CHAPTER 4 – RESULTS AND DISCUSSIONS

4.1. Electrical Component Assembly

4.1.1. Terminal Block

The terminal block, specifically the TB-2508L, plays a crucial role in establishing a secure and reliable connection between the power supply and the Peltier modules in the cooling system. Its selection is based on its ability to accommodate the required current for activating the Peltier modules effectively. The TB-2508L is designed with 8 different poles, which provides ample connection points up to 4 components. In addition, each pole can hold up to 25A current, making it safe to power up more than one Peltier modules all at once. One (+) output pin and (-) output pin of the terminal block are connected to the step-down module, and AWG18 cables are used to jumper one pole to another pole so that the terminal block can connect to many Peltier modules.

4.1.2. Step-Down Module

This model uses step-down model, specifically the SZBK07 DC 6-40V to DC1,2-36V step-down module. The step-down module is used to regulate the voltage of the power supply to the Peltier modules. Without the step-down module, it would be a troublesome work to switch between 12V power supply and 24V power supply when powering up the Peltier modules. Also, the function of the step-down module is for the 24V 30A power supply be able to switch easily between 12V and 15V without any necessary work to remove the cables that are connected to power supply and screwing the cables to the other power supply. With the step-down module, the switching of the voltage can be done by turning the potentiometer that is located on the step-down module board.

After connecting the power supply to the step-down module, the (+) output pin and the (-) output pin are connected to terminal block to be able to supply the desired voltage to the Peltier module. This method of connection is used to solve the problem of limitation of only one (+) output pin and one (-) output pin of step-down module when more than one component needs to be connected to step-down module.

4.2. Temperature change analysis

On this model, there are six setup of Peltier cooling system which is one single Peltier module TEC1 – 12706 powered up with 12V, one single Peltier module TEC1 – 12710 powered up with 12V, cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 powered up with 12V, one single Peltier module TEC1 – 12706 powered up with 15V, one single Peltier module TEC1 – 12710 powered up with 15V, and cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 powered up with 15V. All of the testing of the setup are done outside with average ambient temperature 32^{o}C with testing duration of 30 minutes. The voltage and current measuring is taken with Sanwa CD800a digital multimeter and Fluke 325 clamp meter. In this analysis, the cooling capacity (*Qc)*, Coefficient of Performance (*COP*), temperature difference between initial temperature and final temperature (ΔT), and cooling rate will be calculated to compare which setup is more efficient.

4.2.1. Single Peltier module TEC1 – 12706 with 12V

Table 1. Results of single Peltier module TEC1 – 12706 with 12V (testing one)

Time (Minute)	Hot Side Heatsink (^{o}C)	Cold Side Heatsink (^{o}C)	Chamber Temperature (^{o}C)
0	32.10	31.80	31.37
1	35.90	31.20	31.31
2	38.40	30.90	31.25
3	39.20	30.90	31.19
4	39.70	30.90	31.19
5	39.40	31.00	31.25
6	39.50	31.10	31.37
7	39.90	31.20	31.44
8	39.40	31.20	31.56
9	40.00	31.30	31.62

10	39.30	31.40	31.69
11	39.30	31.40	31.75
12	39.40	31.50	31.81
13	39.10	31.50	31.94
14	39.30	31.60	31.94
15	39.70	31.60	32.00
16	40.00	31.70	32.06
17	39.70	31.70	32.06
18	39.50	31.70	32.13
19	39.20	31.70	32.13
20	39.30	31.70	32.13
21	40.20	31.80	32.19
22	40.80	31.80	32.19
23	40.80	31.90	32.19
24	40.40	31.90	32.25
25	40.50	31.90	32.31
26	40.40	32.00	32.31
27	40.50	32.00	32.31
28	40.20	32.00	32.38
29	40.60	32.00	32.38
30	40.60	32.00	32.38

The *Table 1* above is the results of single Peltier module TEC1 – 12706 with 12V testing one. During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.10^{o}C to final temperature of 40.60^{o}C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature should decrease, but instead in this testing the cold side temperature rises from initial temperature of 31.80^{o}C to final temperature of 32.00^{o}C. The inability of Peltier module TEC1 – 12706 to cool down the heat of the chamber resulted to the chamber temperature rises from initial temperature of 31.37^{o}C to final temperature of 32.38^{o}C. The power consumption of testing one can be calculated using *(eq.1)* which is $P = V \times I$.

Table 2. Power consumption of each component from testing one

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.18A	2.16W
2	Cold side heatsink fan	12V	0.11A	1.32W

3	Peltier module TEC1 - 12706	12V	3.54A	42.48W
	Total	12V	3.83A	45.96W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing one can be calculated using (*eq.4*), which is ΔT = 32.38℃ - 31.37℃= +1.01℃. The + sign indicates that the temperature rises 1.01ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing one can be calculated using (*eq.2*), which is $Qc = m\ x\ C\ x\ \Delta T$ = +33.5J. The + sign indicates that the Peltier module is giving heat load up the chamber of 33.5J instead of cooling it down. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing one can be calculated using (*eq.5*), which is $COP = \frac{33.5J}{42.48W\ x\ 1800s}$ = 4.38x10^{-4} . The Pin is multiplied with 1800 seconds because the Unit Watt is converted to Joule. The value of the COP is absolute, meaning the – or + sign did not affect the result of the COP calculation. As for the cooling rate, it can be calculated with (*eq.5*), which is $Cooling\ rate = \frac{1.01℃}{30\ Min} = +0.03367\ ℃/Min$. The + sign of the cooling rate value indicates that the chamber is heating up 0.03367ºC per minute.

Table 3. Results of single Peltier module TEC1 – 12706 with 12V (testing two)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	31.60	32.30	31.81
1	37.60	31.30	31.75
2	39.20	31.20	31.62
3	39.60	31.10	31.56
4	39.50	31.10	31.50
5	39.30	31.10	31.50
6	39.40	31.20	31.50
7	39.60	31.20	31.56
8	39.60	31.30	31.62
9	40.10	31.30	31.62
10	40.00	31.30	31.69
11	39.90	31.30	31.69
12	40.00	31.40	31.75

13	40.10	31.40	31.75
14	39.70	31.40	31.81
15	39.60	31.50	31.81
16	40.00	31.50	31.81
17	39.90	31.50	31.81
18	40.20	31.40	31.81
19	39.50	31.50	31.81
20	39.70	31.50	31.81
21	39.30	31.40	31.81
22	39.50	31.40	31.81
23	39.10	31.40	31.81
24	39.40	31.40	31.75
25	39.50	31.40	31.75
26	39.40	31.40	31.75
27	39.50	31.30	31.75
28	39.90	31.30	31.75
29	39.30	31.30	31.75
30	39.50	31.40	31.69

The *Table 3* above is the results of single Peltier module TEC1 – 12706 with 12V testing two. During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 31.60℃ to final temperature of 39.50℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreased from initial temperature of 32.30ºC to final temperature of 31.40ºC. This indicates that the Peltier module TEC1 – 12706 is able to cool down the heat of the chamber, resulting in temperature decrease from initial temperature of 31.81ºC to final temperature of 31.69ºC.

Table 4. Power consumption of each component from testing two

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.22A	2.64W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12706	12V	3.56A	42.72W
	Total	12V	3.91A	46.92W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing two is ΔT = 31.81℃ - 31.69℃ = -0.12℃. The minus sign indicates that the temperature decreases 0.12ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing two is $Qc = m\ x\ C\ x\ \Delta T$ = -3.97 J. The minus sign indicates that the Peltier module is cooling down the chamber with a load of J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing two is $COP = \frac{3.97\ \text{J}}{42.72\text{W x } 1800\ \text{s}} = 5.16 \text{ x } 10^{-5}$. The cooling rate of testing two is $Cooling\ rate = \frac{-0.12℃}{30\ Min} = -0.004\ ℃/Min$. The – sign indicates that the Peltier module is cooling down the chamber temperature 0.004ºC per minute.

Table 5. Results of single Peltier module TEC1 – 12706 with 12V (testing three)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	32.20	32.50	31.56
1	37.60	31.30	31.62
2	39.40	31.00	31.56
3	39.40	30.90	31.37
4	39.60	30.90	31.31
5	39.50	30.90	31.25
6	39.40	30.90	31.19
7	39.50	30.90	31.19
8	39.30	30.90	31.19
9	39.30	30.90	31.19
10	39.30	30.90	31.19
11	39.10	30.90	31.19
12	39.00	30.90	31.19
13	38.80	30.90	31.19
14	39.00	30.90	31.19
15	38.80	30.90	31.19
16	38.90	30.90	31.19
17	39.00	30.90	31.19
18	39.30	30.90	31.19
19	39.20	30.90	31.19
20	39.40	30.90	31.19
21	39.30	30.90	31.19
22	38.90	30.80	31.19
23	39.20	30.80	31.19
24	39.20	30.80	31.19
25	39.00	30.80	31.12

26	39.70	30.80	31.12
27	39.70	30.80	31.12
28	39.60	30.70	31.12
29	39.50	30.70	31.06
30	39.50	30.70	31.06

The *Table 5* above is the results of single Peltier module TEC1 – 12706 with 12V testing three. During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.20℃ to final temperature of 39.50℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreased from initial temperature of 32.50°C to final temperature of 30.70°C. This indicates that the Peltier module TEC1 – 12706 is able to cool down the heat of the chamber, resulting in temperature decrease from initial temperature of 31.81°C to final temperature of 31.69°C.

Table 6. Power consumption of each component from testing three

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.23A	2.76W
2	Cold side heatsink fan	12V	0.16A	1.92W
3	Peltier module TEC1 - 12706	12V	3.62A	43.44W
	Total	12V	4.01A	48.12W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing three is ΔT = 31.56℃ - 31.06℃ = -0.50℃. The minus sign indicates that the temperature decreases 0.50°C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing two is $Qc = m\ x\ C\ x\ \Delta T$ = -16.58 J. The - sign indicates that the Peltier module is cooling down the chamber with a load of 0.4477W. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing two is $COP = \frac{16.58J}{43.44W\ x\ 1800s}$ = 2.12 x 10^{-4}. The cooling rate of testing three is $Cooling\ rate = \frac{-0.50℃}{30\ Min} = -0.0167\ ℃/Min$. The value of the

cooling rate indicates that the Peltier module is cooling down the chamber for 0.0167^{o}C per minute.

