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Heat Reduction on Light Emitting Diode Solar Simulator

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Abstract

LED solar simulator converts electrical energy into light and heat. The resulting heat effect apply damage to the LED and affect performance and accuracy test. Despite being equipped with a heatsink and fan cooling system, the temperature of the LED solar simulator is still considerably quite high though it is necessary to lowered the temperature even further to increase its service life. One major challenge faced is the management of the heat generated by the LEDs. This article aims to investigate the effect of placing a copper pipe-based cooling system containing refrigerant R32 and Thermoelectric to reduce the temperature of the LED solar simulator by at least 10%. The use of thermoelectric cooler (type 12706) as an alternative cooling technology is safer for surrounding environment compared to vapor compression. Copper pipes were chosen for better conductivity, flexibility and better heat absorbance, meanwhile refrigerant R32 were chosen for it is environmentally friendly and possess a lower GWP. The test results illustrate the application of a copper pipe-based cooling system containing refrigerant R32 and thermoelectric succeeded in reducing the temperature of the LED solar simulator by 11,41% and increased the level of radiation uniformity from an average of 422 W/m² to 429 W/m² with a depreciation of non-uniformity of 0,84%. Thus, this very combination cooling system is proven effectively reducing the temperature of the LED solar simulator by at least 10%.

Keyword: Reduction; LED Temperature; TEC 12706; Copper Pipe; Refrigerant R32

Introduction

A solar simulator is a device which provide a similar spectral composition and intensity of a sunlight (Tito-haykestep et al., 2020). The type used for the solar simulator is High Power LED (HPL). LEDs have advantages in simulating the complex terrestrial solar spectrum (Sun et al., 2022), it could radiate light with high intensity yet quite affordable (Yassin & Al-Ahmad, 2019). The characteristics of LED lights greatly influence the voltage, current and performance temperature (Al Amin & Emidiana, 2021).

LED performance is influenced by three basic components, namely the LED chip, phosphor layer and lens (Khandekar et al., 2021). In LED packaging, the LED chip produces blue light. Blue light LED chips cannot be applied in products however it need to be packaged to disperse white light. One of many ways to use a phosphor layer which produces yellow light in order for the combination of the LED chip with the phosphor layer could generate white light (Luo et al., 2016). Apart from that, LED chips also produce heat energy. Heat will be generated in the LED chip due to various types of nonradiative recombination and other causes of photon annihilation. Nonradiative recombination is the energy release in atomic vibrations form. The input power released by the LED is converted into heat energy ranging from 70% to 85% (Wang et al., 2019)(Gatapova et al., 2021)(Hamidnia et al., 2018). Performance temperatures on LEDs range from -20ºC to 85ºC. The effect of heat on the LED could possibly cause harm to the solar simulator LED, so heat dissipation in the LED is important to discuss (Pan et al., 2021).

This article is a further development of research related to LED lighting in solar simulators (Jasman, 2023). Previous research has not yet studied deeper about the heat temperature of the LEDs in the solar simulator which may affect the light produced intensity. In general, the cooling system used in the test field is in the form of thermal paste, heatsinks and fans, but this cooling system is unable to completely reduce the heat temperature of the LEDs. Therefore, further research is required to design additional cooling which could perform greater heat reduction device or system of LEDs in solar simulators.

The problem that occurs in the solar simulator is the heat generated by the LED. In this article we focus on the performance temperature of the LED solar simulator. This article aims to reduce heat in the LED solar simulator as the light intensity increases in the 54 x 67 cm test area. This article produces a combination cooling system from thermoelectric with copper pipes containing refrigerant R32. Several methods have been applied, still there are no significant results yet.

