurements and field study on the energy consumption at the PBPI building. Inspection of the air-conditioning and mechanical ventilation (ACMV) and lighting systems were conducted for the building.

The PBPI building provides many of facilities such as language laboratories, lecturer rooms, classrooms and

administration offices as shown in Table 1. The area of the building is 5992.58 m<sup>2</sup> and a picture of this building that consists of three levels. The normal operating hours of this building is from 8:00 AM to 5:00 PM.

Table 1 PBPI building description.

Floor	Content
Ground	Lobby, SALL, 7 Lecturer's room 3 Language lab Main office
First	Language teacher rooms Lecturer rooms 4 Language lab Dean office BAKUTE unit
Second	9 Lecture room ISO room Seminar room

## 3. RESULTS AND DISCUSSION

This section discusses about the data collected and the result obtained from the calculation and sites walk through. All the data will be interpreted and discussed related to the case study building in this study. The results of physical parameter measurement will be compared with the Malaysian Standards for future recommendation to evaluate their performance

The collected data for electricity consumption for the duration of two years (July 2016 to Jun 2018) is presented in Figure 1. As the figure indicates, most of the energy consumption was decreased in March until April. The PBPI timetable will decrease in January until February and July until August.

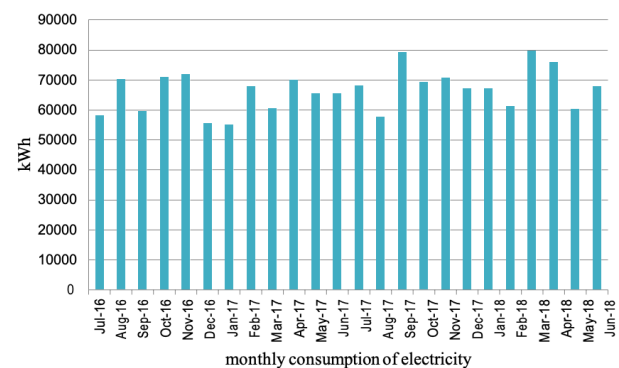


Figure 1 Monthly energy consumption between July 2016 into June 2018.

The case study building was divided into levels and each level is divided into ten measuring points and the

process of observation was conducted. The process observes the ACMV and Lighting specifications of every zone. Figures 2 below shows the total energy consumption for the building.

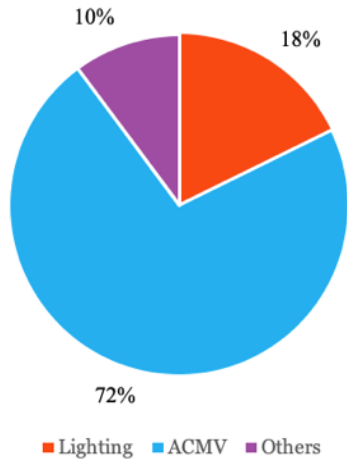


Figure 2 Energy Consumption (%) for PBPI building.

The following steps are recommended for reducing energy consumption.

- (a) Reduce cooling loads: A simple method for reducing cooling load can be implemented through isolating the building from the environment using high scale types of insulation, enhancing the glazing area, and minimizing the infiltration of outside air.
- (b) Reduce lighting loads: Energy usage for lighting can be reduced in two ways: reducing the amount of artificial light required and using more efficient technology.
- (c) Increase efficiency of appliances and cooling equipment, and ventilation.
- (d) Implement commissioning and improve operations and maintenance:
- (e) The actual performance of a building depending on the type of construction as on the quality of the design itself.

#### 4. CONCLUSION

Based on the results, existing ACMV system was found contributing about 72% of the total energy usage. It was followed by lighting, contributing about 18%. All other appliances, however, were found contributing only 10%. This result reveals the importance of taking actions to reduce energy consumption, especially the use of air-conditioning in the building.

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# An integrated approach of monitoring indoor environment inside building

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**Keywords:** Arduino; python; live-feed

**ABSTRACT** – Comprehensive utilization of open-source platform for indoor environment monitoring and visualization is getting prominently accepted due to their admissible tolerance of observational error. The Arduino-based platform is one of a flexible open source microprocessor developmental boards that allowed monitoring activities while permitting multiple platforms for streaming and storing of input from the sensor. This article provides the building blocks for streaming live-feed data from Arduino-based platform using python. Arduino Uno and DHT11 sensor combinations were used to test for a live streaming of temperature and humidity. The live-feed projection of both data was showed in the result section.

