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Experimental Investigation of Integrated Energy Storage on Thermal Performance Enhancement of Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for Air Heating Application

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ABSTRACT

Thermal energy storage (TES) in solar thermal application assist to increase the performance and efficiency of the solar thermal collector system. Various technique has been developed to enhance TES performance such as using water and PCM as energy storage material. Type of material selection and design arrangement also contribute to the performance of solar thermal collector. The aim of this research is to enhance the thermal performance of energy storage on Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for air heating application. The performance study has been conducted to measure the outlet temperature and energy storage rates as per indoor setup under the artificial solar radiation on the effect of parameters such as inner absorber surface area air contact (perforated fins), outer absorber selective coating surface, outer absorber wall thickness, double layer non vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube. The results showed that the performance of temperature outlet, energy store and energy buffer increase at wind speed 0.9 m/s, zero (0) perforated fin, non-coating outer absorber and 2mm outer absorber wall thickness. It was also demonstrated that a double layer vacuum glass tube showed a better thermal performance enhancement compared with double layer non-vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube. This concluded that EGATC performance can be increase with those respective parameters.

1. Introduction

The growing in energy demand and global warming have motivated intensive investigation towards energy usage efficiency and energy storage systems development [1]. One of the effective techniques to decrease the gap between energy supply and demand is thermal energy storage (TES) [2]. TES are divided into three types i.e. latent heat storage, sensible heat storage and reversible

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thermochemical reaction. Latent heat thermal energy storage (LHTES) is promising due to the thermal energy absorptivity and emissivity at consistent temperature during the phase change process by the usage of phase change materials (PCMs) [3].

With regards to sensible heat thermal energy storage (SHTES), the fins usage as extended surface seen as the interesting topic by various researchers [4-7] as per fins have significant consequence in heat transfer improvement. The heat transfer rates optimization contribute to efficiency enhancement and saving of electrical power supplied in numerous manufacturing industries such as computer chips and automobile engines. Due to the economical, lightweight, and compact fins demand, the fin size optimization is very important. There are many types of fins but regularly used are rectangular type plate due to easiness in manufacturing.

The performance of solar thermal collectors can be enhanced through several techniques, such as the usage of extended surface including corrugated absorber, artificial roughness, packed bed materials and fins [8]. Heat transfer via convection may improve by using perforated fins instead of solid fin with optimum angle of inclination. Several studies have been investigated on the fin shape modifications through its body such as cavities, holes, grooves, slots or channels to increase the heat transfer rate.

Abu-Hijleh [9,10] conducted the numerical investigation and initiate that the heat transfer via permeable fins show significant result over solid fins. He concluded that by increasing the number of permeable fins from highly conducting material resulted in increasing of Nusselt number opposing in solid fins. Ahn *et al.,* [11] had experimentally compared the heat transfer rates between rounded and elongated holes at rectangular plate. They showed that elongated holes improve better heat transfer rate compared with rounded holes by reason of pressure drop.

Meanwhile, Ridouane and Campo [12] showed that the grooves channels enhanced the local heat transfer relative to flat passage. Mahdi *et al.,* [13] studied the instantaneous charging and discharging processes in a triplex-tube heat exchanger (TTHX). They concluded that the TTHX with a novel fin configuration were more promising for achieving higher thermal performance between the respective fin system with the one that consists of nanoparticles. On the other hand, Awasarmol and Pise [14] experimentally studied the perforated rectangular fin arrays on natural convection heat transfer. They concluded that while reducing the perforated fin mass by 30%, the fins can improve the heat transfer coefficient up to 32%. Kundu *et al.,* [15] recommended implementing the porous fin of any shape in comparison to the solid fin as it transfers heat at a higher rate. Some studies had demonstrated the perforated fins usage may enhance the heat transfer coefficient [10,16,17].