The ultimate trial used TEC 12706 as a cooling medium(Aulia rahman et al., 2019) for copper pipes embedded into the heatsink fins. Copper pipes perform better conductivity, resistant to pressure, and not easily corroded unlike PVC hoses. Copper pipes are filled with refrigerant R32 which has a faster process of changing state compared to water, furthermore it absorbs heat better yet efficiently. Measurements and tests were carried out on the LED temperature conditions of the heatsink and fan cooling system and the combination heatsink and fan cooling system with a thermoelectric, a copper pipe containing refrigerant R32.

Literature Review

A. LED based Solar Simulator

A solar simulator is a device used to test photovoltaic cells, ensuring the test results comply with the expected conditions. Some common light sources used in solar simulators to test solar cells and modules like mercury xenon lamps, xenon arc lamps, metal halide lamps, and LED lamps. Xenon arc lamps are the most widely used as light sources in solar simulators, while halide arc lamps, carbon arc lamps, and quartz tungsten halogen lamps are also sources in certain types of solar simulator designs (Tito-haykestep et al., 2020). To analyze the measurement results, there are several considerations which inlcuding the non-uniformity of the light intensity produced by the solar simulator. the following equation may help (Moss et al., 2018).

$$Non - uniformity = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \ x\ 100\% \tag{1}$$

Measuring the temporal instability of the solar simulator could also be done using the equation below.

$$Temporal\ Instability = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \ x\ 100\% \tag{2}$$

Furthermore, the relativity between the heat in an LED and the light intensity it generates could be explained through several important parameters includes electrical power used, conversion efficiency (Radiant Power), and heat dissipation. systematically it can be seen as follows (OSRAM, 2018).

Calculation of thermal resistance on LEDs:

$$Q_{LED} = P_{head} = P_{el} - P_{opt} = V_f .\ I_f - \Phi_e \tag{3}$$

By using the practice rule that have been determined for white LEDs:

$$\frac{\Phi_v}{\Phi_e} = 325\ lm/W \tag{4}$$

For Heat Dissipation:

$$P_{heat} = P_{el} - \Phi_e \tag{5}$$

B. Cooling System

Thermoelectric Peltier

Thermoelektric Cooler (TEC) or cooling system is an electronic component that has two sides, where one side generates cold temperatures and the other one produces hot temperatures as electric current is applied (Adrianto, Kennedy M, Reyhan Kiay Demak, 2019). Apart from that, Thermoeletric can be used to regulate room internal temperature as it surrounding, thereby minimizing heat dissipation in the room (Cecconi et al., 2023).Thermoelectric process performance is greatly influenced by its ability to release heat. The heat flow escalation rate relies on both sides of the TEC, where smaller temperature gap between the two sides, may contribute to greater heat flow rate in the device (Adrianto, Kennedy M, Reyhan Kiay Demak, 2019). TEC is an alternative cooling technolgy rather than vapor compression (Alfiansyah, 2021). Thermoelectric offers better accuracy in temperature control system, safer for surrounding environment, better durability, low maintainance and less noise.

Thermoelectric module performance explains that heat transfer occurs from the heat is transfers to the cold side of the thermoelectric module could be detected from the amount of heat pumped by the Peltier effect, the heat transferred from the higher temperature side to lower temperature side due to the thermal conductivity of the thermoelectric material, and part of the Joule heating total effect caused by electric current on thermal resistance. type used in this study is of type TEC 12706 as many as 3 pieces. The systematic formulation is as follows (Amrulah, 2013) (Santoso & Simatupang, 2021).

Heat released on the colder side of the thermoelectric module

$$Q_c = \alpha\ .T_c\ .I - K.\Delta T_p - \frac{I^2\ R}{2} \tag{6}$$

Copper Pipe

In general, cooling systems use copper pipes. Copper pipes are uneasily corroded yet even durable unlike non-brass pipes. Copper pipes offers several advantages over other materials in term of conductivity (better thermal conductivity) and easier to shape (Komaruddin, n.d.)(Hayat et al., 2020).