## 1. INTRODUCTION

Human spends almost an eternity perfecting an indoor environment for the sake of providing a comfort daily activity and working environment. One of the significant efforts is by conducting a monitoring activity to obtaining a full figure on the real environment condition. Since then, the monitoring activity keep improving and evolving succeeding the technology of microcontroller. For a compact microcontroller development board, it surely offered significant features revolving around collectively assessing program for a network of heterogeneous embedded devices. Moreover, Louis [1] described Arduino-based microcontroller development board as a very convenient, affordable yet open source option for utilizing sensors and actuators functionalities. Furthermore, Ali et. al. [2] introduced the term Open Source Building Science Sensors (OSBSS) to further described variety of Arduino platform integration. OSBSS was characterizes as a low-cost open source platform to serve the purpose of capturing an indoor environment and building operational quantifiable parameter for further analysis.

Even though Arduino Integrated Development Environment (IDE) provides a serial monitor which represent as a location where all the input from sensor being dumped however, it is more interactive to project the reading in a form of live-feed graph. Any irregularities can be easily spotted with proper sensor reading projection. For instance, El Hammoumi et. al. [3] utilizing LabVIEW Interface for Arduino (LIFA) as a medium for a real time sensor reading plotting and visualization. Constructing a block diagram for virtual instrumentation thus enables LabVIEW to have serial

connection with Arduino and visualizing the sensor reading. This article provides the building blocks for streaming a live-feed data from Arduino-based platform using python.

## 2. METHODOLOGY

The key element in determining a whole framework is by dictating the whole system architecture which includes software, hardware and algorithm arrangement.

### 2.1 System Architecture

For the purpose of this case study the sensing unit consists of a DHT11 sensor module (temperature and humidity sensor) and Arduino Uno board (ATmega328P) as shown in Figure 1. On the other hand, temperature humidity module provides humidity ratio reading in the range of 20 to 90% and for the temperature reading in the range of zero to 50° C. Moreover, the communication between the DHT11 sensor module and Arduino was assigned on the digital pin.

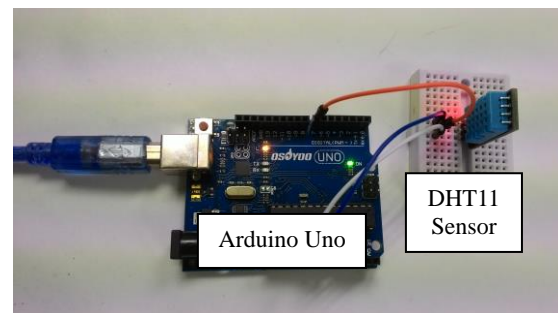


Figure 1 Circuit assembly.

The flow chart in Figure 2 described the algorithm of the passage of Arduino sketch and python code for sensing unit and live-feed streaming respectively. First and foremost, the programs line begins with the inclusion of all necessary python library modules to assist in communication, plotting and updating live graph and provide data array. Next in the line is defining the communication path by which declaring the input pin for sensor and stating the baud rate where python receiving sensor input from the Arduino. Further step is introducing a program loop which enable live feed log and plotting of sensor data. The program stops once the Arduino was disconnected.

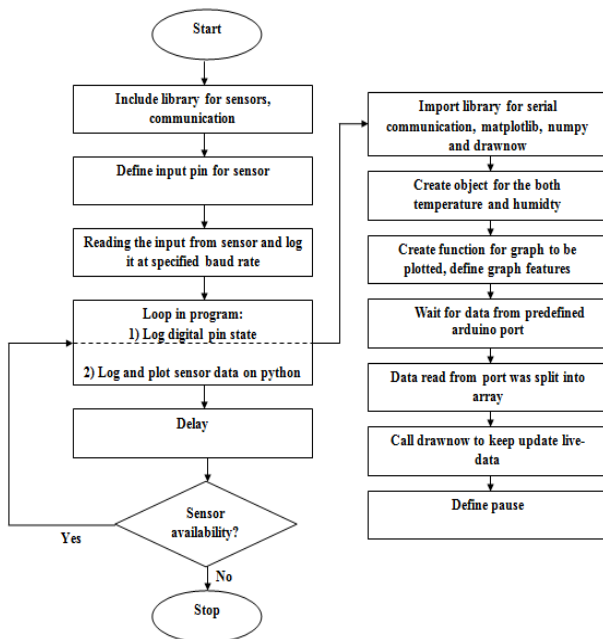


Figure 2 Algorithm on the flow of the Arduino sketch and python code.

