# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Introduction

In this project, there were two Savonius VAWT that had been designed in order to determine the most efficient design of the blade rotor. Some experiments regarding the most efficient design of VAWT had been conducted by some other researchers and students earlier before. The researches consisted of comparing the types of VAWT that have been built, the factor for a better performances such as angular speed (ω), power coefficient ($C_P$), torque coefficient ($C_T$) and tip speed ratio (TSR). The design for both shapes of the blade rotors was chosen based on the literature reviews done and also their theoretical measurements.

To fulfil the objectives of this project, there are some alternative ways to get a better performance for VAWT. Using a wind concentrator had been proposed where it will allow a better wind energy flow to the blade in order to get a better performance of VAWT. Instead of using wind as the only source of air stream, the additional source of air from the air compressor of an air-conditioning system can also be used for good. The design of the wind concentrator was chosen based on the literature reviews and theoretical measurements. Therefore, the performances of Savonius VAWT with and without using the wind concentrator can be investigated.

The real hardware was fostered by referring to the proposed design and analysis of conventional and helical Savonius VAWT blade rotors including the design of wind concentrator. The final output was recorded and analyzed to obtain the final result of the experiment. The summary of the methods are constructed on the project flow plan as depicted in Figure 3.1:

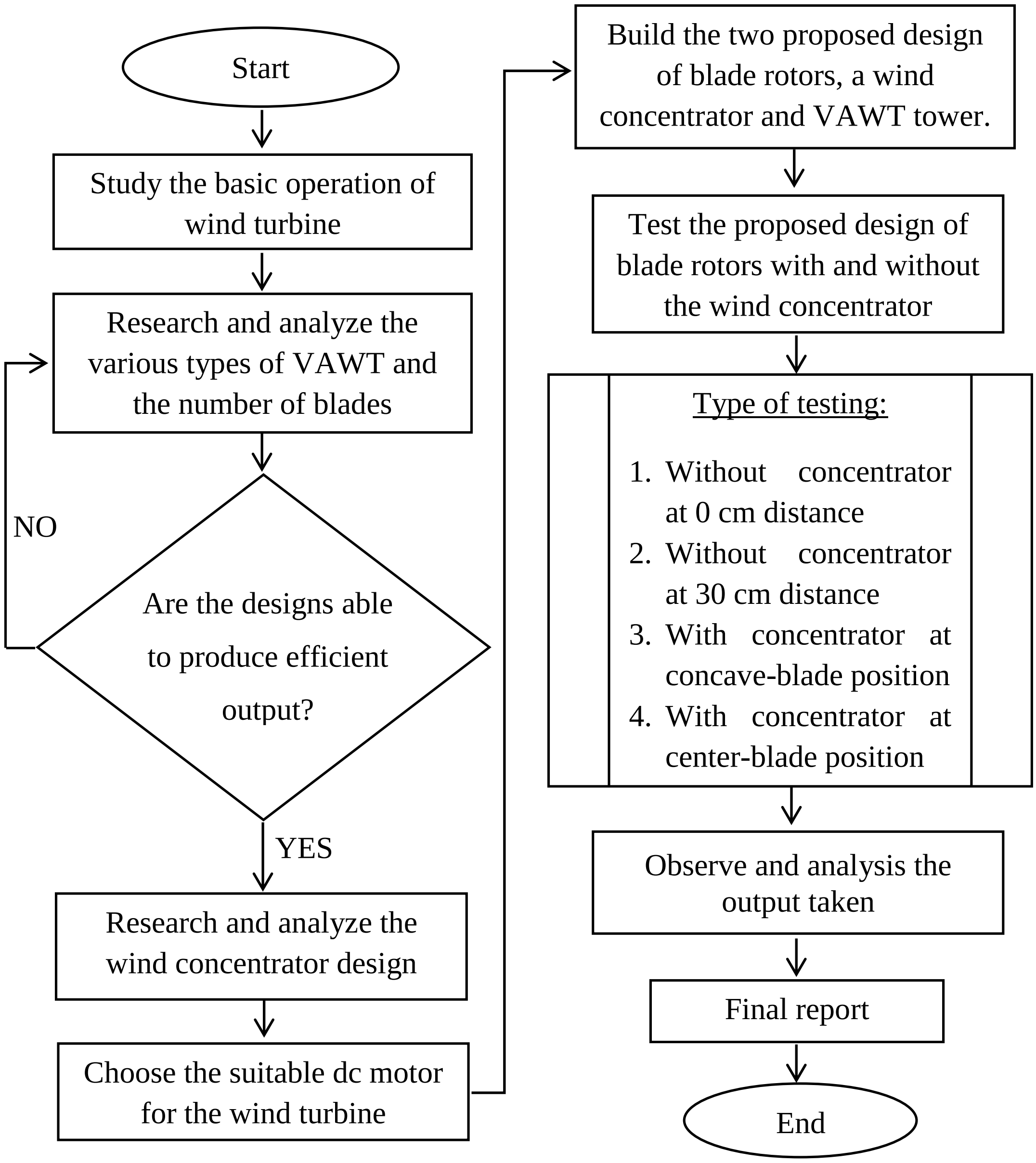
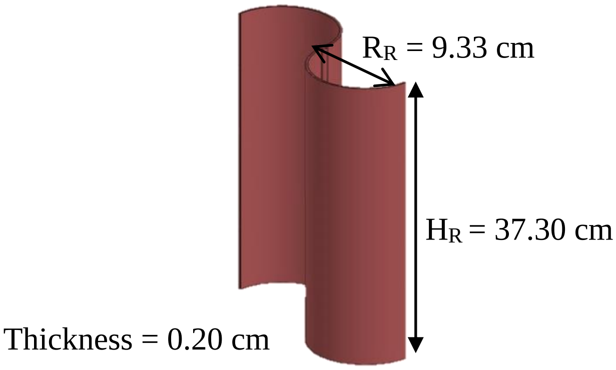
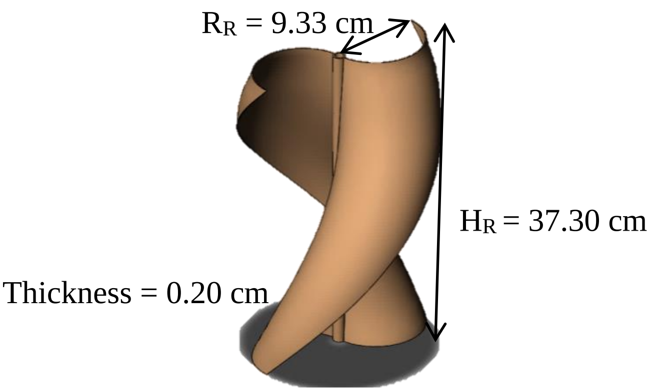



**Figure 3.1:** Project flow plan

## 3.2 Savonius VAWT rotors design

The designs of the two proposed of Savonius VAWT blade rotors vary in their shape. Table 3.1 below visualizes the difference of their designs. However, the dimensions and thickness for both blade rotors were maintained the same.

**Table 3.1:** Designs of Savonius VAWT blade rotors

| No. | Design | Diagram |
|---|---|---|
| 1 | Conventional Savonius |  |
| 2 | Helical Savonius |  |

The parameters that were being considered in this design are listed as follow:

i. Light-emitting Diode (LED)

Based on the lowest power rating among LEDs which are from yellow or red-coloured LED. The maximum power rating is 0.044 W where the voltage is between 1.8 V to 2.2 V and current is 20 mA.