Refrigerant R32

The cooling process requires easy-changing form of materials, from gas to liquid or vice versa. This particular substance is also known as refrigerant (cooling substance). Refrigerant is a fluid used in cooling systems to absorb and release heat through thermodynamic cycles. There are several types of refrigerants available on the market such as R32, R22, R410A. different types posses different percentages of GWP (Global Warming Potential) and ODP (Ozon Depleting Potential) values (Mota-Babiloni et al., 2017).

Tabel 1. Characteristics of Refrigerant R22, R410A & R32 (Refrigerant, 2018)

Object	**R22**	**R410A**	**R32**
ODP	0.05	0	0
GWP	1810	2090	675
Type	Single component Component	Refrigerant pseudo-azeotropic	Single Component Refrigerant
Refrigerant Oil	Mineral Oil	Synthetic Oil	Synthetic Oil
Pressure Ratio	1	1.6	1.6
Service Port	W1/4	W5/16	W5/16

The table above explains that R32 produce a GWP of around 675, which is lower than R410A, which is safer for surrounding environment. Refrigerant R32 (difluoromethane) is a chemical compound with the chemical formula CH_2F_2. R32 offers several advantages of R32, including:

1. Energy efficiency is more efficient compared to other refrigerants.
2. Low global warming potential (GWP).
3. Good cooling capacity
4. Relatively high working pressure

Methods

Design of Cooling System Prototype

The cooling system prototype consists of three main components, namely TEC 12706, copper pipes and refrigerant R32. The copper pipe is inserted into the LED heatsink and adapts to testing media and manage higher temperature areas including each corner of the testing area. This design can be seen in the image below.

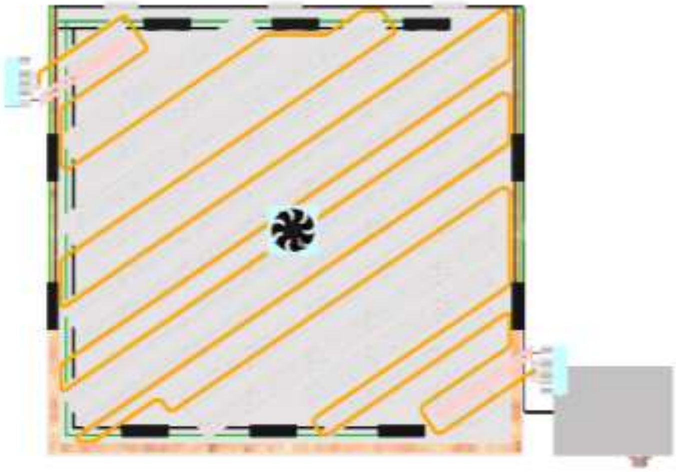
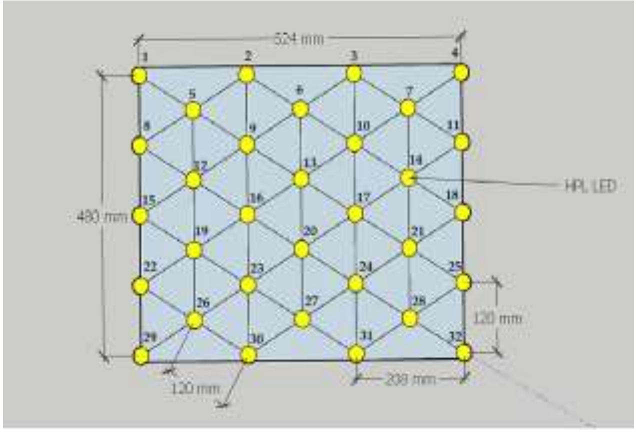


Figure 1. LED cooling system design in solar simulator

Measurement

LED temperature measurements were carried out in two positions. First, measuring the temperature produced by the LED when the LED temperature is in the heatsink and fan cooling system. And secondly, measure the temperature of the LED when the cooling system is combined with heatsink, fan and copper pipe containing refrigerant R32. The tool used to measure temperature is a digital thermometer. The measurement scheme is carried out on the solar simulator test field according to the LED array, totaling 32 LEDs. For each condition, 2 test points were measured, namely on the LED heatsink and on the LED module. Measurements are carried out for 5 minutes and data is collected every 1 minute at the same point on a regular basis (measurement position does not change).