### 3. RESULTS AND DISCUSSION

Figure 3 shows a sample projection of live-feed DHT11 sensor module reading. The features observed on the graph are pre- defined in between the line of code as described in the algorithm section of methodology. To avoid any unnecessary interruption of sensor data projection, ensure only python's were allowed to listen to the Arduino port in the pre-determined serial connection. To enable the live-feed graph using python, highlighted libraries (numpy, matplotlib, drawnow) in the algorithm must first be retrieved. This all the libraries that are crucial to keep the data feed from the serial connection being updating and plot instantaneously.

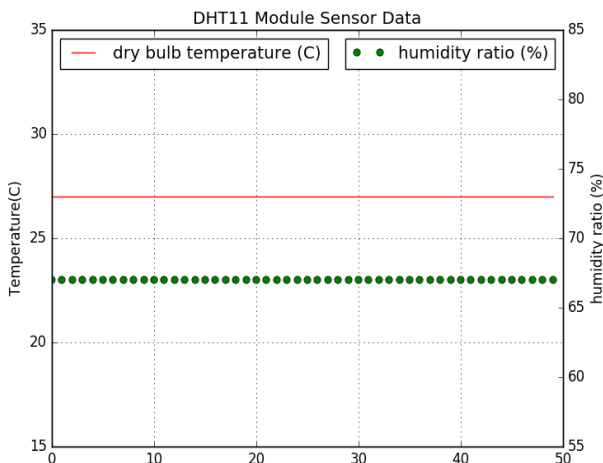


Figure 3 Live-feed sensor module reading projection by using Python.

The features appear on the live-feed graph for instance, the plot lines, set limit and range, colour choices and labelling style is totally flexible and comes in handy with varieties. As for example, the lines `plt.plot(temperature, 'r-', label='dry bulb temperature (C)')` and `plt2.plot(humidity, 'go', label='humidity ratio`

(%)') in the program was written to specify and differentiate between temperature and humidity reading respectively. On the other hand, Figure 4 shows a building block that describes the element to be integrated between Arduino and Python itself. Arduino platform was described sensing unit which obligated to received sensor input and provides a serial connection thus the listening port for Python. While Python actively streams the real-time sensor data it also permitting data dumping into the Comma-separated Values (CSV) file format. Thus, it can be securely stored for further analysis.

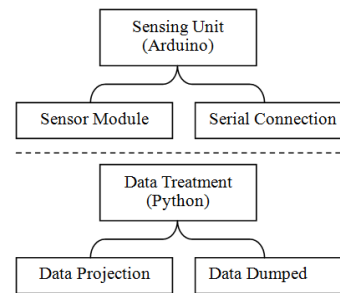


Figure 4 Building block of integration between Arduino and Python.

### 4. CONCLUSION

DHT11 sensor module data projection using python is quite straightforward thus, very convenient. With little effort and basic programming knowledge whole system that utilized an open source platform for monitoring and data visualization can be accomplished successfully. Though Live-feed sensor data streaming is considered as interactive and convenient, other aspects such as data dumping must carefully plan for effortless access.

### ACKNOWLEDGEMENT

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# Investigation on air conditioning oversizing impact using computational approach

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**Keywords:** Oversizing; air conditioning, computational

**ABSTRACT** - This paper aims to investigate air conditioning system's oversizing impact through direct observation and computational approach. In this study, oversizing is determined when a system is sized higher than industry's practice, formation of mold and rapid fluctuation of temperature and relative humidity in a room. The simulation shows that oversized air conditioning system does lead to higher energy consumption and promotes favorable condition for mold growth.

## 1. INTRODUCTION

According to Suruhanjaya Tenaga Malaysia, Residential and commercial sector accounted for 14.6% of Malaysia's total energy consumption in 2015 [1]. With the construction industry projected to grow 7-8% annually, it is safe to assume that energy consumption will steadily increase in the future. With air conditioning system typically contributed around 58% of energy use, it is an important area to analyze in order to avoid any energy wastage in commercial buildings. Despite that, there is tendency to over-design and over-specified by the engineers during design process to mitigate risk, which impact the ability of these systems to operate at their optimum efficiency point.