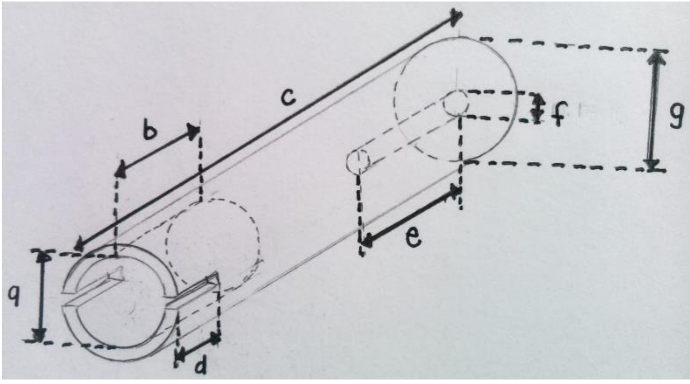
ii. Power coefficient, $\boldsymbol{C_P = \frac{2P}{\rho_a A_R v^3}}$

Based on literature review, the optimum $C_P$ is equals to 0.3 [11, 12].

iii. Aspect ratio = $\frac{H_R}{D_R}$

Based on aspect ratio equation, $H_R$ is height of the rotor while $D_R$ is diameter of the rotor. As the wind potential power produced by the air compressor is low, the optimum aspect ratio for micro-size wind turbine is equals to 2 [12, 24].

A solid shaft design was chosen for both rotor wind turbines. The solid shaft shown in Figure 3.2 was designed to be having a diameter which was superior to the thickness of the rotor blades and the diameter of the DC motor's shaft. The chosen diameter is 1.0 cm because it is the smallest diameter that able to connect to the rotor blades. Besides, the weight is lighter and the cost is cheaper than the solid shaft with greater in diameter length.

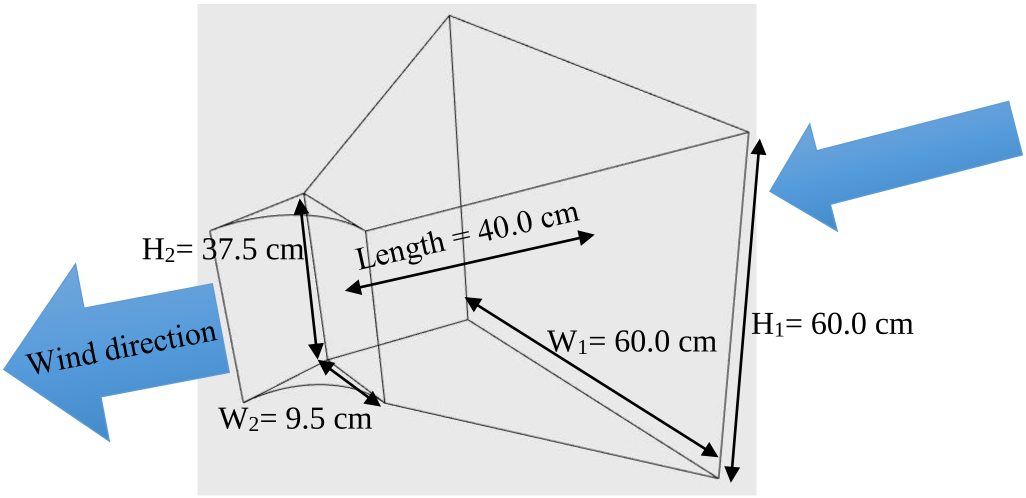



a = 0.75 cm
b = 2.0 cm
c = 20.0 cm
d = 1.0 cm
e = 2.0 cm
f = 0.18 cm
g = 1.0 cm

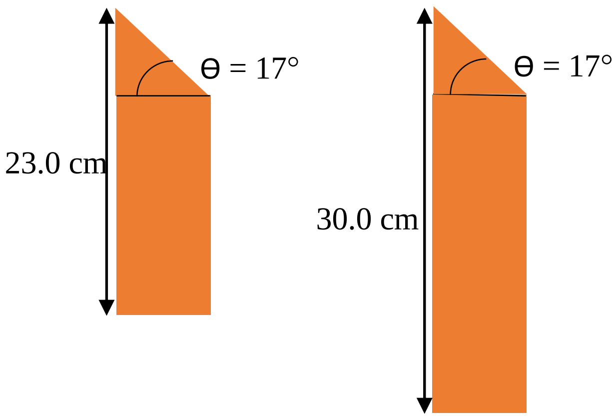
**Figure 3.2:** Shaft design

## 3.3 Wind concentrator design

The wind concentrator design specifications were chosen based on the literature reviews conducted as in Chapter 2. Figure 3.3 shows the design and the dimensions of the wind concentrator.