The performance results of single Peltier module TEC1 – 12706 with 12V testing can be seen on the table below

Table 7. Performance results of single Peltier module TEC1 – 12706 with 12V

Testing	ΔT	Qc	COP	Cooling rate
1	+1.01^{o}C	+33.5J	4.38x10^{-4}	+0.03367^{o}C/Min
2	-0.12^{o}C	-3.97J	5.16x10^{-5}	-0.004^{o}C/Min
3	-0.50^{o}C	-16.58J	2.12x10^{-4}	-0.0167^{o}C/Min

Table 7 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of three testing that are conducted using single Peltier module TEC1 – 12706 with 12V. On this table, it is evident that the first testing did not able to cool down the chamber temperature, but instead heats up the chamber. The evidence can be seen from the value of the ΔT, Qc, and cooling rate of the testing one. The ΔT rises 1.01^{o}C from its initial temperature, the chamber is heated up 33.5J instead of being cooled down, and the chamber temperature rises 0.03367^{o}C per minute. But from testing 2 and testing three results, it is evident that the single Peltier TEC1 – 12706 with 12V is able to cool down the chamber temperature. The evidence can be seen from the result of ΔT, Qc, and cooling rate is in – sign. It means that the heat from the chamber is being absorbed by the Peltier module TEC1 – 12706. From the results, it is evident that the single Peltier module TEC1 – 12706 with 12V is able to cool down the chamber temperature, though it is not very efficient.

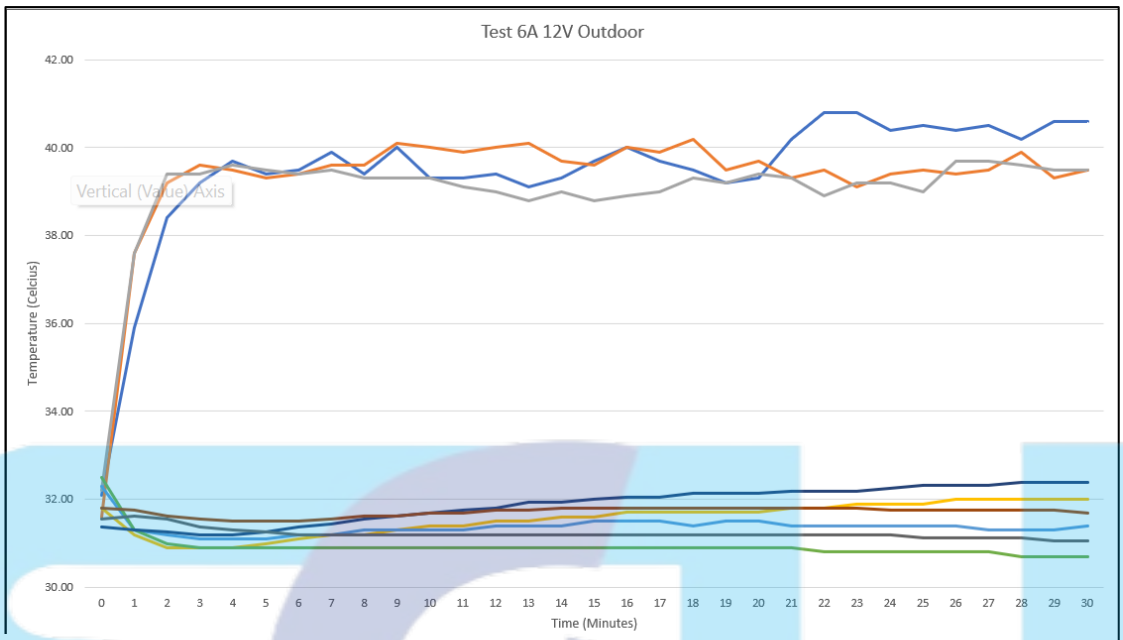

Figure 31. Graph of single 6A Peltier module TEC1 – 12706 with 12V

Figure 32. Graph of single Peltier module TEC1 – 12706 with 12V

4.2.2. Single Peltier module TEC1 – 12710 with 12V

Table 8. Results of single Peltier module TEC1 – 12710 with 12V (testing four)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	32.60	33.00	32.31
1	39.20	32.20	32.19
2	42.00	33.70	32.75
3	42.80	34.80	33.56
4	42.90	35.60	34.31
5	43.40	36.00	34.81
6	43.10	36.40	35.31
7	43.20	36.80	35.69
8	43.60	37.10	36.06
9	44.00	37.40	36.38
10	44.00	37.60	36.63
11	44.00	37.80	36.81
12	44.40	37.90	37.00
13	44.00	38.10	37.19

14	43.90	38.20	37.25
15	44.10	38.30	37.38
16	44.30	38.40	37.50
17	44.20	38.40	37.56
18	43.90	38.50	37.63
19	44.20	38.50	37.69
20	44.20	38.60	37.75
21	44.20	38.70	37.81
22	43.80	38.70	37.88
23	44.00	38.70	37.88
24	44.50	38.90	38.00
25	44.10	38.90	38.00
26	44.50	38.90	38.06
27	44.30	39.00	38.06
28	44.60	39.00	38.13
29	45.00	39.00	38.13
30	44.80	39.00	38.19

The *Table 8* above is the results of single Peltier module TEC1 – 12710 with 12V (testing four). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.60℃ to final temperature of 44.80℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 32.30°C to final temperature of 39.00°C. This indicates that the Peltier module TEC1 – 12710 is unable to cool down the heat of the chamber and instead adding heat to the chamber, resulting in temperature increase from initial temperature of 32.31°C to final temperature of 38.19°C.

Table 9. Power consumption of each component from testing four

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.10A	1.2W
3	Peltier module TEC1 - 12710	12V	5.33A	63.96W
	Total	12V	5.63A	67.56W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing four is ΔT = 38.19℃ - 32.31℃= +5.88℃. This indicates that the temperature rises 5.88ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing four is $Qc = 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ +5.88℃$ = +195.01J. The positive sign Qc results indicates that the Peltier module TEC1 – 12710 is not cooling, but giving heat load of 195.01J to the chamber instead. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing four is $COP = \frac{195.01J}{63.96W\ x\ 1800s} = 1.69 \text{ x } 10^{-3}$. The cooling rate of single Peltier module TEC1 – 12710 testing four is $Cooling\ rate = \frac{5.88℃}{30\ Min} = +0.196\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.196ºC every minute that it is turned on.

Table 10. Results of single Peltier module TEC1 – 12710 with 12V (testing five)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	32.80	32.50	32.19
1	39.30	31.90	32.19
2	42.30	32.60	32.12
3	42.70	33.50	32.12
4	42.80	34.10	33.25
5	43.20	35.10	34.31
6	43.20	36.00	34.94
7	43.50	36.80	35.25
8	43.70	37.00	35.69
9	44.10	37.50	36.12
10	44.10	37.90	36.50
11	44.20	38.00	36.87
12	44.30	38.20	36.94
13	44.20	38.40	37.19
14	44.10	38.40	37.31
15	44.00	38.50	37.56
16	44.20	38.50	37.61
17	44.10	38.70	37.69
18	44.10	38.70	37.75
19	44.40	38.90	37.75
20	44.50	38.90	37.75
21	44.20	38.90	38.19
22	44.10	39.00	38.19
23	44.10	39.10	38.19
24	44.20	38.90	38.19

25	44.40	38.90	38.25
26	44.50	39.00	38.25
27	44.30	39.00	38.25
28	44.60	38.80	38.25
29	44.70	38.90	38.25
30	44.50	39.10	38.25

The *Table 10* above is the results of single Peltier module TEC1 – 12710 with 12V (testing five). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.80℃ to final temperature of 44.50℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 32.50ºC to final temperature of 39.10ºC. This indicates that the Peltier module TEC1 – 12710 is unable to cool down the heat of the chamber and instead adding heat to the chamber, resulting in temperature increase from initial temperature of 32.19ºC to final temperature of 38.25ºC.

Table 11.Power consumption from each component from testing five

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.21A	2.52W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12710	12V	5.30A	63.6W
	Total	12V	5.64A	67.68W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing five is ΔT = 38.25℃ - 32.19℃= +6.06℃. This indicates that the temperature rises 6.06ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing five is $Qc = 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x + 6.06℃$ = +200.98J. The positive sign Qc results indicates that the Peltier module TEC1 – 12710 is not cooling, but giving heat load of 12.54W to the chamber instead. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing five is $COP = \frac{200.98J}{63.6W\ x\ 1800s} = 1.75\text{x}10^{-3}$. The cooling

rate of single Peltier module TEC1 – 12710 testing four is $Cooling\ rate = \frac{6.06℃}{30\ Min} = +0.202\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.202ºC every minute that it is turned on.

Table 12. Results of single Peltier module TEC1 – 12710 with 12V (testing six)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	32.70	32.80	32.56
1	38.90	32.20	32.25
2	42.10	33.60	32.19
3	42.30	34.60	32.19
4	42.60	35.30	32.56
5	42.70	36.20	33.06
6	42.90	36.50	33.94
7	43.20	36.90	34.62
8	43.50	37.00	34.87
9	43.70	37.20	35.50
10	43.90	37.40	36.19
11	44.20	37.90	36.62
12	44.10	38.00	37.19
13	44.30	38.10	37.31
14	44.20	38.10	37.62
15	44.50	38.30	37.81
16	44.60	38.50	37.81
17	44.30	38.50	37.81
18	44.20	38.50	37.81
19	44.40	38.70	37.94
20	44.20	38.70	37.94
21	44.30	38.70	37.94
22	44.30	38.90	37.94
23	44.20	38.90	37.94
24	44.10	38.80	37.94
25	44.50	38.80	38.06
26	44.30	38.80	38.06
27	44.20	38.90	38.06
28	44.60	38.90	38.06
29	44.50	38.90	38.06
30	44.30	38.90	38.06

The *Table 12* above is the results of single Peltier module TEC1 – 12710 with 12V (testing six). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.70℃ to final temperature of 44.30℃, indicating that the hot

side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 32.80°C to final temperature of 38.90°C. This indicates that the Peltier module TEC1 – 12710 is unable to cool down the heat of the chamber and instead adding heat to the chamber, resulting in temperature increase from initial temperature of 32.56°C to final temperature of 38.06°C.

Table 13. Power consumption of each component from testing six

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.14A	1.68W
3	Peltier module TEC1 - 12710	12V	5.35A	64.2W
	Total	12V	5.69A	68.28W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing six is ΔT = 32.56℃ - 38.06℃ = + 5.50℃. This indicates that the temperature rises 6.06°C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing six is $Qc = 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ +5.50℃$ = +182.4J. The positive sign Qc results indicates that the Peltier module TEC1 – 12710 is not cooling, but giving heat load of 11.38W to the chamber instead. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing six is $COP = \frac{182.4J}{64.2W\ x\ 1800s} = 1.57x10^{-3}$. The cooling rate of single Peltier module TEC1 – 12710 testing four is $Cooling\ rate = \frac{5.50℃}{30\ Min} = +0.183\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.183°C every minute that it is turned on.