Fugure 2. Temperature Measurement Matrix on 32 LEDs (Jasman, 2023)

Temperature measurements are carried out to determine the temperature produced by the LED and heatsink. The temperature produced by an LED may vary depending on the intensity of the acquired light. The temperature produced on the LED heatsink is the result of the LED heat reduction.

Testing

Testing the light intensity on LEDs uses a measurement scheme on the solar simulator test field. The test field measures 53.5 x 66.9 cm, testing is carried out according to a 5 x 5 cm matrix with 154 sample points (11 x 14). The distance between the LED and the test point is 20 cm to ensure the light produced by the LED can be acquired properly by the test point. The tool used to test light intensity is a solar power meter or called a luxmeter. This specific tool possesses an elastic sensor that could be easily positioned. When testing the sensor, it is placed in the matrix provided in the solar simulator test chamber/field. Light intensity testing can also help determine the performance of the LED in producing light that meets your needs. LED performance can be checked by measuring the intensity of the light produced and the temperature produced. Thus, this article may assist in improving LED performance and ensure that solar simulators can be used effectively to test LED performance.

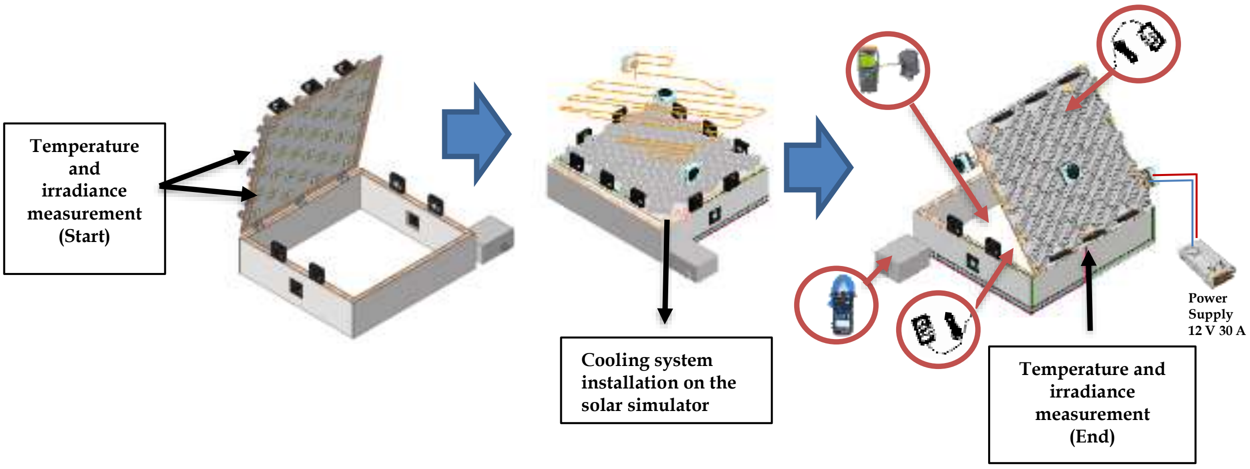


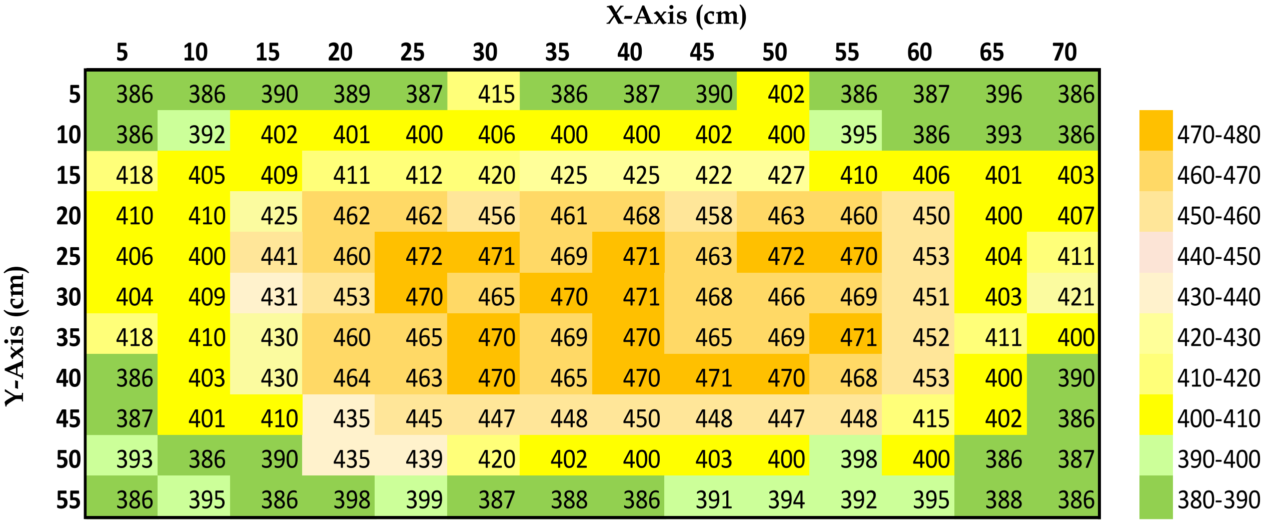
Figure 3. Flow of temperature measurement and light intensity testing on LEDs

Initial measurement of LED temperature conditions using a heatsink and fan cooling system. After getting the initial measurement results, the next step is to install the combination cooling system which has been designed to adapt and be combined with the solar simulator. Next, final measurements are carried out so that they can be analyzed and concluded.