(a) Wind concentrator design




(b) Wind concentrator's stand design

**Figure 3.3:** Wind concentrator design's dimension

The parameters that were considered in this design are listed as follows:

i. Dimension of outlet of the air compressor

The outlet dimensions of the air compressor is equal to the dimensions of the inlet of the wind concentrator; height ($H_1$) and width ($W_2$) is 60.0 m respectively.

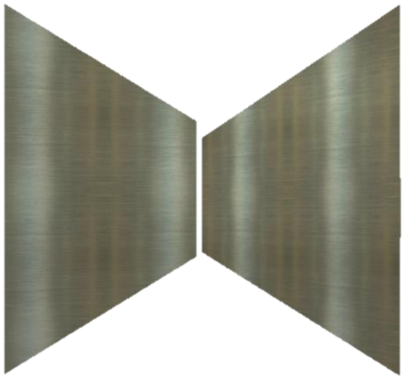
ii. Height and radius of the blade rotor design

For the dimensions of the wind concentrator's outlet were depending on the height and radius of the blade rotor design as in Table 3.1. Since it may be difficult to cut the part of the wind concentrator as the exact measurement of blade rotor, the height ($H_2$) and width ($W_2$) had to be changed to 37.5 cm and 9.5 cm from 37.3 cm and 9.33 cm.

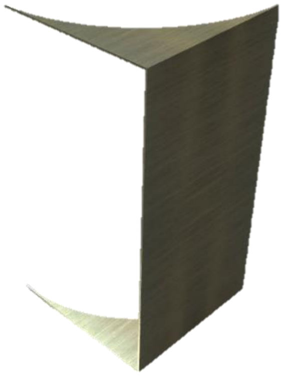
iii. Bernoulli's equation, $\rho_{a1}A_1v_1 = \rho_{a2}A_2v_2$

The design of the wind concentrator in Figure 2.7 had to be improvised for the purpose of this project by also considering the Bernoulli's Equation (2.10) where the velocity of air can be increased when flowing through a large area to small area with a constant air density.

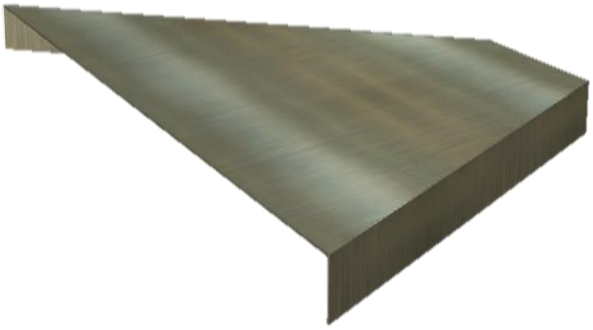
In order to make the fabrication process of the wind concentrator easier, the separated parts of the wind concentrator as shown in Figure 3.4 was initially designed. It was to ensure that the fabrication process can be done smoothly as the design had shown clearly the steps to fabricate the wind concentrator.