Table 14. Performance results of single Peltier TEC1 -12710 with 12V

Testing	ΔT	Qc	COP	Cooling rate
1	+5.88°C	+195.01J	$1.69x10^{-3}$	+0.196°C/Min

2	+6.06°C	+200.98J	$1.75x10^{-3}$	+0.202°C/Min
3	+5.50°C	+182.4J	$1.57x10^{-3}$	+0.183°C/Min

Table 14 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of three testing that are conducted using single Peltier module TEC1 – 12710 with 12V. On this table, it is evident that the single Peltier module TEC1 -12710 with 12V is not able to cool down the chamber, but instead heating it up thus resulting in the ΔT, Qc, and cooling rate become + value. The + value indicates that the heat is not absorbed by single Peltier module TEC1 – 12710 with12V, but instead the heat is released by the single Peltier module TEC1 – 12710 with 12V. It is assumed that this setup did not have enough heat dissipation of the hot side single Peltier module TEC1 – 12710 with 12V, thus resulting in the heat being spread into the cold side of the single Peltier module TEC1 – 12710. The evidence is that the cold side heatsink temperature also rising in Table 8, Table 10, and Table 12.

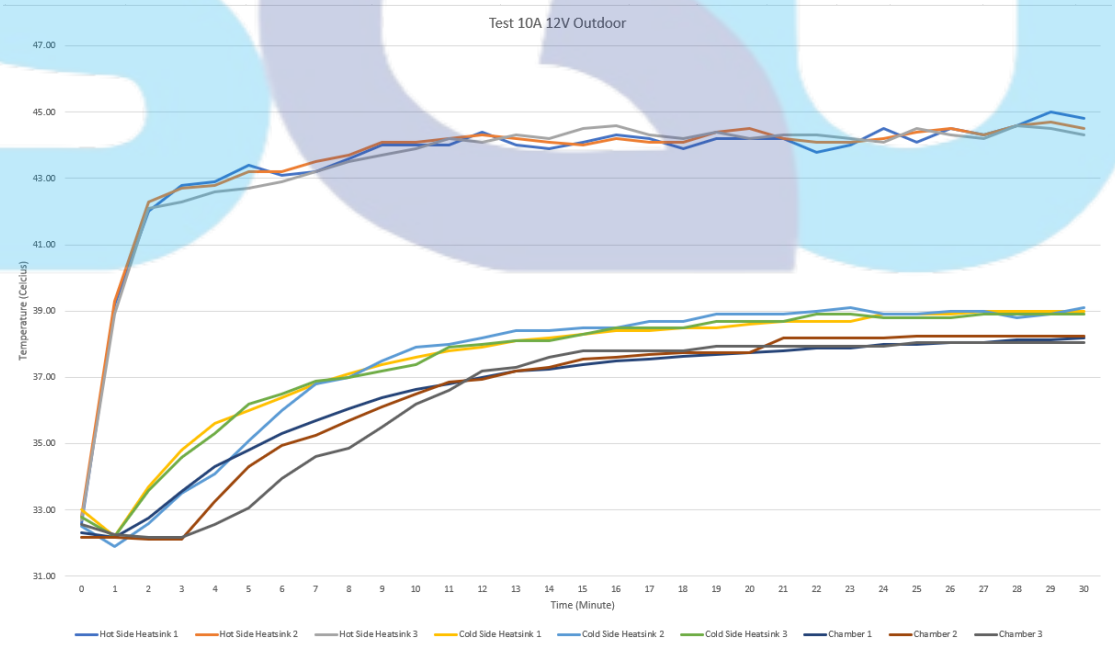

Figure 33. Graph of single Peltier module TEC1 – 12710 with 12V

4.2.3. Cascade stacked Peltier module TEC1 – 12706 and TEC1 -12710 with 12V

Table 15.Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing seven)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	31.10	27.90	27.50
1	46.20	23.10	26.62
2	53.00	22.70	25.50
3	55.10	22.80	25.06
4	55.80	23.00	24.94
5	56.00	23.10	25.00
6	56.20	23.10	25.06
7	56.50	23.30	25.19
8	55.80	23.50	25.25
9	56.80	23.60	25.31
10	56.60	23.80	25.44
11	55.30	23.70	25.50
12	56.70	23.80	25.56
13	56.50	23.90	25.69
14	56.30	24.00	25.75
15	55.50	24.10	25.81
16	55.20	24.20	25.94
17	55.30	24.20	26.00
18	55.00	24.30	26.06
19	55.90	24.30	26.12
20	56.00	24.40	26.19
21	55.20	24.40	26.25
22	56.30	24.40	26.25
23	56.20	24.50	26.25
24	56.80	24.50	26.31
25	56.60	24.40	26.25
26	56.80	24.50	26.25
27	56.60	24.50	26.31
28	56.30	24.50	26.31
29	55.90	24.50	26.37
30	56.10	24.50	26.37

The *Table 15* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing seven). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 31.10℃ to final temperature of 56.10℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 27.90°C to final temperature of 24.50°C. This indicates that the cascade stacked

Peltier module TEC1 – 12706 and TEC1 – 12710 is effectively cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 27.50°C to final temperature of 26.37°C.

Table 16. Power consumption of each component from testing seven

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.12A	1.44W
3	Peltier module TEC1 - 12706	12V	3.33A	39.96W
4	Peltier module TEC1 - 12710	12V	5.85A	70.2W
	Total	12V	9.5A	114W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing seven is ΔT = 26.37℃ - 27.50℃ = -1.13℃. This indicates that the temperature decreases 1.13°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing seven is $Qc = 0.033\,Kg\,x\,1005J/Kg \cdot K\,x\,-1.13℃$ = -37.48J. The negative sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 3.2544W. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing seven is $COP = \frac{37.48J}{110.16W\,x\,1800s} = 1.89\text{x}10^{-4}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing seven is $Cooling\ rate = \frac{-1.13℃}{30\ Min} = -0.0376\ ℃/Min$. The – sign indicates that the chamber is being cooled down at a rate of 0.0376°C every minute that it is turned on.

Table 17. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing eight)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	31.40	31.90	31.81
1	46.80	26.60	30.37
2	51.50	25.70	28.81
3	53.50	25.40	27.94
4	54.00	25.30	27.37
5	54.50	25.10	27.06
6	54.20	25.00	26.87
7	54.80	24.90	26.69
8	54.40	24.80	26.56
9	54.50	24.60	26.44
10	54.20	24.60	26.37
11	55.60	24.60	26.31
12	54.30	24.50	26.25
13	55.60	24.50	26.25
14	55.00	24.30	26.19
15	55.30	24.30	26.12
16	55.50	24.30	26.06
17	55.30	24.20	26.06
18	54.70	24.20	26.00
19	55.40	24.20	25.94
20	55.30	24.10	25.87
21	55.30	24.00	25.87
22	55.20	24.00	25.81
23	55.10	24.00	25.81
24	54.70	23.90	25.75
25	54.50	23.90	25.75
26	54.60	23.80	25.69
27	54.00	23.80	25.69
28	54.60	23.80	25.62
29	55.10	23.80	25.62
30	53.90	23.80	25.62

The *Table 17* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing eight). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 31.40℃ to final temperature of 53.90℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 31.90°C to final temperature of 23.80°C. This indicates that the cascade stacked

Peltier module TEC1 – 12706 and TEC1 – 12710 is effectively cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 31.81°C to final temperature of 25.62°C.

Table 18. Power consumption of each component from testing eight

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.21A	2.52W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12706	12V	3.31A	39.72W
4	Peltier module TEC1 - 12710	12V	5.85A	70.2W
	Total	12V	9.48A	113.76W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing eight is ΔT = 25.62℃ - 31.81℃ = -6.19℃. This indicates that the temperature decreases 6.19°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing eight is $Qc = 0.033\,Kg\,x\,1005J/Kg \cdot K\,x\,-6.19℃$ = -205.29J. The negative sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 205.29J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing eight is $COP = \frac{205.29J}{109.92W\,x\,1800s}$ =1.03x10^{-3}. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing eight is $Cooling\,rate = \frac{-6.19℃}{30\,Min} = -0.2063\,℃/Min$. The – sign indicates that the chamber is being cooled down at a rate of 0.2063°C every minute that it is turned on.

Table 19. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing nine)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	32.40	32.40	33.00
1	47.90	27.20	31.75
2	53.50	26.40	30.12
3	54.20	26.30	29.25
4	56.30	26.10	28.69
5	57.20	26.10	28.31
6	57.30	26.00	28.06
7	56.60	25.90	27.94
8	57.20	25.90	27.81
9	56.40	25.80	27.75
10	56.70	25.80	27.69
11	56.60	25.80	27.69
12	56.80	25.80	27.69
13	55.90	25.70	27.62
14	55.80	25.80	27.62
15	55.70	25.80	27.62
16	55.40	25.80	27.62
17	56.00	25.80	27.69
18	55.30	25.80	27.69
19	55.20	25.80	27.69
20	57.30	25.80	27.69
21	56.10	25.80	27.69
22	57.30	25.70	27.62
23	57.10	25.70	27.69
24	56.40	25.70	27.62
25	57.70	25.70	27.62
26	56.10	25.70	27.56
27	57.00	25.70	27.62
28	55.30	25.70	27.62
29	55.90	25.70	27.62
30	56.10	25.70	27.62

The *Table 19* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V (testing nine). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.40℃ to final temperature of 56.10℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 32.40°C to final temperature of 25.70°C. This indicates that the cascade stacked

Peltier module TEC1 – 12706 and TEC1 – 12710 is effectively cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 33.00°C to final temperature of 27.62°C.

Table 20. Power consumption of each component from testing nine

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12706	12V	3.2A	38.4W
4	Peltier module TEC1 - 12710	12V	5.8A	69.6W
	Total	12V	9.33A	111.96W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing nine is ΔT = 27.62℃ - 33.00℃ = -5.38℃. This indicates that the temperature decreases 5.38°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing nine is $Qc = 0.033\,Kg\,x\,1005J/Kg \cdot K\,x\,-5.38℃$= -178.42J. The negative sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 178.42J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing nine is $COP = \frac{178.42J}{108W\,x\,1800s} = 9.17\text{x}10^{-4}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing nine is $Cooling\ rate = \frac{-5.38℃}{30\ Min} = -0.1793\ ℃/Min.$ The – sign indicates that the chamber is being cooled down at a rate of 0.1793°C every minute that it is turned on.