Regarding the shape of fin, Ben-Nakhi *et al.,* [18] investigated the open cavity effect on natural convection. They found that the hot surfaces attached with thin fins increases the heat transfer rate. Zhnegguo *et al.,* [19] applied petal shaped finned tubes to improve the heat transfer. Awasarmol *et al.,* [20] studied the permeability fins effects of natural and forced convection heat transfer. They conclude that the respective permeable fins perform better than the solid fins. Some researchers reported a similar trend for circular shaped perforated fins [14,20,21].

Commonly, material used in thermal energy storage such as copper, aluminium and stainless steel. Amongst these three (3), cooper is better in rapid temperature rise due to high conductivity [22] but the price is quite expensive and limited due the material profile as well as non-commercially used for food industry in Malaysia. Aluminium offer low price but lower in density [23] thus limited due to commercial specification and the fittings for design assembly. Furthermore, low density [23] also effected low in energy storage compared to stainless steel. Current Malaysia market price as per March 2021 for 4'× 8' metal sheet with 1 mm thickness are Copper RM514.04 (Source: Pumpline (KL) Sdn. Bhd.), Aluminium RM126.60 and Stainless-Steel RM360.00 (Source: Sam’s Metal Trading (Kuantan) Sdn. Bhd.) based on the global reference non-ferrous metal [24] and stainless-steel [25] market price. Stainless steel has better specific heat capacity [23] compared to copper which gives the former a higher energy storage capability. This non-corrosive material is suitable and widely used for the usage in food industry and established as food grade material. Even though stainless steel has low thermal conductivity [23] compared with aluminium and copper, this factor deemed as irrelevant due to the closed system design of EGATC.

Coating in solar thermal collector is normally used to enhance the efficiency of solar thermal system. It converts radiation from daylight into heat energy. Normally, selective coating with flat black in colour is used [26-28] due to its low price. The pigment of flat black colour itself have ability in energy absorption and the absence of reflection might prevent the solar radiation losses through radiation [29]. Thus, the selective coating could apply to obtain small capacity of energy storage in solar thermal collector [30]. It has also been proved by other researchers that by increasing the high heat capacity of a material may also enhance thermal energy storage (TES) ability. Manickam *et. al*. [31] had studied on magnesium hydride coated with stainless steel to improve the activation process, kinetics and thermal conductivity at moderate temperature thermal storage.

The aim of this study is to enhance the thermal performance of EGATC. There are various factors that influences the thermal performance of an EGATC. However, current study is focused on inner absorber design, outer absorber coating and its thickness, and the glass tube configuration. To the authors' best knowledge, the effect of perforated fins, outer absorber coating and its thickness on the thermal absorber inside an evacuated glass has not been investigated. The reports available in literature only focuses on an evacuated glass principle and its application. The findings may also deliver beneficial information on TES due to performance enhancement of the EGATC systems.

2. Methodology

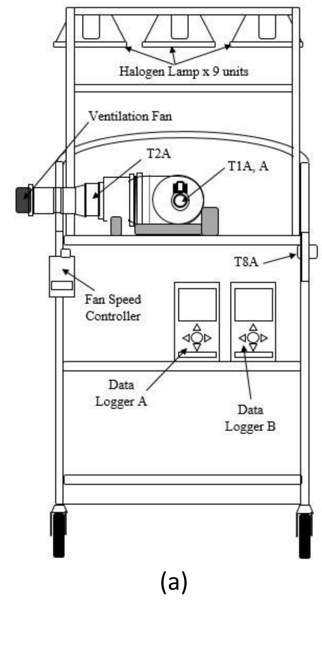
2.1 Device and Apparatus

Two (2) units of data Logger, 8-Channel Temperature Meter, that is Data Logger A and Data Logger B were used to record the temperature data during the experiment. Out of 16-channel, 6-channel were unused, and others ten (10) channel were allocated for temperature data. Ten (10) unit of K-type thermocouple were applied to record the temperature data namely, T1A until T8A were used for Data Logger A while T1B and T2B were used for Data Logger B. T1A and T2A were allocated to measure the air inlet and outlet temperature respectively while T3A, T1B, T4A, T2B and T5A were allocated to measure the outer absorber temperature at five (5) different location. T6A and T7A were used to measure the outer glass surface temperature of an evacuated tube. Meanwhile T8A was used to record the ambient temperature. The experiment was run as the indoor experiment under the artificial solar radiation along for charging and discharging. The temperature data was recorded by data logger for every one (1) minute.