**(a)**
Design of plate for left and right side



**(b)**
Design of plate for focusing the wind to the blade

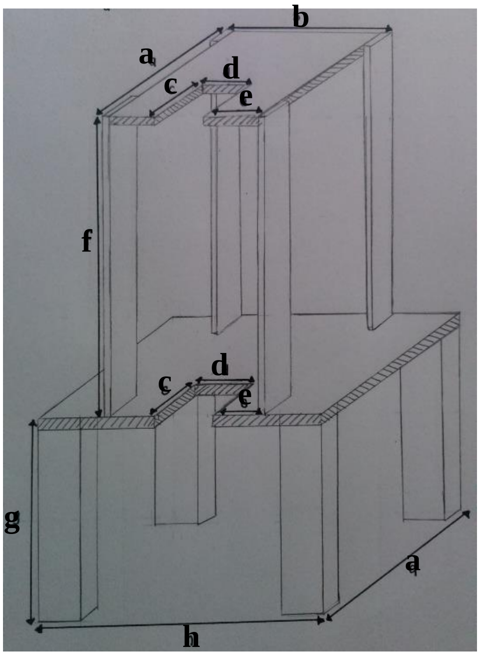


**(c)** Design of plate for upper and lower part

**Figure 3.4:** Wind concentrator separate part's design

## 3.4 VAWT tower design

A VAWT tower is the main structure which supports rotor, generation power and elevates the rotating blades above the earth boundary layer. The main parameter considered in this design was the stability of the tower. It was to ensure the efficiency and safety so that it can reduce the overall vibrations level when the walls were being hit by the wind and when the rotor started to rotate. Therefore, the tower will gain high stability and low noise level [24]. The design of VAWT tower of this project is shown in Figure 3.5.




a = 24.0 cm
b = 28.0 cm
c = 17.0 cm
d = 10.0 cm
e = 9.0 cm
f = 58.0 cm
g = 33.0 cm
h = 46.0 cm

**Figure 3.5:** VAWT tower design

## 3.5 DC motor

Direct current (DC) motor is a device that can convert mechanical energy to electrical energy. Mechanical energy comes from the rotation of the rotor which is connected to the shaft of the DC motor and the electricity produced will be connected to the load from the output terminal as shown in Figure 3.6. Based on the rating of LED mention earlier, a DC motor with the ratings of 3 V and 0.2 A was chosen.

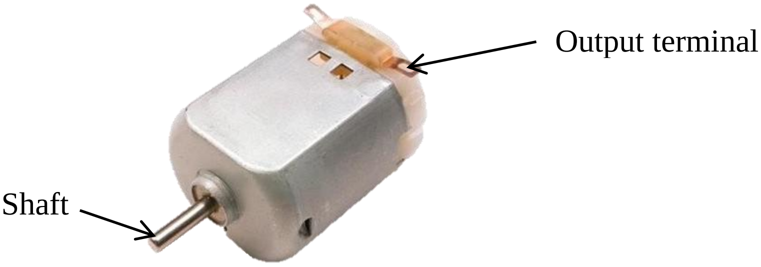



**Figure 3.6:** DC motor

### 3.6 Source of wind

The chosen green energy that has the potential to be developed in Malaysia is wind energy. However, to benefit the air produced by the air compressor, this project had considered them as an additional input as well. The air that flows out of the air compressor can be useful on generating electricity. The air compressor that had been installed at P16, FKE shown in Figure 3.7 was the chosen air compressor for testing purposes.


**Figure 3.7:** Source of wind energy from air compressor located at P16, FKE

## 3.7 Hardware fabrication

### 3.7.1 Savonius VAWT blade rotors fabrication

Polylatic acid (PLA) plastic was chosen as the material for developing the blade rotors. It was produced by using the three-dimensional (3D) printing machine. PLA plastics are environmental friendly material, produce no harmful fumes and less time needed during 3D printing processes were conducted.

The detailed materials, machineries and tools that were used for the process along with the production procedures are listed as follows:

**a. Materials**

i. PLA plastic
ii. 10 mm solid aluminium rod (80 cm)
iii. Epoxy glue
iv. 400 ml Anchor Aerosol Spray Paint

**b. Machinery**

i. 3D printing formaker V200
ii. Milling machine
iii. Lathe machine

**c. Tools**

i. Ruler
ii. Jigsaw

## d. Procedures

**Part A: Blade Rotors**

1. The sketched 3D drawings of conventional and helical blade rotors were produced by using Solidwork$^{TM}$ software as shown in Table 3.1.
2. As the dimensions of the blade rotors were out of scale from the provided by 3D printing machine, each blade rotors were separated in half for production purposes. Figure 3.8 shows the final product of the 3D drawings which were printed (developed) by using 3D printing formaker V200.