Table 21. Performance results of cascade stacker Peltier module TEC1- 12706 and TEC1 – 12710 with 12V

Testing	ΔT	Qc	COP	Cooling rate
1	−1.13℃	-37.48J	$1.89x10^{-4}$	$-0.0376\ ℃/Min$
2	−6.19 ℃	-205.29J	$1.03x10^{-3}$	$-0.2063\ ℃/Min$
3	-5.38 ℃	-178.42J	$9.17x10^{-4}$	$-0.1793\ ℃/Min$

Table 21 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of three testing that are conducted using cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V. On this table, it is evident that the cascade stacked Peltier module TEC1 – 12706 and TEC1 -12710 with 12V is able to cool down the chamber efficiently within the testing that are conducted. Looking from the value of ΔT, Qc, COP, and cooling rate of this setup and comparing it to the results from the previous setup of 12V, the cascade stacked Peltier module setup have the best value, indicating that this setup is more efficient than the previous two setup of 12V, in terms

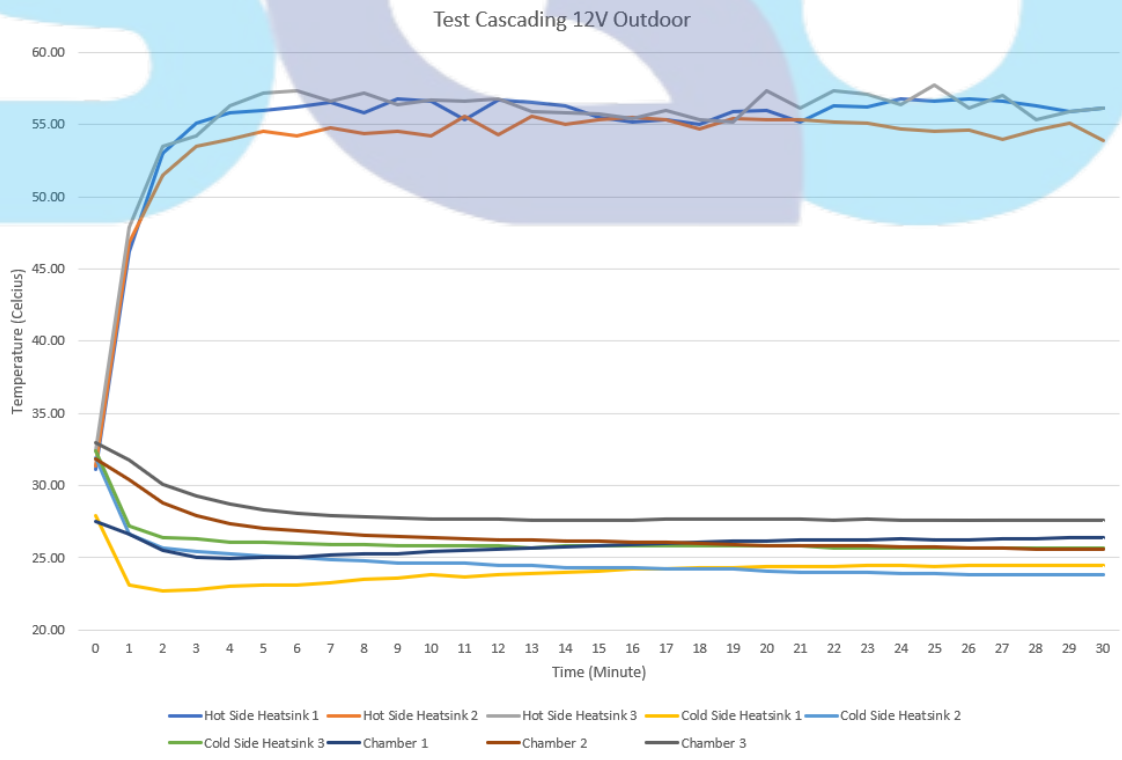

Figure 34. Graph of cascade stacked Peltier module TEC1 – 12706 and TEC1 -12710 with 12V graph

4.2.4. Single Peltier module TEC1 – 12706 with 15V

Table 22. Results of single Peltier module TEC1- 12706 with 15V (testing ten)

Time (Minute)	Hot Side Heatsink (^{o}C)	Cold Side Heatsink (^{o}C)	Chamber Temperature (^{o}C)
0	32.40	32.40	33.00
1	41.20	25.80	29.12
2	45.70	25.40	28.06
3	47.10	25.30	27.44
4	47.30	25.30	27.12
5	47.70	25.30	27.00
6	47.30	25.20	26.94
7	47.90	25.10	26.87
8	48.10	25.10	26.87
9	48.30	25.10	26.81
10	48.00	25.10	26.81
11	48.40	25.10	26.81
12	48.60	25.10	26.81
13	48.60	25.10	26.81
14	48.50	25.20	26.81
15	48.50	25.10	26.81
16	48.60	25.10	26.81
17	48.80	25.10	26.81
18	48.80	25.11	26.81
19	48.50	25.10	26.81
20	48.70	25.10	26.81
21	48.80	25.10	26.81
22	48.60	25.10	26.87
23	48.30	25.10	26.87
24	48.70	25.10	26.87
25	48.80	25.10	26.87
26	48.50	25.10	26.81
27	48.60	25.10	26.81
28	48.70	25.10	26.81
29	47.90	25.10	26.81
30	48.10	25.00	26.75

The *Table 22* above is the results of single Peltier module TEC1 – 12706 with 15V (testing ten). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.40℃ to final temperature of 48.10℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side

heatsink temperature decreases from initial temperature of 32.40°C to final temperature of 25.00°C. This indicates that the Peltier module TEC1 – 12706 is transferring the heat from the chamber effectively, resulting in temperature decrease from initial temperature of 33.00°C to final temperature of 26.75°C.

Table 23. Power consumption of each component from testing ten

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.23A	2.76W
2	Cold side heatsink fan	12V	0.17A	2.04W
3	Peltier module TEC1 - 12706	15V	3.83A	57.45W
	Total	12V and 15V	4.23A	62.25W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing ten is ΔT = 26.75℃ - 33.00℃= -6.25℃. This indicates that the temperature decreases 6.25°C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing ten is $Qc = 0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -6.25℃$= -207.28J. The - sign Qc results indicates that the Peltier module TEC1 – 12706 is absorbing the heat from the chamber equivalent to a heat load of 207.28J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing ten is $COP = \frac{207.28J}{62.25W\ x\ 1800s} = 1.84\text{x}10^{-3}$. The cooling rate of single Peltier module TEC1 – 12706 testing ten is $Cooling\ rate = \frac{-6.25℃}{30\ Min} = -0.208\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.208°C every minute that it is turned on.

Table 24. Results of single Peltier module TEC1 – 12706 with 15V (testing eleven)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	33.30	33.50	32.13
1	42.90	28.50	31.44

2	46.70	27.10	30.19
3	48.00	26.60	29.19
4	48.30	26.20	28.62
5	48.50	25.90	28.12
6	48.30	25.70	27.87
7	48.70	25.60	27.62
8	48.40	25.40	27.44
9	48.30	25.30	27.31
10	48.80	25.30	27.19
11	48.90	25.20	27.06
12	48.20	25.10	27.00
13	48.60	25.00	26.94
14	48.60	25.00	26.87
15	49.00	24.90	26.81
16	48.50	24.90	26.75
17	48.50	24.90	26.69
18	48.80	24.70	26.62
19	48.60	24.60	26.56
20	48.50	24.60	26.56
21	48.50	24.60	26.50
22	48.30	24.50	26.44
23	48.60	24.40	26.37
24	48.30	24.40	26.31
25	48.70	24.30	26.31
26	48.30	24.30	26.25
27	48.40	24.40	26.25
28	49.10	24.30	26.25
29	49.20	24.40	26.25
30	48.50	24.30	26.25

The *Table 24* above is the results of single Peltier module TEC1 – 12706 with 15V (testing eleven). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.30℃ to final temperature of 48.50℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 33.50^{o}C to final temperature of 24.30^{o}C. This indicates that the Peltier module TEC1 – 12706 is transferring the heat from the chamber effectively, resulting in temperature decrease from initial temperature of 32.13^{o}C to final temperature of 26.25^{o}C.

Table 25. Power consumption of each component from testing eleven

Number	Components	Voltage	Current	Power

1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.16A	1.92W
3	Peltier module TEC1 - 12706	15V	3.9A	58.5W
	Total	12V and 15V	4.26A	62.82W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing eleven is ΔT = 26.75℃ - 33.00℃= -5.88℃. This indicates that the temperature decreases 5.88ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing eleven is $Qc = 0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -5.88℃$= -195.01J. The - sign Qc results indicates that the Peltier module TEC1 – 12706 is absorbing the heat from the chamber equivalent to a heat load of 195.01J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing eleven is $COP = \frac{195.01J}{62.82Wx\ 1800s} = 1.72x10^{-3}$. The cooling rate of single Peltier module TEC1 – 12706 testing eleven is $Cooling\ rate = \frac{-5.88℃}{30\ Min} = -0.196\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.196ºC every minute that it is turned on.

Table 26. Results of single Peltier module TEC1 – 12706 with 15V (testing twelve)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	32.40	32.70	32.75
1	43.00	27.70	31.75
2	46.60	26.60	30.50
3	47.80	26.10	29.50
4	48.20	25.80	28.81
5	48.60	25.50	28.31
6	48.20	25.30	27.94
7	48.60	25.10	27.62
8	48.30	25.00	27.44
9	48.60	24.80	27.25
10	48.50	24.70	27.06

11	48.60	24.50	26.94
12	48.30	24.40	26.81
13	48.70	24.30	26.75
14	48.80	24.30	26.62
15	48.60	24.20	26.56
16	48.50	24.10	26.50
17	48.70	24.10	26.44
18	48.60	24.00	26.37
19	48.50	23.90	26.31
20	48.50	23.90	26.25
21	48.60	23.80	26.19
22	48.90	23.80	26.19
23	48.60	23.80	26.12
24	49.00	23.80	26.12
25	48.80	23.80	26.06
26	48.50	23.70	26.06
27	48.20	23.60	26.00
28	48.30	23.60	25.94
29	48.40	23.60	25.94
30	48.80	23.60	25.87

The *Table 26* above is the results of single Peltier module TEC1 – 12706 with 15V (testing twelve). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 32.40℃ to final temperature of 48.80℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 32.70^{o}C to final temperature of 23.60^{o}C. This indicates that the Peltier module TEC1 – 12706 is transferring the heat from the chamber effectively, resulting in temperature decrease from initial temperature of 32.75^{o}C to final temperature of 25.87^{o}C.