As the test rig calibration's setup, the artificial solar radiation was calibrated before each experiment was run. The artificial solar radiation was consisting of nine (9) halogen lamps (150W, 220-240V, 50/60Hz) in series-parallel connection with matrix 3x3 arrangement. The current reading measured by UNI-T Mini Clamp Meter (UT210E) was setup to 7.57Amp in order to produce the value of solar radiation 700 w/m². The reading was monitored for every five (5) minutes at three (3) different point until the end of experiment and the data was recorded manually. For the first experimental setup, EGATC was insert with zero (0) perforated fin at inner absorber. Each zero (0) perforated fin experiment were carried out with wind speed 0.0 m/s, 0.7 m/s, 0.9 m/s, 1.1 m/s, 1.3 m/s, 1.5 m/s and 1.7 m/s. The similar working procedure was followed for the others parameter experiments with the seven (7) perforated fins. The data of each wind speed experiment for zero (0) and seven (7) perforated fins were compared to determine better design of perforated fin and appropriate wind speed in this experiment. The identified design then was setup for the next parameter experiments namely outer absorber selective coating and outer absorber wall thickness. Others parameters of evacuated tube also had been tested with the same design setup such as. double layer non vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube. All the recorded data was analysed and the graph was plotted after the experiment was conducted.

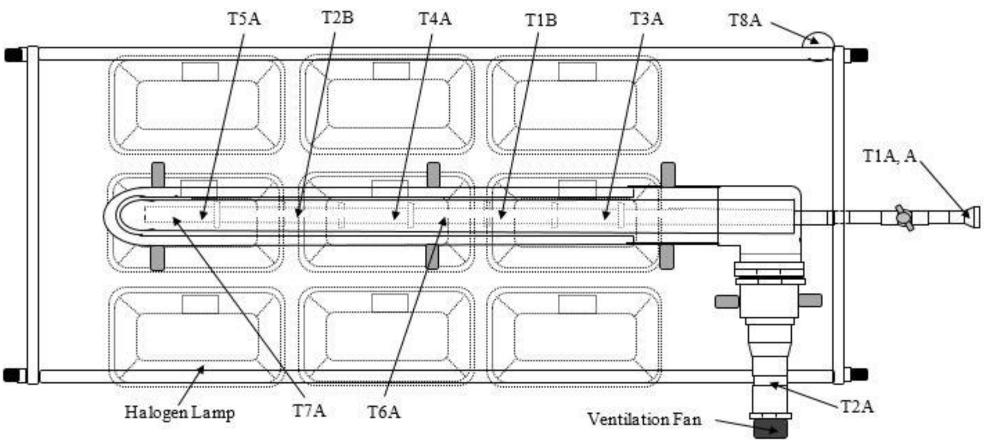
The apparatus was exposed to the artificial solar radiation with 700 W/m² for 30 minutes on charging and other 30 minutes on discharging. The artificial solar radiation flux was measured using TES ELECTRICAL ELECTRONIC CORPORATION, Datalogging Solar Power Meter (TES-1333R). The reading was recorded every five (5) minutes at three (3) different location along the experiment in order to monitor the consistency of flux produce by the simulator. In order to measure the temperature, APPLENT TECHNOLOGIES, Multi-Channel Temperature Meter (8-CH) (AT4208) was utilized. The wind speed was measured by UNI-T Mini Digital Anemometer (UT363). The solar thermal collector applied in this research namely Evacuated Glass–Thermal Absorber Tube Collector (EGATC) was reported in previous study by Zakaria *et al.,* [32]. The thermal absorber was divided into two (2) parts particularly inner absorber and outer absorber. Inner absorber comprises of small diameter pipe affix with either zero (0) or seven (7) perforated fins while outer absorber comprises of large diameter pipe closed by one side end cap. Both inner and outer absorbers were attached together inside the evacuated glass.