**Figure 3.8:** Separation part of conventional and helical blade rotors

3. All of the separated parts of the blades were being combined by using epoxy glue. Figure 3.9 shows the two half parts of helical Savonius blade rotor that were attached and left to dry for a day to make sure a perfect combination of the blade is achieved.

**Figure 3.9:** Helical blade rotor that had been attached

4. The blade rotors were painted by using anchor aerosol spray paint to enhance the durability of the blade rotors.

**Part B: Shaft of rotors**

1. The sketching of the rotor's shaft was drawn as shown in Figure 3.2.
2. A solid aluminium rod had being cut by using a jigsaw to obtain four aluminium rods with identical length of 20 cm each.
3. All of the solid aluminium rods were being lathed afterwards to produce a hollow section at 2 cm length by lathe machine where the diameter at one end was 0.75 cm and the other end was 0.18 cm. The purpose for lathing each of the rod's end with certain diameter was to connect one end to the blade rotors and another end to the DC motor.

(a) Hollow section with diameter 0.75 cm

(b) Hollow section with diameter 0.18 cm

**Figure 3.10:** Hollow section at end of aluminium rods

4. Two slots with 1cm length were made at the end of the rods with diameter 0.75 cm hollow as shown in Figure 3.11 below.

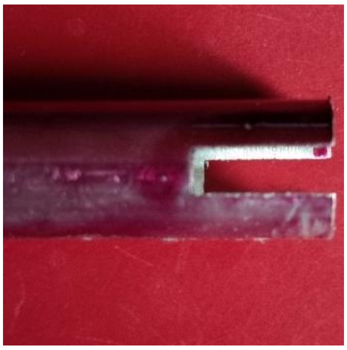


**Figure 3.11:** Slots at the end of rods with diameter 0.75 cm hollow

5. After all of the aluminium rods produced already fulfil the required criteria, the rods were first being attached to the center-end of the rotor blades as shown in Figure 3.12. The purpose of connecting the rods to the blade rotors was to make the rods can acted as the shaft for the rotors. After the glue was left to dry for approximately 30 minutes, the DC motor was then being installed at one end of the shaft.

**Figure 3.12:** The combination of blade rotors and shaft

### 3.7.2 Wind concentrator fabrication

The chosen material for designing the wind concentrator was aluminium because of its suitable material properties. Aluminium is light in weight, corrosion resistance, have good rigidity, a recyclable material, easy to construct and low in cost [14].

The detailed materials, machineries and tools that were used for the process are listed as follow:

**a. Materials**

i. 2 pieces of 2 mm aluminium plate (68.0 cm x 40.0 cm)
ii. 2 mm aluminium plate (60.0 cm x 40.0 cm)
iii. 2 mm aluminium plate (60.0 cm x 55.5 cm)
iv. 2 mm aluminium plate (56.0 cm x 15.0 cm)
v. 40 mm wooden block

**b. Machinery**

i. Metal cutting machine
ii. Folding machine
iii. Soldering machine

**c. Tools**

i. Ruler
ii. Coping saw
iii. Handsaw
iv. Rivet gun

## d. Procedures

1. All of the materials and tools were prepared before the construction started.
2. The exact dimensions of every parts of the wind concentrator as shown in Figure 3.3 were marked on the aluminium plate and the wooden block before being cut by using metal cutting machine and coping saw and handsaw. Coping saw was used to cut the aluminium plate in curve shape.
3. Aluminium plate for designing the proposed design in Figure 3.4 (b) and (c) that had being cut was folded for about 90°. After that, every parts of the aluminium plate required to develop the wind concentrator were clipped which shown in Figure 3.13 to confirm the exact part before all of them being connected to each other.