Results and Discussion

A. The result of light intensity with heatsink and LED cooling system (Initial Condition)

Measurements were carried out for 5 minutes and data was taken every 1 minute. Light intensity, LED temperature and heatsink temperature were measured according to a 5 x 5 cm matrix with a total of 154 data collection points. Therefore, the following are the results of the light intensity.



X-Axis (cm)

Y-Axis (cm)

	5	10	15	20	25	30	35	40	45	50	55	60	65	70
5	386	386	390	389	387	415	386	387	390	402	386	387	396	386
10	386	392	402	401	400	406	400	400	402	400	395	386	393	386
15	418	405	409	411	412	420	425	425	422	427	410	406	401	403
20	410	410	425	462	462	456	461	468	458	463	460	450	400	407
25	406	400	441	460	472	471	469	471	463	472	470	453	404	411
30	404	409	431	453	470	465	470	471	468	466	469	451	403	421
35	418	410	430	460	465	470	469	470	465	469	471	452	411	400
40	386	403	430	464	463	470	465	470	471	470	468	453	400	390
45	387	401	410	435	445	447	448	450	448	447	448	415	402	386
50	393	386	390	435	439	420	402	400	403	400	398	400	386	387
55	386	395	386	398	399	387	388	386	391	394	392	395	388	386

470-480
460-470
450-460
440-450
430-440
420-430
410-420
400-410
390-400
380-390

Figure 4. The results of the light intensity on starting conditions

The results of measuring the minimum light intensity were 386 W/m² and the maximum light intensity was 471 W/m². The level of uniformity can be calculated using equation (1) as follows:

$$\text{Non- uniformity} = 9.92\ \%$$

Therefore, the uniformity rate is 90.08.