Determination the effect of the parameters such as. inner absorber surface area air contact (perforated fins), outer absorber selective coating surface, outer absorber wall thickness, double layer non vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube on thermal performance enhancement was conducted and the experiment was setup including sensor location as shown in Figure 1.



Label	Description
T1A	Ideal EGATC inlet temperature
T2A	Ideal EGATC outlet temperature
T3A	Ideal EGATC front thermal absorber temperature
T4A	Ideal EGATC middle thermal absorber temperature
T5A	Ideal EGATC rear thermal absorber temperature
T6A	Ideal EGATC middle outer glass surface temperature
T7A	Ideal EGATC rear outer glass surface temperature
T8A	Ambient temperature
T1B	Ideal EGATC front-middle thermal absorber temperature
T2B	Ideal EGATC middle-rear thermal absorber temperature
A	Area of inlet duct, (m^2) (Area of inlet duct, A = 5.47×10^{-4} m^2)

(a)

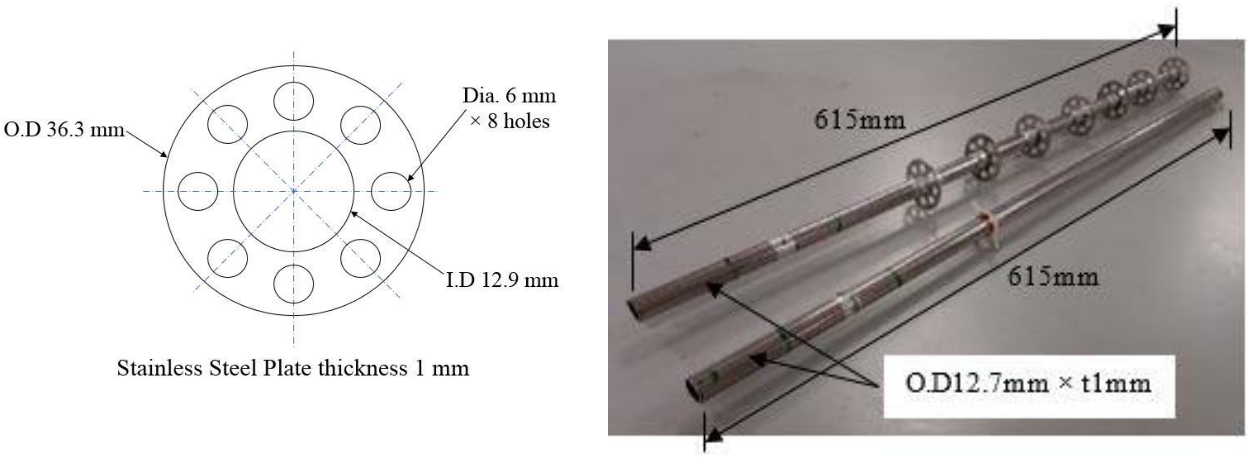


(b)

Fig. 1. Experimental setup for determining of the effect on thermal performance enhancement. (a) Side view and (b) Top view of the test rig

2.2 Experimental Parameters (Energy Storage Characteristic)

For first parameter experimental setup on inner absorber surface area air contact (perforated fins), inner absorber was made up by stainless steel pipe attached with stainless steel perforated fins i.e. (0) zero or seven (7) perforated fins. The fin array under consideration was made of seven (7) stainless steel fins with 1mm thickness**.** Figure 2(a) shown the schematic of fin with its perforations configuration and their dimensions (in mm). Drilling eight (8) arrays holes of 6mm diameters in the solid rounded fins to forms the perforated fins. The fins are attached to the inner absorber as shown in Figure 2(b). It also shown the comparison on inner absorber without perforated fin experimental setup.