Table 27. Power consumption of each component from testing twelve

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.28A	3.36W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12706	12V	3.95A	59.25W

	Total	12V and 15V	4.34A	64.05W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing twelve is ΔT = 25.87℃ - 32.75℃= -6.88℃. This indicates that the temperature decreases 6.88ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing twelve is $Qc =$ $0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ \ -6.88℃$ = -228.17J. The - sign Qc results indicates that the Peltier module TEC1 – 12706 is absorbing the heat from the chamber equivalent to a heat load of 228.17J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing twelve is $COP = \frac{228.17J}{64.05W\ x\ 1800s} = 1.97x10^{-3}$. The cooling rate of single Peltier module TEC1 – 12706 testing twelve is $Cooling\ rate = \frac{-6.88℃}{30\ Min} = -0.229\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.229ºC every minute that it is turned on.

Table 28. Results of single Peltier module TEC1 – 12706 with 15V (testing thirteen)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	33.40	33.80	32.38
1	43.00	28.30	31.81
2	46.60	26.70	30.50
3	47.60	26.10	29.50
4	48.30	25.70	28.75
5	48.40	25.30	28.19
6	48.50	25.10	27.75
7	48.40	24.90	27.44
8	48.80	24.70	27.19
9	48.50	24.50	26.94
10	48.80	24.30	26.75
11	48.90	24.20	26.62
12	48.70	24.10	26.56
13	48.30	23.90	26.44
14	48.30	23.80	26.31
15	48.40	23.80	26.19
16	48.50	23.70	26.06
17	48.40	23.60	26.00
18	48.30	23.60	25.94
19	48.50	23.50	25.89

20	48.50	23.50	25.81
21	48.40	23.40	25.81
22	48.10	23.30	25.75
23	48.10	23.20	25.69
24	48.10	23.20	25.62
25	48.40	23.20	25.62
26	48.30	23.20	25.56
27	48.20	23.20	25.50
28	48.50	23.20	25.50
29	48.70	23.10	25.50
30	48.70	23.20	25.50

The *Table 28* above is the results of single Peltier module TEC1 – 12706 with 15V (testing thirteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.40℃ to final temperature of 48.70℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 33.80^{o}C to final temperature of 23.20^{o}C. This indicates that the Peltier module TEC1 – 12706 is transferring the heat from the chamber effectively, resulting in temperature decrease from initial temperature of 32.38^{o}C to final temperature of 25.50^{o}C.

Table 29. Power consumption of each component from testing thirteen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.24A	2.88W
2	Cold side heatsink fan	12V	0.12A	1.44W
3	Peltier module TEC1 - 12706	15V	3.97A	59.55W
	Total	12V and 15V	4.33A	63.87W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing thirteen is ΔT = 25.50℃ - 32.38℃= -6.88℃. This indicates that the temperature decreases 5.88^{o}C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing thirteen is $Qc = 0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -6.88℃$ = -228.17J. The - sign Qc results indicates that

the Peltier module TEC1 – 12706 is absorbing the heat from the chamber equivalent to a heat load of 228.17J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing thirteen is $COP = \frac{228.17J}{63.87W\ x\ 1800s} = 1.98\text{x}10^{-3}$. The cooling rate of single Peltier module TEC1 – 12706 testing thirteen is $Cooling\ rate = \frac{-6.88℃}{30\ Min} = -0.229\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.229°C every minute that it is turned on.

Table 30. Results of single Peltier module TEC1 – 12706 with 15V (testing fourteen)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	33.70	33.50	32.31
1	42.60	29.40	31.94
2	45.70	28.90	31.25
3	47.60	28.10	30.56
4	48.50	26.70	28.69
5	48.30	25.30	28.25
6	48.30	25.10	27.94
7	48.50	24.90	27.56
8	48.70	24.70	27.19
9	48.70	24.50	27.00
10	48.30	24.30	26.87
11	48.70	24.20	26.81
12	48.80	24.10	26.62
13	48.70	23.90	26.56
14	48.70	23.80	26.50
15	48.10	23.80	26.31
16	48.40	23.70	26.19
17	48.20	23.60	26.06
18	48.20	23.60	26.00
19	48.60	23.50	25.94
20	48.60	23.50	25.87
21	48.10	23.40	25.87
22	48.20	23.30	25.81
23	48.40	23.20	25.75
24	48.20	23.20	25.75
25	48.10	23.20	25.62
26	48.70	23.20	25.62
27	48.40	23.20	25.56
28	48.60	23.20	25.56
29	48.30	23.10	25.56

30	48.80	23.20	25.50

The *Table 30* above is the results of single Peltier module TEC1 – 12706 with 15V (testing fourteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.70℃ to final temperature of 48.80℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 33.50^{o}C to final temperature of 23.20^{o}C. This indicates that the Peltier module TEC1 – 12706 is transferring the heat from the chamber effectively, resulting in temperature decrease from initial temperature of 32.31^{o}C to final temperature of 25.50^{o}C.

Table 31. Power consumption of each component from testing fourteen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.21A	2.52W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12706	15V	3.94A	59.1W
	Total	12V and 15V	4.28A	63.18W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12706 testing fourteen is ΔT = 25.50℃ - 32.31℃= -6.81℃. This indicates that the temperature decreases 6.81^{o}C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12706 testing fourteen is $Qc =$ $0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ -6.81℃$= -225.85J. The - sign Qc results indicates that the Peltier module TEC1 – 12706 is absorbing the heat from the chamber equivalent to a heat load of 225.85J. For the coefficient of performance of the single Peltier module TEC1 – 12706 testing fourteen is $COP = \frac{225.85J}{63.18W\ x\ 1800s} = 1.98\text{x}10^{-3}$. The cooling rate of single Peltier module TEC1 – 12706 testing fourteen is $Cooling\ rate = \frac{-6.81℃}{30\ Min} = -0.227\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.227^{o}C every minute that it is turned on.

Table 32. Performance results of single Peltier module TEC1 – 12706

Testing	ΔT	Qc	COP	Cooling rate
1	-6.25°C	-207.84W	$1.84x10^{-3}$	-0.208°C/Min
2	-5.88°C	-195.01J	$1.72x10^{-3}$	-0.197°C/Min
3	-6.88°C	-228.17J	$1.97x10^{-3}$	-0.205°C/Min
4	-6.88°C	-228.17J	$1.98x10^{-3}$	-0.229°C/Min
5	-6.81°C	-225.85J	$1.98x10^{-3}$	-0.227°C/Min

Table 32 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of five testing that are conducted using single Peltier module TEC1 – 12706 with 15V. On this table, it is evident that the single Peltier module TEC1 -12706 with 15V is able to transfer the heat from the chamber effectively within five testing that are conducted. Looking at the value of the ΔT, Qc, COP, and cooling rate of single Peltier module TEC1 – 12706 with 15V, it is evident that this setup can match the cooling performance of cascade stacked Peltier module TEC1 - 12706 and TEC1 – 12710 with 12V. The evidence is that the cooling rate of this setup is better than the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V, but the drawback of this setup is that it has bigger power consumption than the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V.

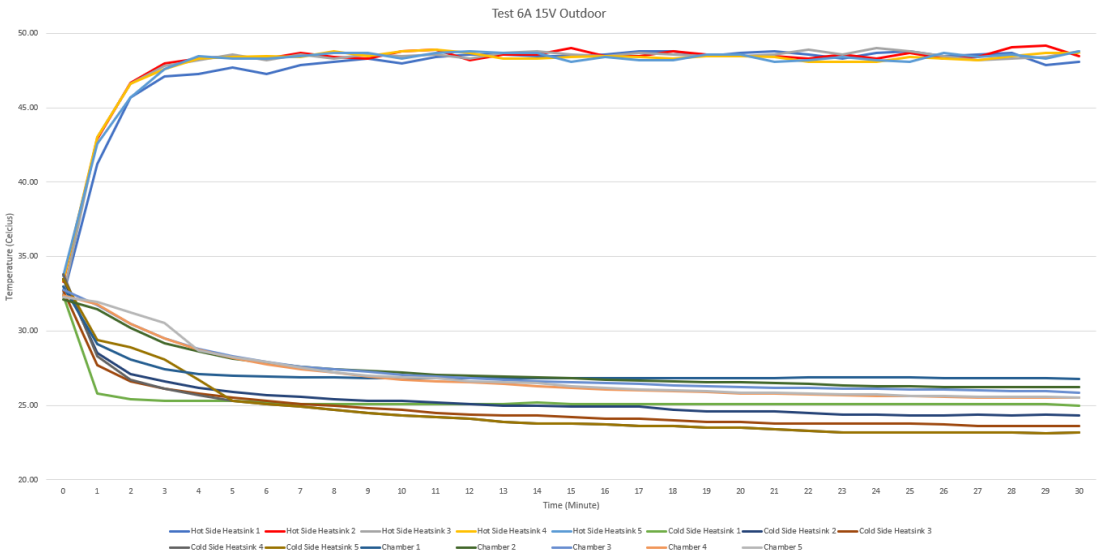

Figure 35. Graph of single Peltier module TEC1 – 12706 with 15V

4.2.5. Single Peltier module TEC1 – 12710 with 15V

Table 33. Results of single Peltier module TEC1 – 12710 with 15V (testing fifteen)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	29.70	30.00	29.06
1	44.30	26.30	28.00
2	48.70	26.00	27.56
3	48.60	26.20	27.37
4	50.80	26.50	27.37
5	49.50	26.60	27.50
6	51.00	26.80	27.62
7	50.80	26.80	27.75
8	51.30	27.10	27.87
9	51.50	27.20	28.00
10	51.30	27.30	28.06
11	51.50	27.40	28.12
12	51.60	27.40	28.25
13	51.60	27.50	28.25
14	51.80	27.50	28.31
15	51.80	27.60	28.37
16	51.90	27.50	28.44
17	51.50	27.60	28.44
18	51.30	27.60	28.50
19	51.40	27.60	28.50
20	51.40	27.60	28.50
21	51.30	27.60	28.50
22	51.60	27.60	28.50
23	51.60	27.60	28.50
24	51.60	27.60	28.50
25	51.30	27.60	28.50
26	51.50	27.60	28.50
27	51.80	27.60	28.50
28	51.70	27.60	28.50
29	52.00	27.70	28.56
30	51.50	27.70	28.56

The *Table 33* above is the results of single Peltier module TEC1 – 12710 with 15V (testing fifteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 29.70°C to final temperature of 51.50°C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 30.00°C to final temperature

of 27.70°C. This indicates that the Peltier module TEC1 – 12710 is transferring the heat from the chamber effectively, thus resulting in temperature decrease from initial temperature of 29.06°C to final temperature of 28.56°C.