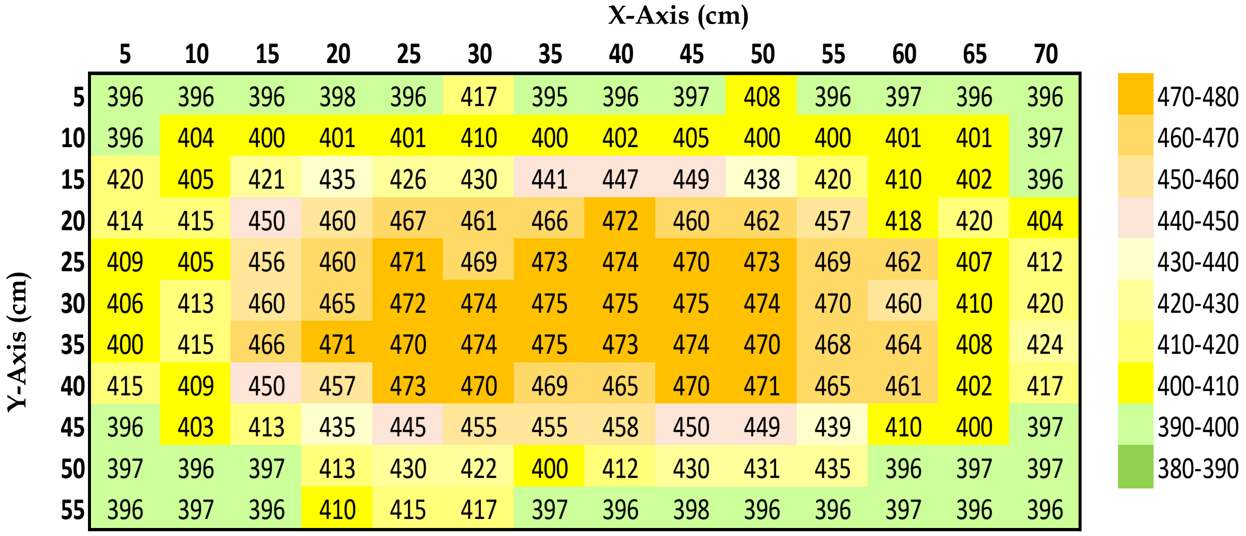
B. Cooling System Design Result

In the initial stage of assembling TEC 12706 which requires several components on two sides. On the higher temperature side of the thermoelectric which has been smeared with thermal paste, a 98 x 98 x 25 mm heatsink, fan and fan casing are attached. On the lower temperature side, thermoelectric has been smeared with thermal paste and then attached with an insulating sponge and a heatsink measuring 40 x 60 x 18 mm. This cooling system is designed using TEC 12706 with 3 sets, copper pipes with a diameter of 0.4 mm. with a length of 7 m which has been inserted and bent to suit the heatsink fins on the test area. Next, the copper pipe is filled with refrigerant R32 at a pressure of 50 psi. The results of the cooling system design are as follows.

Figure 5. Prototype of the LED cooling system in the solar simulator

C. Light intensity test results with a combination cooling system (Final conditions)

When the TEC 12706 cooling system works, it takes time to cool the copper pipes that have been filled with refrigerant R32. The time required is the ratio between the heat capacity that must be removed and the cooling capacity pumped by the TEC 12706. In accordance with equation (6), the heat released on the cold side of the thermoelectric module is 46,425 J and the heat capacity that must be removed is 9.22 J. therefore, the time needed for the TEC 12706 to cool the copper pipe is 5.66 minutes. Measurements were taken for 5.66 minutes and data was taken every 1 minute. The following are the results of the light intensity in the last test.



	5	10	15	20	25	30	35	40	45	50	55	60	65	70
5	396	396	396	398	396	417	395	396	397	408	396	397	396	396
10	396	404	400	401	401	410	400	402	405	400	400	401	401	397
15	420	405	421	435	426	430	441	447	449	438	420	410	402	396
20	414	415	450	460	467	461	466	472	460	462	457	418	420	404
25	409	405	456	460	471	469	473	474	470	473	469	462	407	412
30	406	413	460	465	472	474	475	475	475	474	470	460	410	420
35	400	415	466	471	470	474	475	473	474	470	468	464	408	424
40	415	409	450	457	473	470	469	465	470	471	465	461	402	417
45	396	403	413	435	445	455	455	458	450	449	439	410	400	397
50	397	396	397	413	430	422	400	412	430	431	435	396	397	397
55	396	397	396	410	415	417	397	396	398	396	396	397	396	396

Figure 6. The LED Light Intensity using Cooling system

The results of measuring light intensity in the final conditions, the minimum was 396 W/m² and the maximum light intensity was 475 W/m². The level of uniformity can be calculated using equation (1) and the results are as follows.