Study on the impact of oversized air conditioning system has been conducted many times in the past. Simulation tools has been widely used to study oversizing impact due to its dynamic ability to simulate various building condition. The study by Djunaedy et al for example has shown that oversizing of rooftop unit (RTU) amounted to 37% to 48% of energy increases compared to as-designed condition [2]. Woradehjumroen et al analysis of 268 RTUs finds that oversized capacities is prevalent with energy penalty between 34.66 kW to 226.41 kW [3]. James et al collected data on 368 homes and found 3.7% to 9.3% increases of energy with oversized capacity between 20% to 50% [4]. Booten et al provides further explanation in explaining that oversized air conditioning unit leads to additional energy use due to increase on-off cycling relative to correctly sized unit [5].

Another undesirable consequence of poorly designed air conditioning system is that it can promote mold growth in buildings. Mold growth is undesirable since it creates odor problems, cause damage to building material and hazardous to human health. Source of mold

in air conditioning system can come from outdoor air or inside the air conditioning system components itself. Malaysia's tropical climate means that outside air flowing inside the air conditioning system is naturally high in moisture content favorable by mold. Furthermore, the air conditioning system components itself provides conducive breeding ground as it is easily found in filters, insulation and drain pan as reported by Prezant et al [6]. According to Yau and Ng, mold growth in a room is exacerbated when the air conditioning system's cooling coil fails to remove air moisture content below 70% relative humidity [7].

However, majority of the studies as discussed earlier are conducted in seasonal countries and cannot be compared to Malaysia's tropical weather. Furthermore, the seasonal countries weather is not conducive for mold growth. Thus, this study aim to understand the impact of air conditioning oversizing to both energy and mold based on real building facing these issues.

## 2. BACKGROUND AND METHODOLOGY

A University Bio-Molecule Laboratory in Perak has been severely infected by mold which raises health concern among its occupants. The air into the room is delivered by water cooled, ducted fan coil unit (FCU) and returned back through ceiling plenum. Room temperature and relative humidity is recorded using data logger. To ensure that mold problem originates from air conditioning system, all other potential causes of mold such as leak water pipe or unnecessary infiltration openings were checked and confirmed to be non-existent. Existing air conditioning system's parameters are then compared to recommended figures as provided in ASHRAE Handbook – Fundamental [8].

To achieve the objective of this work, the existing FCU cooling capacity and air flow is remodeled using IES-VE 2017 software as shown in Figure 1.

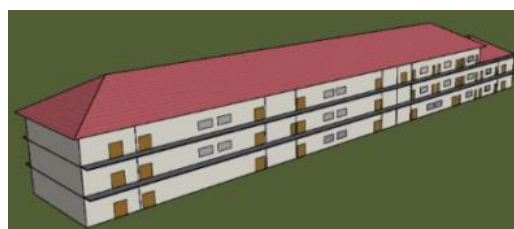


Figure 1 Building model using IES-VE.

The simulation setting is modelled to resemble the actual building as closely as possible including its building envelope properties, internal and external heat sources and air conditioning system's components as shown in Table 1. The simulation setting was then resized using the simulation tool in order to establish the room's optimal air conditioning needs. The simulation result's capacity, temperature and relative humidity were then compared and analyzed to draw conclusion.

Table 1 Simulation setting using IES-VE 2017/

Component	Setting
Building Envelope	Area 1,860 ft <sup>2</sup>
	Wall 0.4 Btu/hr/ft <sup>2</sup> /°F
	Window 1.2 Btu/hr/ft <sup>2</sup> /°F
	Floor 0.25 Btu/hr/ft <sup>2</sup> /°F
Internal Heat Source	People 40 person
	Lighting 2 W/ft <sup>2</sup>
	Equipment 0.5 W/ft <sup>2</sup>
Air Conditioning System Components	1. Fan
	2. Cooling Coil
	3. Ducting
	4. Chilled Water From Chiller

### 3. RESULTS AND DISCUSSION

From the gathered data, temperature and relative humidity recorded is at favorable range for mold growth as manifested by its formation at wall and office furniture. The temperature and relative humidity recorded is shown in Figure 2 and Table 2.