(a) (b)

Fig. 2. The perforated fins used in the parameter experimental setup. (a) Schematic diagram of the perforated fin (b) Two type of perforated fins experimental setup i.e. inner absorber without perforated fin and inner absorber with 7 perforated fins

For second experimental setup on outer absorber selective coating surface, the outer absorber was made up by stainless steel pipe was coated with selective coating surface (flat black colour). This outer absorber was compared with the same configuration of outer absorber without selective coating surface (standard stainless-steel finishes). Figure 3 shown the coated outer absorber and non-coated outer absorber.

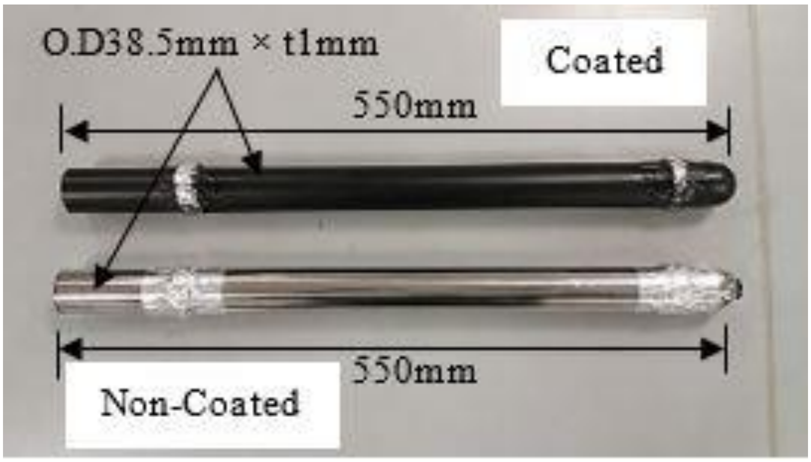


Fig. 3. Coated and non-coated outer absorber used for the parameter experimental setup

While for the third parameter experimental setup on outer absorber wall thickness, the outer absorber was made up by 1 mm wall thickness stainless-steel pipe was compared with 2 mm wall thickness stainless-steel pipe. The outer absorber used in the experiment was shown in Figure 4.

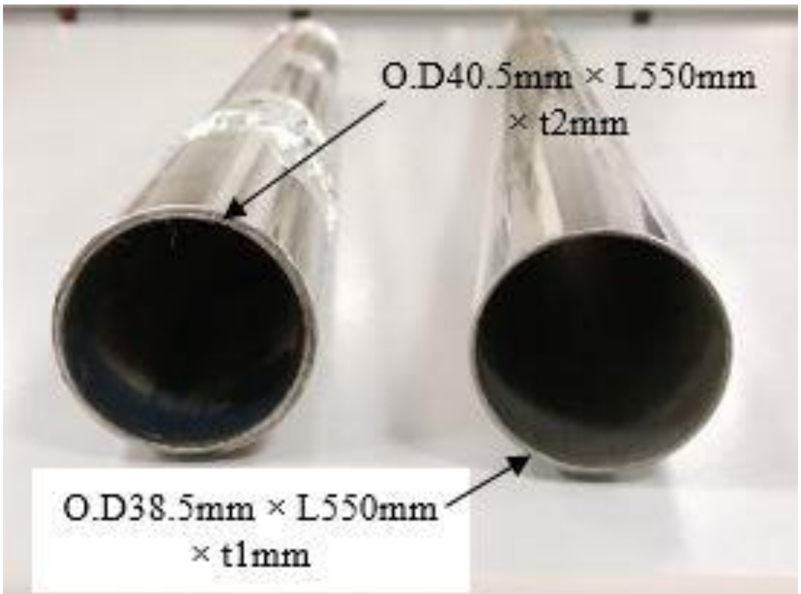
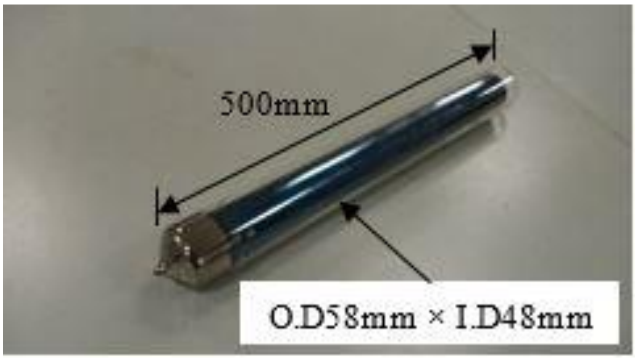