Non- uniformity = 9.07 %

Therefore, the uniformity rate is = 90.92.

Temporal Instability Test

Temporal instability is obtained from the results of continuous measurements of LED light intensity within 5 minutes. Measurements were recorded every 1 minute at the same and fixed point in each matrix.

Table 2. Average results Measurements using an additional cooling system in the test field

Time (m)	Heatsink Temperature (˚C)	Light Intensity (W/m²)
0	25.8	500
1	27.4	462
2	34.8	449
3	38.3	438
4	41.5	431
5	42.7	429

Table 2 explain that over time the temperature of the LED increases respectively then the heat is significanlty reduced caused by the heatsink, fan and cooling system TEC 12706 ranging from 27.4 - 42.7 ˚C, unlike measurements in the initial condition, there is a change of 1 minute the heatsink temperature in the final condition is lower than the heatsink temperature in the initial condition. And in the final state LED temperature does not increase significantly. On the 4th minute, the radiation and temperature show stability. The maximum average radiation value is 500 W/m² and the minimum is 429 W/m². From equation (2), the temporal level of radiation instability is obtained as follows.

Temporal instability = 7.64 %

Therefore, the stability rate is 92.35

D. Comparison of Early and Late Stage Test

Early stage conditions and later on the temperature reduced by a cooling system at the final stage as the graph follows.

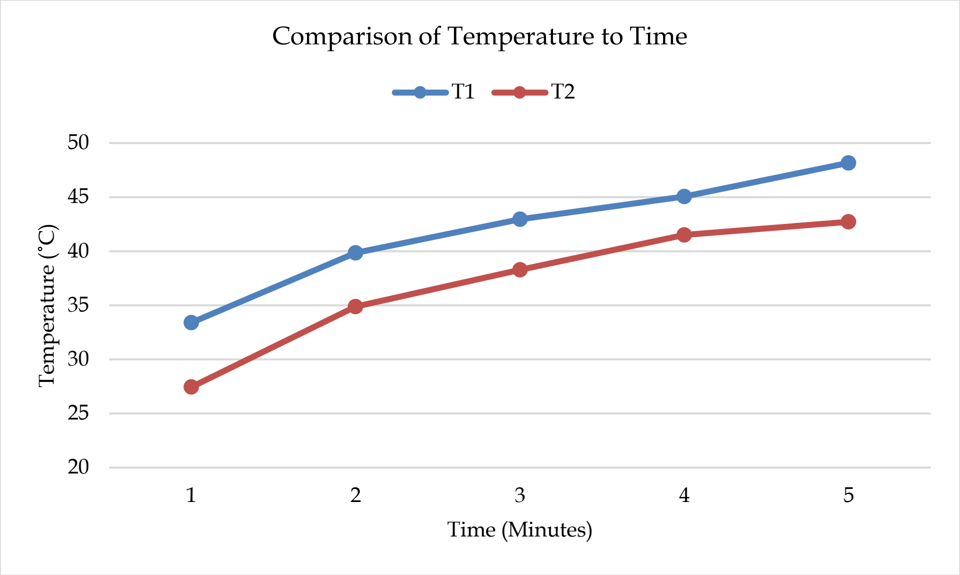


Figure 7. Comparison of Temperature to Time

Figure 7 explained that implementing the cooling system, the temperature on the heatsink decreases over time. In the 5th minute, the initial condition temperature obtained with the heatsink and fan cooling system (T1) was 48.2 °C and the final condition temperature after applying the Peltier combination cooling system (T2) was 42.7. The percentage temperature reduction can be seen as follows.

$$\text{Reduction Percentage} = \left(\frac{T1-T2}{T1}\right) x\ 100 = 11{,}41\ \%$$

Using a combination cooling system of heatsink, fan with TEC 12706, copper pipe containing refrigerant resulting in a temperature reduction of 11,41%.