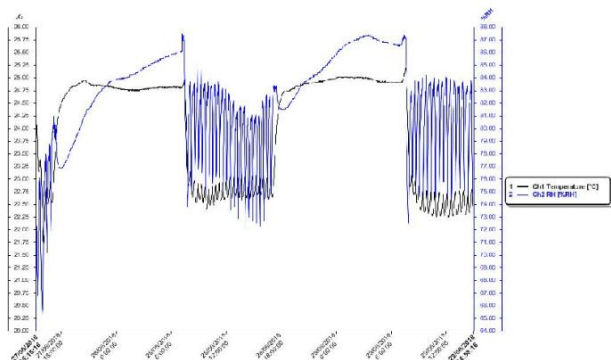


Figure 2 Temperature and relative humidity profile.

Table 2 Average recorded temperature and relative humidity.

Time	Temperature (°C)	RH (%)
Overall	23.99	82.3
0700 - 1800	22.5	77.1
1800 - 0700	24.8	84.9

Using ASHRAE Pocket Guide for Air Conditioning, Heating, Ventilation, Refrigeration's recommendation, the FCU unit capacity can be categorized as oversized considering that the cooling load per area is 70.2 Btu/ft<sup>2</sup> and flow rate per area is 2.4 cfm/ft<sup>2</sup> which is higher than the recommended value of 60 Btu/ft<sup>2</sup> and 1.4 cfm/ft<sup>2</sup> [9]. Room temperature profile supports this observation where it shows that temperature rise and fall within short period of time. This indicate that the FCU only need short time to cool

the room before cooling process stops by shutting off the control valve. Relative humidity also show rapid rise whenever control valves shuts off. Its consistently high room relative humidity during operating hours shows that the cooling coil is improperly sized and fail to dehumidify incoming air.

The simulated optimal air conditioning capacity of the room is compared with existing FCU as shown in table 3 while the simulated temperature and relative humidity between existing and re-calculated FCU is shown in table 4. Result shows that the simulated FCU cooling capacity per area and flowrate per area falls within ASHRAE recommended average which implies that the existing FCU cooling capacity is oversized by 42.3% while its air flowrate is oversized by 95.6%.

Table 3 Comparison of FCU capacity.

Comparison	Existing	Simulated
Capacity (Btu/hr)	143,000	100,518
Airflow (CFM)	4,500	2,300
Cooling per area (Btu/ft <sup>2</sup> )	75.9	50.6
Air Change (nos.)	14.6	7.2
Airflow per area (CFM/ft <sup>2</sup> )	2.3	1.2
Energy (MWh)	3.8	1.3

Table 4 Comparison of room temperature and relative humidity.

Average	Simulated existing		Simulated re-calculated	
	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)
Overall	25.6	74.5	25.7	65.6
0700 - 1800	23.3	75.2	23.1	59.1
1800 - 0700	27.3	73.9	27.5	70.2

Similar to field data, relative humidity for simulated FCU at original cooling capacity remain consistently high. Result of simulated re-calculated FCU on the other hand shows that relative humidity has been reduced to within acceptable range as shown in Figure 3. In term of energy, the impact of reducing FCU capacity is significant as it only consumes 34.2% power compared to existing FCU.

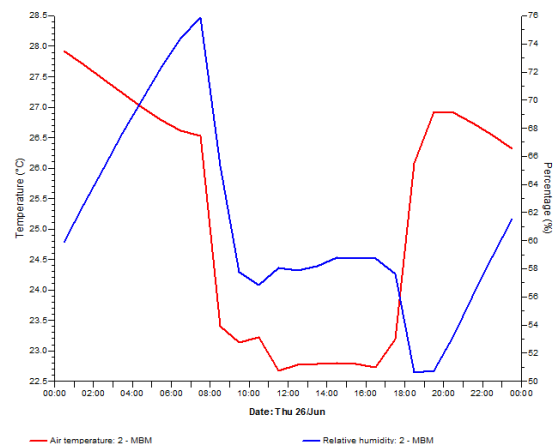


Figure 3 Simulated temperature and relative humidity profile.



#### 4. CONCLUSION

The simulation results has shown that (i) oversized air condition system lead to higher relative humidity which is favorable for mold growth and (ii) leads to unnecessary energy wastage due to high power consumption. As the simulation above only represents FCU blower, the energy saving for the whole air conditioning system should be higher once saving from other energy-intensive equipment such as chillers, pumps and cooling towers are considered.