Fig. 4. 1mm and 2mm outer absorber wall thickness used for the parameter experimental setup

Typical double glass evacuated tube design consists of inner and outer glass tube. The double glass evacuated tube used in this experimental setup was manufactured by MISOLIE TECHNOLOGY made from high borosilicate glass with vacuum tightness 5.0×10^{-3}Pa. Both outer and inner tube were transparent tempered glass with thickness 1.6mm and the outer surface of inner tube was coated with thin film absorptive coating property of stainless steel–aluminium nitride (SS-Al N). For parameter experimental setup, this standard configuration of evacuated tube was compared with another three (3) parameters which are double layer non vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube as shown in Figure 5.

The thermal absorber acts as heat storage material comprising inner absorber and outer absorber. These thermal absorbers were assembled together inside evacuated tube as shown in Figure 6.



(a)

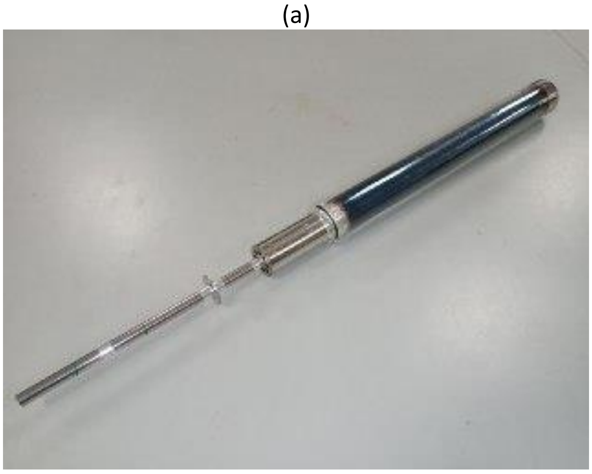
(b)

(c)

(d)

Fig. 5. The parameters involved in the experimental setup (a) standard configuration of evacuated tube available in the market (b) double layer non vacuum glass tube (c) single layer transparent outer glass tube (d) single layer thin film inner glass tube

(a)



(b)

Fig. 6. (a) Design arrangement of EGATC (b) EGATC assembled components

3. Thermal Energy Storage and Performance Evaluation of the System

For assumption, the system was considered as a closed system and does not involve any wind and elevation change. Hence, the heat transfer rate of the collector is expressed as Eq. (1) and Eq. (2) [33,34]

$$\dot{Q}_{Collector} = \rho A v C_{p(air)}(T_o - T_i) \tag{1}$$

Eq. (1) was used to convert energy from solar radiation into heat to rise the outlet temperature of the collector by referring to inlet temperature. While, Eq. (2) was used to calculate energy from solar radiation that converted into energy storage on the thermal absorber by referring to instantaneous energy accumulation for each second. The heat transfer rate of the thermal absorber storage was expressed as [33,34]

$$Q_{Store} = \frac{m_{ab}C_{p(ab)}(T_2 - T_1)}{t_2 - t_1} \tag{2}$$

where

ρ	=	Density of air (kg/m^3)
A	=	Area of inlet duct (m^2)
v	=	Velocity of air at inlet duct (m/s)
$C_{p(air)}$	=	Specific heat of air (kJ/kgK)
$T_{\boldsymbol{o}}$	=	Air outlet temperature (K)
T_i	=	Air inlet temperature (K)
m_{ab}	=	mass of thermal absorber (kg)
$C_{p(ab)}$	=	Specific heat of thermal absorber (kJ/kgK)
$T_{\mathbf{2}}$	=	Temperature of thermal absorber after heat gain (K)
$T_{\mathbf{1}}$	=	Temperature of thermal absorber before heat gain (K)
$t_{\mathbf{2}}$	=	Time after heat gain (s)
t_1	=	Time before heat gain (s)