E. Temperature Influence to The Light Intensity

LEDs convert energy into two, namely heat energy and light energy, the heat produced by LEDs unable to be separated from light energy. If the heat energy consumed by the LED is small, the light radiation will increase. The grap below explain the effect of temperature on the light intensity of the LED by measuring for 5 minutes.

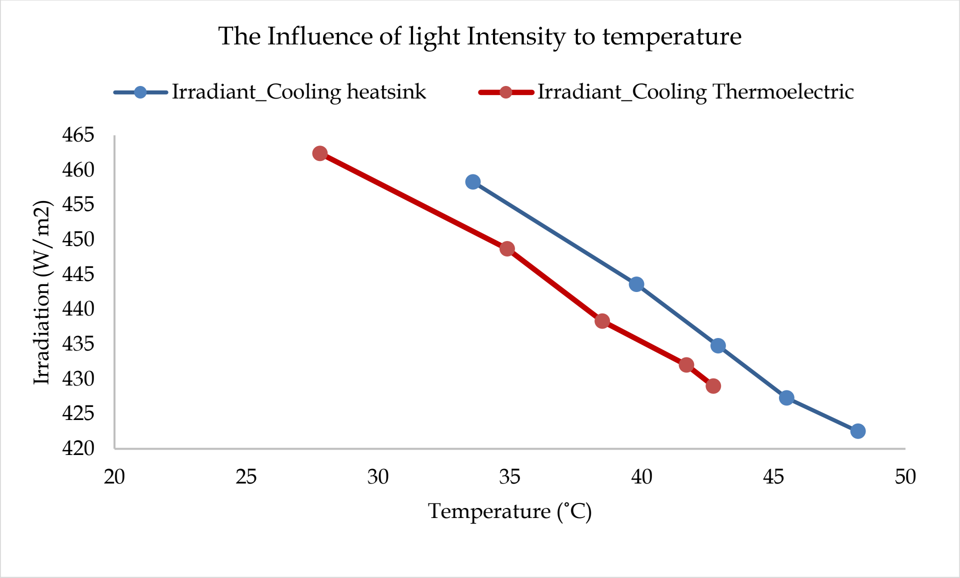


Figure 8. The Influence of Temperature to Light Intensity

Based on Figure 8, the lower the temperature is reduced contribute to better quality of light intensity on the LED. LED heat production is not the same as electrical energy, some of the electrical energy is converted into radiation energy (light). Calculation of LED thermal resistance/heat generation can use equations (3) (4) and (5).

P = V.I
P = 187 volt. 7,26 Ampere = 1.357,62 Watt

The power generated from the solar simulator is 1.357,62 watt. Using 32 leds in the solar simulator, it can be estimated that 1 led produces 42,42 watt of energy.

Furthermore, According to the datasheet, the LED solar simulator has a luminous flux $\Phi_v$of 5600 lumens. By using equation (4) you get a result of $\Phi_e$of 17,32 watt.

Furthermore, for the heat dissipation produced by the led in the solar simulator may use equation (5) and get a result of 25,18 watt. Therefore, it can be concluded that the heat energy produced by each led in the solar simulator is 25,18 watt.

Conclusions

The utilization of a copper pipe-based cooling system containing refrigerant R32 and Peltier 12706 is proven effectively reducing the temperature in the LED solar simulator by around 10%. Apart from that, the utilization of this cooling system also increases the level of light intensity uniformity in the LED Solar simulator.

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