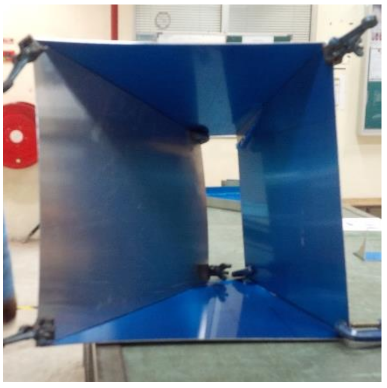


**Figure 3.13:** The aluminium plates were clipped

4. The main body part of the wind concentrator was connected by rivet using a rivet gun. Therefore, the aluminium plates will hold tightly in their position.
5. To make sure that the design is perfectly aligned with the other parts of the aluminium plates, the last plate as shown in Figure 3.4 (b) was soldered to the main body of the wind concentrator.

6. The last construction part for fabricating the wind concentrator was the attachment of four (4) wooden blocks as its stands by using the epoxy glue. Figure 3.14 shows the complete structure of the wind concentrator.

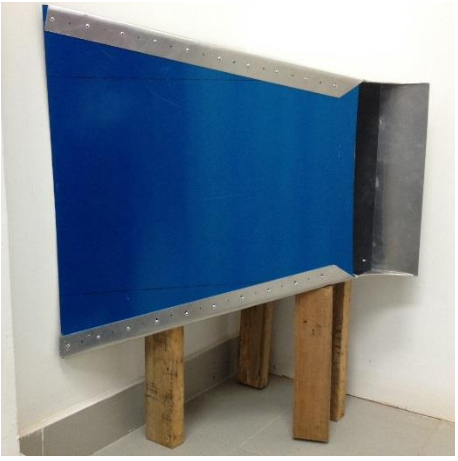


**Figure 3.14:** Complete structure of the wind concentrator.

### 3.7.3 VAWT tower fabrication

The VAWT tower was fabricated only by using some used woods such as wooden blocks, wooden pallets and plywood. The tower was designed to be fabricated along with a bearing which helps to reduce some rotational frictions happened when the rotors are rotating.

The detailed materials, machineries and tools that were used for the process along with the production procedures are listed as follows:

**a. Materials**

i. 30 mm wooden block
ii. 15 mm wooden pallet
iii. 10 mm plywood
iv. 10 mm bearing

**b. Machinery**

i. Milling machine

**c. Tools**

i. 90° angle ruler
ii. Handsaw
iii. Jigsaw
iv. Sand paper
v. Nail gun

**d. Procedures**

1. All of the materials and tools were prepared before the fabrication started.
2. The exact dimensions as shown in Figure 3.5 were marked on the wooden blocks and pallets. The wooden blocks were being cut according to the desired dimensions by using a handsaw compared to both the wooden pallets and the plywood that can only being cut by using a jigsaw due to their smaller thickness.
3. The lower base of the tower was the first to be fabricated. A 90° angled ruler was used to make sure that the wooden block was perpendicular positioned to the lower base of the tower. Each of the wooden blocks was attached to the lower base by using a nail gun after approximately sure that they have achieved an angle of 90°. The importance of this angle was to ensure the stability of the tower.

4. The upper base of tower was constructed upon the completion of the lower base. Each of the wooden pallets was being attached to the upper base by using a nail gun after approximately sure that they have achieved an angle of 90°.
5. After completed the upper base part of the tower, both the upper and the lower bases were combined together to produce a complete structure of a VAWT tower by using a nail gun.
6. In order to ensure that the rotors were able to fit perfectly into the VAWT tower, the exact dimensions of bearing was marked on top of 4 pieces of plywood right at the centre.
7. Each pieces of plywood had undergone a milling process before being installed with a bearing. At first, the plywood was drilled by using a 12 mm -sized endmill to ensure that the shaft will be able to rotate smoothly. Afterwards, the plywood was then being drilled for about 7 mm depth by using a 25 mm-sized endmill to ensure that the bearing will fit right into the plywood. Figure 3.15 below shows the attachment of bearing into the plywood.