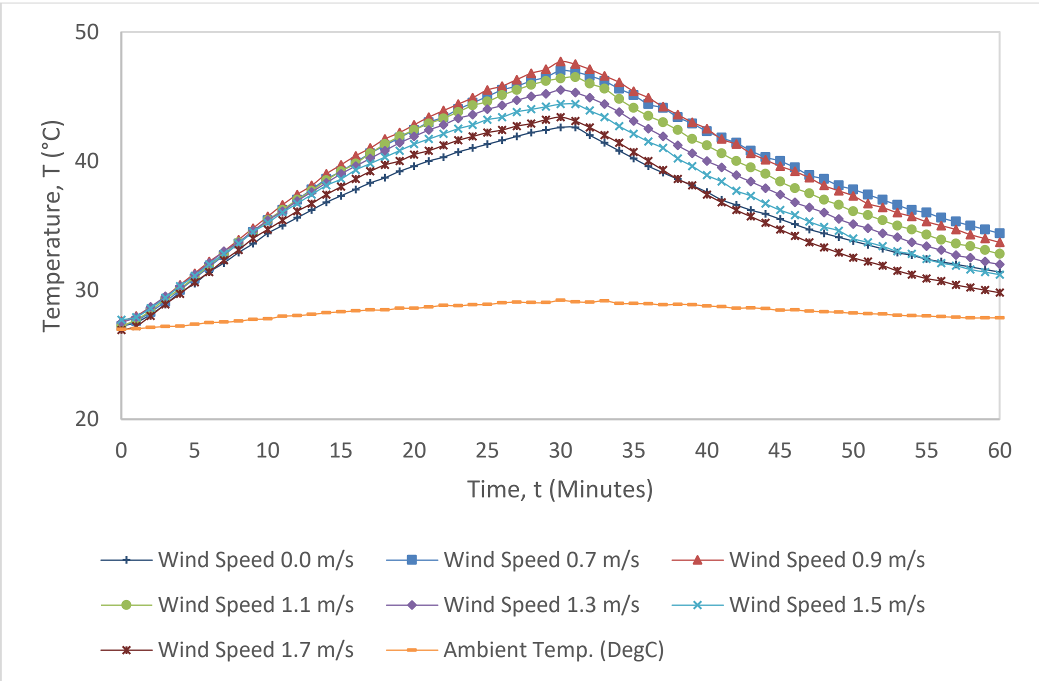
The indoor experiment was done for 12 days from November 2020 to December 2020 (Figure 7). The experiment was done to monitor the outlet temperature of EGATC air heater.

Figure 8(a) and Figure 8(b) shown the result for the first experimental setup to determine the ideal design of perforated fin and appropriate wind speed at radiation 700 watt/m² between zero (0) perforated fin and seven (7) perforated fins with varies wind speed of 0.0 m/s, 0.7 m/s, 0.9 m/s, 1.1 m/s, 1.3 m/s, 1.5 m/s and 1.7 m/s. In consideration of maximum outlet temperature at minutes 30, wind speed at 0.9 m/s was chosen with outlet temperature 47.7 °C for zero (0) perforated fin and 48.0 °C for seven (7) perforated fins. A lower mass flow rate resulting in high outlet temperature of the air. This is because, at lower mass flow rate, the higher residential time of the flowing air around the surface of thermal absorber increases the heat transfer amount between them. Since zero (0) perforated fin showed the highest daily energy store, Q_{Store}(Daily) with 4.46 KJ compared with seven (7) perforated fins 3.42 KJ, it was chosen as the ideal design. Zero (0) perforated fin may produce laminar air flow resulting in lower outlet temperature at minutes 30 but gain better energy store, Q_{Store} value. In the other side, seven (7) perforated fins with turbulence air flow built up the outlet temperature at minutes 30 but lowering the energy store, Q_{Store} value.