Table 34. Power consumption of each component from testing fifteen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.24A	2.88W
2	Cold side heatsink fan	12V	0.18A	2.16W
3	Peltier module TEC1 - 12710	15V	6.73A	100.95W
	Total	12V and 15V	7.15A	105.99W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing fifteen is ΔT = 28.56℃ - 29.06℃= -0.5℃. This indicates that the temperature decreases 0.5°C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing fifteen is $Qc = = 0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -0.5℃ = = -16.58J$. The - sign Qc results indicates that the Peltier module TEC1 – 12710 is absorbing the heat from the chamber equivalent to a heat load of 16.58J. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing fifteen is $COP = \frac{16.58J}{105.99W\ x\ 1800s} = 8.69\text{x}10^{-5}$. The cooling rate of single Peltier module TEC1 – 12710 testing fifteen is $Cooling\ rate = \frac{-0.5℃}{30\ Min} = -0.0167\ ℃/Min$. The - sign indicates that the chamber is being cooled down at a rate of 0.0167°C every minute that it is turned on.

Table 35. Results of single Peltier module TEC1 – 12710 with 15V (testing sixteen)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	29.60	30.00	29.81
1	36.80	29.80	29.31
2	39.70	28.40	29.06
3	42.50	29.00	29.12

4	43.80	29.20	29.31
5	45.40	29.30	29.44
6	47.90	29.50	29.50
7	48.10	29.60	29.69
8	47.70	29.80	29.81
9	48.10	29.90	29.94
10	48.10	30.00	30.12
11	48.50	30.10	30.19
12	48.40	30.20	30.31
13	48.40	30.20	30.37
14	48.70	30.20	30.44
15	48.60	30.30	30.50
16	48.40	30.40	30.50
17	48.90	30.40	30.56
18	48.60	30.40	30.62
19	49.10	30.50	30.69
20	49.10	30.50	30.75
21	48.70	30.50	30.75
22	49.00	30.50	30.75
23	48.60	30.40	30.75
24	48.70	30.40	30.75
25	49.20	30.50	30.75
26	49.40	30.50	30.75
27	49.10	30.50	30.81
28	49.60	30.50	30.81
29	49.60	30.60	30.81
30	49.60	30.60	30.81

The *Table 35* above is the results of single Peltier module TEC1 – 12710 with 15V (testing sixteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 29.60℃ to final temperature of 49.60℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 30.00^{o}C to final temperature of 30.60^{o}C. This indicates that the Peltier module TEC1 – 12710 is unable to transfer the heat from the chamber effectively, resulting in temperature increase from initial temperature of 29.81^{o}C to final temperature of 30.81^{o}C.

Table 36. Power consumption of each component from testing sixteen

Number	Components	Voltage	Current	Power

1	Hot side heatsink fan	12V	0.22A	2.64W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12710	15V	6.74A	101.1W
	Total	12V and 15V	7.09A	105.3W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing sixteen is ΔT = 30.81℃ - 29.81℃= +1℃. This indicates that the temperature increases 1°C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing sixteen is $Qc = = 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ + 1℃ = = +33.17J$. The + sign Qc results indicates that the Peltier module TEC1 – 12710 is not absorbing the heat from the chamber, but instead giving heat load of 33.17J. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing sixteen is $COP = \frac{33.17J}{105.3W\ x\ 1800s} = 1.75x10^{-4}$. The cooling rate of single Peltier module TEC1 – 12710 testing sixteen is $Cooling\ rate = \frac{1℃}{30\ Min} = +0.0333\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.0333°C every minute that it is turned on.

Table 37. Results of single Peltier module TEC1 – 12710 with 15V (testing seventeen)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	30.20	29.90	29.56
1	35.60	25.90	29.25
2	39.80	25.70	29.00
3	42.60	26.00	28.94
4	45.70	26.20	29.19
5	47.10	26.60	29.31
6	47.40	26.60	29.56
7	48.00	26.60	29.62
8	48.20	26.60	29.81
9	48.10	26.90	29.87
10	48.20	27.00	29.94
11	48.20	27.10	29.94

12	48.50	27.50	30.00
13	48.50	27.80	30.12
14	48.70	28.10	30.31
15	48.90	28.40	20.37
16	49.10	28.70	30.44
17	49.20	29.00	30.44
18	49.30	29.20	30.44
19	49.50	29.20	30.56
20	49.20	29.40	30.62
21	48.80	29.50	30.69
22	49.40	29.40	30.75
23	49.50	29.60	30.75
24	49.60	29.90	30.75
25	49.50	30.40	30.75
26	49.50	30.50	30.75
27	49.50	30.50	30.75
28	49.40	30.60	30.75
29	49.30	30.60	30.75
30	49.30	30.60	30.75

The *Table 37* above is the results of single Peltier module TEC1 – 12710 with 15V (testing seventeen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 30.20℃ to final temperature of 49.30℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 29.90^{o}C to final temperature of 30.60^{o}C. This indicates that the Peltier module TEC1 – 12710 is not transferring the heat from the chamber effectively, but instead adding heat to the chamber. This resulted in temperature increase from initial temperature of 29.56^{o}C to final temperature of 30.75^{o}C.

Table 38. Power consumption of each component from testing seventeen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12710	15V	6.72A	100.8W

	Total	12V and 15V	7.03A	104.52W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing seventeen is ΔT = 30.75℃ - 29.56℃= +1.19℃. This indicates that the temperature increases 1.19ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing seventeen is $Qc = = 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ + 1.19℃ = = +39.47J$. The + sign Qc results indicates that the Peltier module TEC1 – 12710 is not absorbing the heat from the chamber, but giving heat load of 39.47J to the chamber. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing seventeen is $COP = \frac{39.47J}{104.52W\ x\ 1800s} =$ 2.09x10^{-4}. The cooling rate of single Peltier module TEC1 – 12710 testing seventeen is $Cooling\ rate = \frac{1.19℃}{30\ Min} = +0.0396\ ℃/Min.$ The + sign indicates that the chamber is being heated up at a rate of 0.0396ºC every minute that it is turned on.

Table 39. Results of single Peltier module TEC1 – 12710 with 15V (testing eighteen)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	30.10	29.50	29.87
1	34.80	27.30	29.19
2	37.40	27.00	28.62
3	39.40	27.50	28.50
4	40.20	27.70	28.31
5	41.30	27.80	28.12
6	44.50	27.90	28.06
7	47.30	27.80	28.06
8	47.70	27.80	28.12
9	48.20	27.90	28.19
10	48.40	28.00	28.25
11	48.70	28.10	28.44
12	49.00	28.30	28.56
13	49.00	28.10	28.81
14	49.10	28.40	28.81
15	49.20	28.50	28.87
16	49.10	28.40	28.94
17	48.90	28.60	29.12
18	49.10	28.80	29.19
19	49.20	29.10	29.31

20	49.30	29.20	29.50
21	49.20	29.30	29.56
22	49.10	29.30	29.62
23	49.10	29.50	29.81
24	49.10	29.60	29.94
25	49.00	29.70	30.06
26	49.00	29.90	30.06
27	49.20	29.70	30.06
28	49.10	29.90	30.06
29	49.10	29.90	30.06
30	49.10	29.70	30.06

The *Table 39* above is the results of single Peltier module TEC1 – 12710 with 15V (testing eighteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 29.70℃ to final temperature of 49.10℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature increases from initial temperature of 29.50^{o}C to final temperature of 29.70^{o}C. This indicates that the Peltier module TEC1 – 12710 is not transferring heat from the chamber effectively, but instead giving heat to the chamber. This resulted in the chamber temperature increased from initial temperature of 29.87^{o}C to final temperature of 30.06^{o}C.

Table 40. Power consumption of each component from testing eighteen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.24A	2.88W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12710	15V	6.7A	100.5W
	Total	12V and 15V	7.05A	104.7W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing eighteen is ΔT = 30.06℃ - 29.87℃= +0.19℃. This indicates that the temperature increases 0.19^{o}C from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing eighteen is $Qc =$

$0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ +0.19℃$= = +6.3J. The + sign Qc results indicates that the Peltier module TEC1 – 12710 is not absorbing the heat from the chamber, but instead giving heat load 6.3J to the chamber. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing eighteen is $COP = \frac{6.3J}{104.7W\ x\ 1800s} =$ 3.34x10^{-5}. The cooling rate of single Peltier module TEC1 – 12710 testing eighteen is $Cooling\ rate = \frac{0.19℃}{30\ Min} = +0.0633\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.0633ºC every minute that it is turned on.

Table 41. Results of single Peltier module TEC1 – 12710 with 15V (testing nineteen)

Time (Minute)	Hot Side Heatsink (ºC)	Cold Side Heatsink (ºC)	Chamber Temperature (ºC)
0	29.80	29.80	29.31
1	35.50	27.40	29.19
2	37.90	27.20	29.12
3	39.70	27.10	28.81
4	41.50	27.20	28.87
5	42.60	27.40	28.94
6	44.60	27.80	29.00
7	45.20	28.20	29.00
8	46.20	28.60	29.00
9	48.40	28.70	29.00
10	48.60	28.80	29.00
11	48.70	28.90	29.12
12	48.50	28.90	29.12
13	48.70	28.90	29.12
14	48.80	28.90	29.19
15	48.80	29.10	29.44
16	48.70	29.10	29.62
17	48.90	29.20	29.81
18	49.10	29.30	29.87
19	49.10	29.20	29.94
20	49.20	29.70	30.06
21	49.20	29.90	30.12
22	49.10	30.00	30.19
23	49.10	30.10	30.44
24	49.00	30.30	30.56
25	48.90	30.10	30.56
26	48.90	30.30	30.56
27	49.20	30.40	30.56
28	49.20	30.40	30.56

29	49.10	30.40	30.56
30	49.10	30.50	30.56

The *Table 41* above is the results of single Peltier module TEC1 – 12710 with 15V (testing nineteen). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 29.80℃ to final temperature of 49.10℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature rises from initial temperature of 29.80ºC to final temperature of 30.50ºC. This indicates that the Peltier module TEC1 – 12710 is not transferring the heat from the chamber effectively, but instead giving heat load to the chamber. This resulted in temperature increase from initial temperature of 29.31ºC to final temperature of 30.56ºC.