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# Performance analysis of DC-DC converters for road pavement thermoelectric system

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**Keywords:** Road pavement; thermoelectric; DC-DC converter

**ABSTRACT** – This paper aims to investigate the performance and behavior of road pavement thermoelectric system which can generate electrical power based on thermal energy harvesting. Two types of DC-DC converters were studied to find which can store generated power from TEG (Thermoelectric generator) efficiently into a supercapacitor. Both the indoor and outdoor experiments showed that DC1577A can charge supercapacitor faster than ECT310.

## 1. INTRODUCTION

Sun produces sunlight or light energy that also offer thermal energy. This thermal energy will be absorbed to earth surface causing them to be hot. Road surface which is paved by human absorbs and stores more thermal energy due to its black color causing them to be hotter than soil. This provides an idea for researchers to harvest thermal energy from road pavement.

Datta has developed TE energy harvesting prototypes for road pavement by studying the metal conducting plate dimension. The prototypes able to produce average power of 10mW in 8 hours for weather condition in South Texas [1].

DC-DC converter is a device that can convert an input voltage to another desired voltage. DC-DC converter can be divided into two; buck converter to produce a lower voltage than the input voltage, while a boost converter generates a higher voltage. MPPT or Maximum Power Point Tracking is a DC-DC converter that can optimize or maximize the power extraction from solar panel or TEG to a storage device by changing the current or voltage, so it matches the storage device.

Several researchers have proved that DC-DC converter can help produce higher power efficiency. Experiment done by Mamur and Ashika [2] showed that their portable TEG device can produce 92% of power efficiency when using DC-DC boost converter with MPPT compared to direct connection to the battery with only 55% efficiency. According to Montecucco et al., a system which computes MPPT algorithm using a buck converter embedded with a microcontroller can quickly and precisely track more than 90% maximum power from TEG [3].

Aim of the paper is to examine the performance of road pavement TEG system based on the output voltage from DC-DC converters. The experiments are conducted inside and outside laboratory experiments to show the real world performance of the system.

## 2. METHODOLOGY

A pavement sample was constructed using a plywood box with a dimension of 300mm x 300mm x 100mm (length x width x height) which is then filled with cold premix asphalt. 5 copper plates with dimension of 300mm x 40mm x 1mm (length x width x thickness) were used as heat collectors. One ends of the copper plates were planted into the pavement sample while the other ends were glued to the hot side of TEGs. A water tank with a dimension of 350mm x 150mm x 160mm (length x width x height) is then attached to the cold side of TEG using thermal paste. The water tank is used to cool down the TEG and generate high temperature gradient between both side of TEG (hot and cold sides) because the higher the temperature difference, the greater the voltage output.

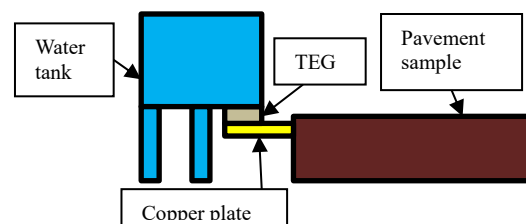


Figure 1 Experimental setup diagram.



Figure 2 Outdoor experimental setup.

Two types of DC-DC converters were used in the experiment; DC 1577A and ECT 310. Both converters were chosen because they can produce output voltage about 5 V while the storage device to be charged were 2 pieces of 2.5V 5F supercapacitors in series which produced 5V total of electrical power. The experiments were conducted up to four hours.

These tests are divided into two parts; Part I: Indoor Test and Part II: Outdoor Test. For indoor test, the experiments were conducted inside a laboratory. The pavement sample was covered with a box which contain of two 100W incandescent light bulbs. The box and bulbs will provide constant environment to ensure the data is reliable. The outdoor tests were done by harvesting thermal energy from sun to the asphalt sample and

transfer it to metal plates. The outdoor test is important because it will show the performance of the prototype in the real world. The outdoor test is conducted at 11.00 AM until 3.00 PM because highest amount of sunlight is produced during that time.

### 3. RESULTS AND DISCUSSION

All the graph has the same setting, where “Input 0” is the input voltage from TEGs to the DC-DC converter while “Input 2” is the supercapacitor voltage.