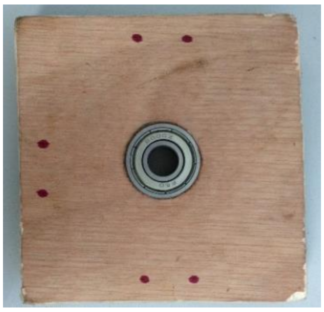
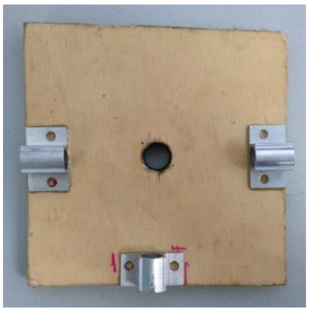


**Figure 3.15:** Attachment of bearing into the plywood

8. The last construction part for fabricating the VAWT tower that shown in Figure 3.16 was the attachment of Grendel on both sides of bases and the plywood to hold the shaft of the wind turbine in the right position. Figure 3.17 shows the complete structure of the VAWT tower.

**(a)**

Grendel being attached at the upper base of VAWT tower



**(b)**

Grendel being attached at the plywood

**Figure 3.16:** Position of Grendel attached at VAWT tower

**Figure 3.17:** Complete structure of the VAWT tower

## 3.9 Comparison testing

The two different types of Savonius VAWT blade rotors will be tested on four (4) different types of testing during the comparison testing. Listed as follow are the types of comparison testing that were conducted:

i. Without concentrator at 0 cm distance
ii. Without concentrator at 30 cm distance
iii. With concentrator at concave-blade position
iv. With concentrator at center-blade position

A constant wind speed produced by the air compressor was the source of wind energy to generate electricity in this project. As the airflow out of the air compressor is constant, it improved the results of the testing to become more accurate as the pressure of wind exerted to each of the blade rotors are equal. Listed below are the details on tools and procedures of the testing.

**a. Tools**

i. Anemometer
ii. Multimeter
iii. Tachometer
iv. Torque meter
v. Measuring tape

**b. Procedures**

1. All of the tools and fabricated hardware were prepared.
2. The hardware arrangement that was set up for the first testing was the ones without using the wind concentrator at 0 cm distance on conventional Savonius rotor blade. The distance was measured by using a measuring tape.
3. The wind speed for this condition was measured by using an anemometer and the measurements were repeatedly taken for 10 times to analyze the average wind speed produced.
4. The voltage (V) and current (I) generated by VAWT were measured by using a multimeter and also repeatedly taken for 10 times.
5. The rotational speed (RPM) and the torque of the rotor blade's rotations were measured using tachometer and torque meter. The measurements were also repeatedly taken for 10 times.
6. All of the data taken were recorded and tabulated to analyze electrical power ($P_E$), mechanical power ($P_M$), angular speed ($\omega$), power coefficient ($C_P$), torque coefficient ($C_T$) and tip speed ratio (TSR).
7. Steps 1 to 6 were repeated for another testing which shown in Figure 3.18 where (a) the testing were using without concentrator at 0 cm; (b) without concentrator at 30cm distance; (c) with concentrator at concave-blade position; and (d) with concentrator at center-blade position.
8. Steps 1 to 7 were repeated to test on the helical Savonius blade rotor.
9. The comparison from the data taken from other testing were observed and analyzed in the end of this project.

(a) Without concentrator at 0 cm distance

(d) With concentrator at center-blade position

(b) Without concentrator at 30 cm distance

(c) With concentrator at concave-blade position

**Figure 3.18:** Four (4) types of testing being conducted