Table 42. Power consumption of each component from testing nineteen

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.21A	2.52W
2	Cold side heatsink fan	12V	0.16A	1.92W
3	Peltier module TEC1 - 12710	15V	6.72A	100.8W
	Total	12V and 15V	7.09A	105.24W

The temperature difference between initial temperature with final temperature of single Peltier module TEC1 – 12710 testing nineteen is ΔT = 30.56℃ - 29.31℃= +1.25℃. This indicates that the temperature increases 1.25ºC from the initial temperature. The cooling capacity of the single Peltier module TEC1 – 12710 testing nineteen is $Qc =$ $0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ +1.25℃ = = +41.45J$. The + sign Qc results indicates that the Peltier module TEC1 – 12710 is not absorbing the heat from the chamber, but instead giving heat load of 41.45J. For the coefficient of performance of the single Peltier module TEC1 – 12710 testing nineteen is $COP = \frac{41.45J}{105.24W\ x\ 1800s} = 2.19\text{x}10^{-4}$. The cooling rate of single Peltier module TEC1 – 12710 testing nineteen is

$Cooling\ rate = \frac{1.25℃}{30\ Min} = +0.0417\ ℃/Min$. The + sign indicates that the chamber is being heated up at a rate of 0.0417°C every minute that it is turned on.

Table 43. Performance results of single Peltier module TEC1 – 12710 with 15V

Testing	ΔT	Qc	COP	Cooling rate
1	-0.5°C	-16.58J	$8.69x10^{-5}$	-0.0167°C/Min
2	+1°C	+33.17J	$1.75x10^{-4}$	+0.0333°C/Min
3	+6.88°C	+39.47J	$2.09x10^{-4}$	+0.0396°C/Min
4	+0.19°C	+6.3J	$3.34x10^{-5}$	+0.0633°C/Min
5	+1.25°C	+41.45J	$2.19x10^{-4}$	+0.227°C/Min

Table 43 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of five testing that are conducted using single Peltier module TEC1 – 12710 with 15V. On this table, it is evident that the single Peltier module TEC1 -12710 with 12V is not able to transfer the heat from the chamber effectively within five testing that are conducted. Looking at the value of the ΔT, Qc, COP, and cooling rate of single Peltier module TEC1 – 12710 with 15V, it is evident that this setup did not succeed in cooling down the chamber. It is assumed that the inability of the Peltier module TEC1 – 12710 with 15V to cool down the chamber is because of the insufficient of the hot side heatsink to dissipate the heat from the hot side Peltier module TEC1 – 12710.

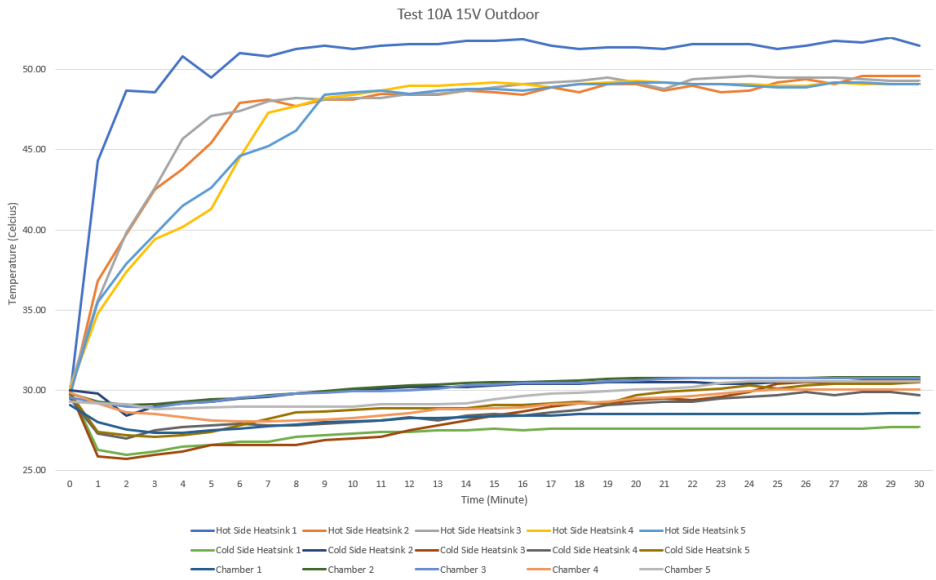

Figure 36. Graph of single Peltier TEC1 – 12710 with 15V

4.2.6. Cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V

Table 44. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	31.10	30.40	31.56
1	53.30	25.50	29.31
2	60.90	25.70	28.19
3	62.90	26.30	27.50
4	63.20	26.60	27.37
5	64.60	27.10	27.69
6	64.80	27.40	27.94
7	63.70	27.70	28.31
8	64.40	27.90	28.56
9	64.20	28.20	28.81
10	64.90	28.40	29.06
11	65.30	28.60	29.31
12	65.40	28.80	29.50
13	65.20	29.00	29.69
14	65.00	29.20	29.87
15	65.30	29.30	30.00
16	65.00	29.50	30.12
17	64.80	29.60	30.31
18	63.80	29.70	30.44
19	64.80	29.70	30.50
20	64.60	29.80	30.56
21	65.10	29.90	30.62
22	64.60	29.90	30.69
23	65.50	30.00	30.81
24	65.80	30.10	30.81
25	66.10	30.10	30.84
26	65.20	30.20	31.00
27	65.60	30.20	31.06
28	65.00	30.30	31.12
29	65.20	30.30	31.12
30	65.80	30.30	31.12

The *Table 44* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 31.10℃ to final temperature of 65.80℃, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases slightly from initial

temperature of 30.40°C to final temperature of 30.30°C. This indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 31.56°C to final temperature of 31.12°C.

Table 45. Power consumption of each component from testing twenty

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.20A	2.4W
2	Cold side heatsink fan	12V	0.14A	1.68W
3	Peltier module TEC1 - 12706	15V	3.25A	48.75W
4	Peltier module TEC1 - 12710	15V	6.74A	101.1W
	Total	12V and 15V	10.33A	153.93W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty is ΔT = 31.12℃ - 31.56℃ = -0.44℃. This indicates that the temperature decreases 0.44°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty is $Qc == 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ -0.44℃$= -14.6J. The - sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 14.6J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty is $COP = \frac{14.6J}{152.93W\ x\ 1800s} =$ $5.3x10^{-5}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty is $Cooling\ rate = \frac{-0.44℃}{30\ Min} = -0.0147\ ℃/Min.$ The – sign indicates that the chamber is being cooled down at a rate of 0.0147°C every minute that it is turned on.

Table 46. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-one)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	31.00	31.70	31.12
1	52.80	27.20	30.19
2	61.20	27.40	29.44
3	62.50	27.70	29.25
4	63.80	28.00	29.19
5	64.10	28.30	29.25
6	64.10	28.50	29.44
7	64.40	28.70	29.50
8	64.50	28.80	29.62
9	64.80	29.00	29.75
10	64.00	29.00	29.87
11	64.00	29.20	30.00
12	63.60	29.20	30.06
13	64.60	29.30	30.06
14	64.60	29.40	30.19
15	64.30	29.40	30.25
16	64.60	29.30	30.25
17	64.60	29.40	30.25
18	64.60	29.50	30.31
19	64.50	29.50	30.31
20	64.70	29.50	30.31
21	64.90	29.50	30.37
22	64.70	29.50	30.37
23	64.10	29.50	30.37
24	64.50	29.60	30.37
25	64.60	29.50	30.44
26	64.80	29.60	30.44
27	64.30	29.60	30.44
28	64.70	29.60	30.44
29	64.90	29.60	30.44
30	64.90	29.60	30.44

The *Table 46* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-one). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 31.00°C to final temperature of 64.90°C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases slightly from initial temperature of 31.70°C to final temperature of 29.60°C. This indicates that the cascade

stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 31.12ºC to final temperature of 30.44ºC.

Table 47. Power consumption of each component from testing twenty-one

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.22A	2.64W
2	Cold side heatsink fan	12V	0.13A	1.56W
3	Peltier module TEC1 - 12706	15V	3.56A	53.4W
4	Peltier module TEC1 - 12710	15V	6.7A	100.5W
	Total	12V and 15V	10.61A	158.1W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-one is ΔT = 30.44℃ - 31.12℃ = -0.68℃. This indicates that the temperature decreases 0.68ºC from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-one is $Qc ==$ $0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -0.68℃=$ = -22.55J. The - sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 22.55J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-one is $COP = \frac{22.55J}{158.1W\ x\ 1800s} = 7.92\text{x}10^{-5}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-one is $Cooling\ rate = \frac{-0.68℃}{30\ Min} = -0.0227\ ℃/Min.$ The – sign indicates that the chamber is being cooled down at a rate of 0.0227ºC every minute that it is turned on.

Table 48. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-two)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	33.70	34.70	31.12
1	51.20	29.30	31.00
2	61.00	28.60	30.31
3	63.50	28.70	30.00
4	64.00	28.80	29.87
5	64.40	28.90	29.81
6	64.50	28.90	29.87
7	64.80	29.00	29.87
8	64.90	29.10	29.94
9	64.80	29.20	29.94
10	64.80	29.20	30.00
11	64.90	29.30	30.06
12	64.40	29.30	30.06
13	65.00	29.30	30.12
14	64.90	29.30	30.12
15	65.00	29.30	30.12
16	64.70	29.30	30.19
17	64.70	29.30	30.19
18	64.50	29.30	30.19
19	64.40	29.30	30.19
20	64.30	29.30	30.19
21	64.20	29.30	30.19
22	64.30	29.30	30.19
23	64.80	29.30	30.12
24	64.50	29.20	30.12
25	64.80	29.30	30.12
26	64.90	29.30	30.19
27	64.50	29.30	30.19
28	65.20	29.30	30.19
29	65.00	29.30	30.19
30	64.90	29.40	30.19

The *Table 48* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-two). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.70°C to final temperature of 64.90°C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 34.70°C to final temperature of 29.40°C. This indicates that the cascade stacked

Peltier module TEC1 – 12706 and TEC1 – 12710 is cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 31.12°C to final temperature of 30.19°C.