#### 3.1 Part I: Indoor Test

As shown in Figure 3, the input voltage increases and maintain at nearly 60mV. At this time, the ECT310 already produces 5V output because ECT310 just need a minimal of 20mV input to boost to 5V. The supercapacitor charging slowly from 0V until a maximum value of 750.10mV.

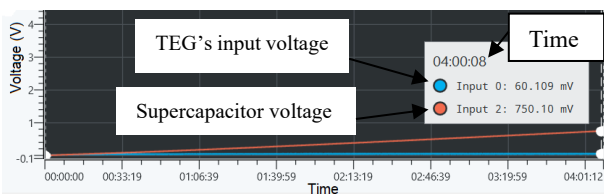


Figure 3 Graph for ECT310 indoor.

Figure 4 shows the TEG input voltage increases from 0 to 405.43mV in 15 minutes and 19 seconds. During this time, the input voltage is less than the MPPT voltage (400mV), thus the MPPT circuit adjusts its inductor current so the voltage input ascends to 400mV. When it reaches 400mV, the MPPT voltage is maintained but the MPPT's current increases. Thus, the charging of supercapacitor becomes faster. The maximum voltage stored in the supercapacitor is 4.3766V.

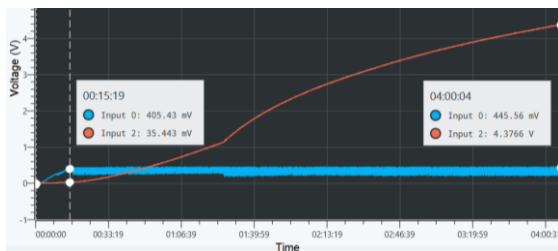


Figure 4 Graph for MPPT DC1577A indoor.

#### 3.2 Part II: Outdoor Test

Based on Figure 5, input voltage increased from 0V and maintain at about 50mV. Supercapacitor final value is 732.34mV.

Figure 6 shows the TEG's input voltage increases from 0V to 0.4V in about 15 minutes and 5 seconds. The voltage of supercapacitor increases until 4.1524V.

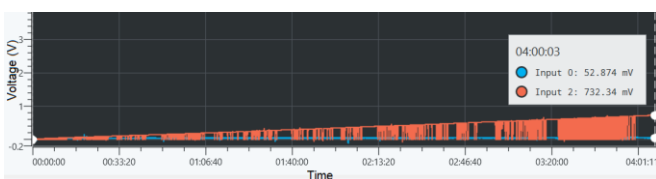


Figure 5 Graph for ECT310 outdoor.

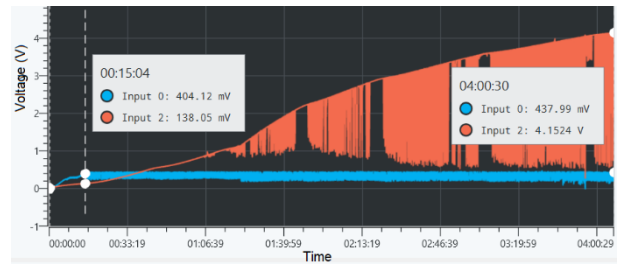


Figure 6 Graph for MPPT DC1577A outdoor.

In comparing for both DC-DC converters, the DC1577A showed more promising ability to charge supercapacitor more efficiently. This is due to the fact of DC1577A is an MPPT which enable it to extract the maximum available power from TEG, while ECT310 is a normal DC-DC converter which only able to produce higher voltage output. Moreover, the experiments showed that the indoor test can charge supercapacitor faster compared to outdoor test because pavement sample does not have to experience external noises such as wind and cloud. Wind can blow cool air to pavement surface which makes the thermal energy is carried away consequently make it cooler than it should be. Cloud movement can also affect the heat absorption from sun because cloud can prevent solar to reach the pavement surface for a short period of time frequently, which makes it less hot.

### 4. CONCLUSION

In conclusion, DC-DC converter for thermal energy harvesting from road pavement can increase voltage input from TEGs to charge supercapacitor. DC-DC converter with MPPT ability (DC1577A) can charge supercapacitor faster 4.1524V compare to normal DC-DC converter 0.732mV within the same period of time. Wind and cloud can affect road pavement heat absorption thus decreasing power output from TEG.

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