Table 49. Power consumption of each component from testing twenty-two

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.23A	2.76W
2	Cold side heatsink fan	12V	0.14A	1.68W
3	Peltier module TEC1 - 12706	15V	3.65A	54.75W
4	Peltier module TEC1 - 12710	15V	6.72A	100.8W
	Total	12V and 15V	10.74A	159.99W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-two is ΔT = 30.19℃ - 31.12℃ = -0.93℃. This indicates that the temperature decreases 0.93°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-two is $Qc =$ $0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -0.93℃$= -30.84J. The - sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 30.84J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-two is $COP = \frac{30.84J}{159.99W\ x\ 1800s} = 1.07\text{x}10^{-4}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-two is $Cooling\ rate = \frac{-0.93℃}{30\ Min} = -0.031\ ℃/Min$. The – sign indicates that the chamber is being cooled down at a rate of 0.031°C every minute that it is turned on.

Table 50. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-three)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	33.70	32.10	32.31
1	49.40	30.60	32.06
2	57.80	30.20	31.81
3	60.80	29.70	31.56
4	61.50	29.30	31.25
5	61.90	29.30	31.06
6	62.30	29.20	30.62
7	63.40	29.20	30.56
8	63.70	29.20	30.31
9	64.10	29.20	30.12
10	64.30	29.20	29.94
11	64.40	29.10	29.81
12	64.60	29.10	29.62
13	64.70	29.00	29.50
14	64.40	29.10	29.50
15	64.50	29.10	29.25
16	64.60	29.20	29.31
17	64.60	29.30	29.31
18	64.70	29.50	29.56
19	64.30	29.60	29.87
20	64.50	29.60	30.31
21	64.70	29.50	30.56
22	65.00	29.60	30.62
23	65.10	29.60	30.62
24	64.80	29.60	30.62
25	64.60	29.50	30.81
26	64.70	29.50	30.81
27	64.60	29.60	30.81
28	64.70	29.70	30.81
29	64.70	29.70	30.87
30	64.70	29.70	30.87

The *Table 50* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-three). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.70°C to final temperature of 64.70°C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 32.10°C to final temperature of 29.70°C. This indicates that the cascade stacked

Peltier module TEC1 – 12706 and TEC1 – 12710 is cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 32.31°C to final temperature of 30.87°C.

Table 51. Power consumption of each component from testing twenty-three

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.24A	2.88W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12706	15V	3.64A	54.6W
4	Peltier module TEC1 - 12710	15V	6.71A	100.65W
	Total	12V and 15V	10.7A	159.45W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-three is ΔT = 30.87℃ - 32.31℃ = -1.44℃. This indicates that the temperature decreases 1.44°C from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-three is $Qc = 0.033\ Kg\ x\ 1005 J/Kg \cdot K\ x\ -1.44℃$= -47.75J. The - sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 47.75J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-three is $COP = \frac{47.75J}{159.45W\ x\ 1800s} = 1.66\text{x}10^{-4}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-three is $Cooling\ rate = \frac{-1.44℃}{30\ Min} = -0.048\ ℃/Min.$ The – sign indicates that the chamber is being cooled down at a rate of 0.048°C every minute that it is turned on.

Table 52. Results of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-four)

Time (Minute)	Hot Side Heatsink (°C)	Cold Side Heatsink (°C)	Chamber Temperature (°C)
0	32.80	32.50	32.56
1	50.30	32.10	32.56
2	62.50	31.80	31.81
3	63.60	30.70	31.62
4	64.20	29.80	31.31
5	64.40	29.60	31.06
6	64.30	29.20	30.94
7	64.50	29.40	30.62
8	64.20	29.40	30.25
9	64.60	29.30	30.06
10	65.20	29.20	29.81
11	64.70	29.10	29.62
12	64.60	29.20	29.56
13	64.70	29.20	29.56
14	64.80	29.20	29.56
15	65.20	29.50	29.87
16	64.40	29.50	30.06
17	64.70	29.60	30.12
18	64.40	29.80	20.19
19	64.60	29.60	30.25
20	64.70	29.60	30.31
21	64.50	29.60	30.50
22	64.30	29.80	30.56
23	64.50	29.40	30.81
24	64.60	29.50	30.94
25	64.30	29.50	31.00
26	64.60	29.50	31.06
27	64.70	29.40	31.06
28	64.50	29.40	31.06
29	64.70	29.50	31.06
30	64.80	29.40	31.06

The *Table 52* above is the results of cascade stacker Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V (testing twenty-four). During 30 minutes of testing, the hot side heatsink temperature rises from initial temperature of 33.70°C to final temperature of 64.80°C, indicating that the hot side heatsink is absorbing the heat from the cold side Peltier module. The cold side heatsink temperature decreases from initial temperature of 32.5°C to final temperature of 29.40°C. This indicates that the cascade stacked Peltier

module TEC1 – 12706 and TEC1 – 12710 is cooling down the chamber temperature, thus resulting in temperature decrease from initial temperature of 32.56ºC to final temperature of 31.06ºC.

Table 53. Power consumption of each component from testing twenty-four

Number	Components	Voltage	Current	Power
1	Hot side heatsink fan	12V	0.21A	2.52W
2	Cold side heatsink fan	12V	0.11A	1.32W
3	Peltier module TEC1 - 12706	15V	3.6A	54W
4	Peltier module TEC1 - 12710	15V	6.67A	100.05W
	Total	12V and 15V	10.59A	157.89W

The temperature difference between initial temperature with final temperature of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-four is ΔT = 31.06℃ - 32.56℃ = -1.5℃. This indicates that the temperature decreases 1.5ºC from the initial temperature. The cooling capacity of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-four is $Qc == 0.033\ Kg\ x\ 1005J/Kg \cdot K\ x\ -1.5℃ =$ = -49.74J. The - sign Qc results indicates that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 is absorbing heat of the chamber equivalent to a heat load of 49.74J. For the coefficient of performance of the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-four is $COP = \frac{49.74J}{157.89W\ x\ 1800s} = 1.75x10^{-4}$. The cooling rate of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 testing twenty-four is $Cooling\ rate = \frac{-1.5℃}{30\ Min} = -0.05\ ℃/Min$. The – sign indicates that the chamber is being cooled down at a rate of 0.05ºC every minute that it is turned on.

Table 54. Performance results of cascade stacked Peltier TEC1 – 12706 and TEC1 – 12710 with 15V

Testing	ΔT	Qc	COP	Cooling rate
1	−0.44℃	-14.6J	$5.3x10^{-5}$	$-0.0147\ ℃/Min$
2	−0.68 ℃	-22.55J	$7.92x10^{-5}$	$-0.0227\ ℃/Min$
3	-0.93℃	-30.84J	$1.07x10^{-4}$	$-0.031\ ℃/Min$
4	-1.44 ℃	-47.75J	$1.66x10^{-4}$	$-0.048\ ℃/Min$
5	-1.5 ℃	-49.74J	$1.75x10^{-4}$	$-0.05\ ℃/Min$

Table 54 shows the temperature difference (ΔT), cooling capacity (Qc), COP, and cooling rate of five testing that are conducted using cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V. On this table, it is evident that the cascade stacked Peltier module TEC1 – 12706 and TEC1 -12710 with 15V is able to slightly cool down the chamber within the five testing that are conducted. Looking from the value of ΔT, Qc, COP, and cooling rate of this setup and comparing the results from the previous setup of 15V, the cascade stacked Peltier module is not an optimal setup for cooling down the temperature of the chamber. The value of ΔT, Qc, COP, and cooling rate of the single 6A Peltier module TEC1 - 12706 setup is significantly better than this setup.

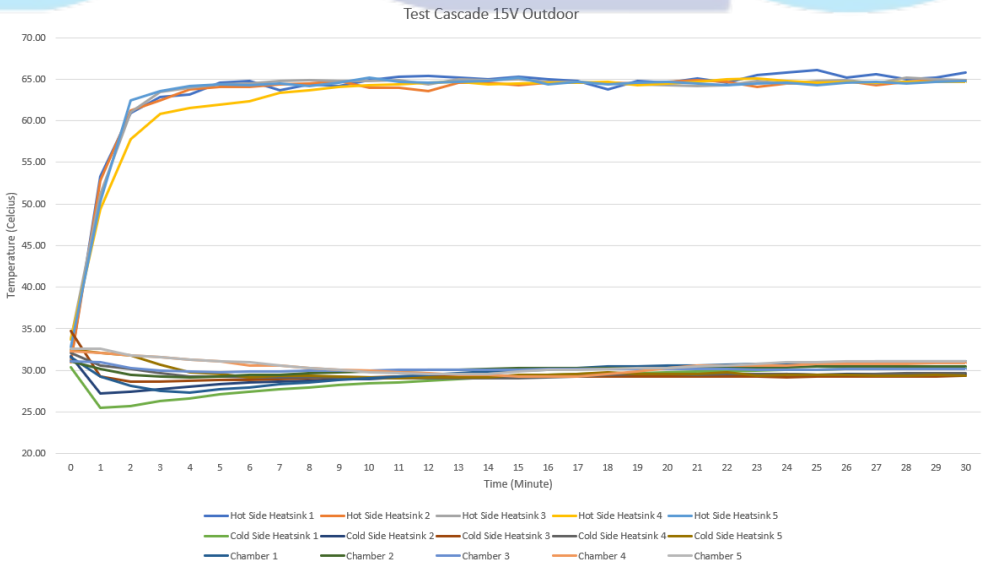

Figure 37. Graph of cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 15V

Many factors affect the results of Peltier cooling system, some of it is the heat dissipation of the heatsink, the power input, the insulation of the system, the specification of the Peltier module itself, and the ambient temperature of the system's surroundings. From the six setup testing that are conducted above, the best value of ΔT, Qc, COP, and cooling rate are achieved by two out of six setup, which is cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V, and single Peltier module TEC1 – 12706 with 15V. According to *Table 21.* the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V achieved better cooling capacity (Qc) and Coefficient of Performance (COP) than the single Peltier module TEC1 – 12706 with 15V. The COP value show that the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V is more efficient than single Peltier module TEC1 – 12706 with 15V, because it can achieve similar final temperature with lesser power consumption. The cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V can achieve better result because it has enhanced temperature differential, utilizing the first stack of the Peltier module to transfer the heat directly to the second stack of the Peltier module. Also, by stacking two Peltier modules together, their cooling capacity is increased because the cooling effect is compounded, allowing for greater heat absorption and dissipation. But according to *Table 32.* the single Peltier module TEC1 – 12706 with 15V achieved better temperature difference (ΔT) and cooling rate than the cascade stacked Peltier module TEC1 – 12706 and TEC1 – 12710 with 12V.