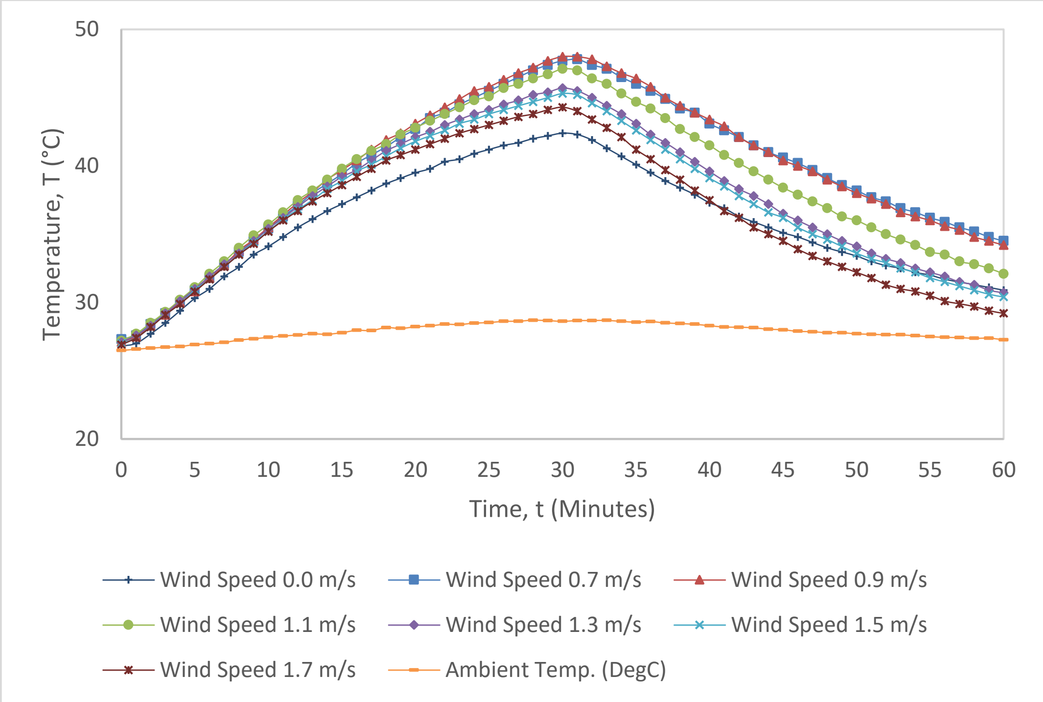
(a)

(b)

Fig. 7. The setup of indoor experiment under the artificial solar radiation (a) during charging (b) during discharging



(a)



(b)

Fig. 8. Result of outlet temperature histories for first experimental setup to determine the ideal design of fin and appropriate wind speed. (a) Experiment of zero (0) perforated fin EGATC (b) Experiment of seven (7) perforated fin EGATC

These parameters then were used for next parameter experiment. The next parameter experiments were conduct on zero (0) perforated fin and wind speed at 0.9 m/s with outer absorber selective coating surface, outer absorber wall thickness, double layer non vacuum glass tube, single layer transparent outer glass tube and single layer thin film inner glass tube. These experiments were compared to the similar arrangement of zero (0) perforated fin, non-coating outer absorber with 1mm wall thickness EGATC also known as zero (0) perforated fin EGATC at wind speed 0.9 m/s. Figure 9 shown the outlet temperature histories for each parameter experiments at radiation 700 watt/m^2. The maximum outlet temperature at minutes 30, shows 0 perforated fin EGATC with 47.7 ^{o}C, 0 fin with Outer absorber selective coating surface 48.4 ^{o}C, 0 fin with 2mm Outer absorber wall thickness 46.0 ^{o}C, 0 fin with double layer non vacuum glass tube 43.8 ^{o}C, 0 fin with single layer transparent outer glass tube 44.1 ^{o}C and 0 fin with single layer thin film inner glass tube 43.6 ^{o}C.

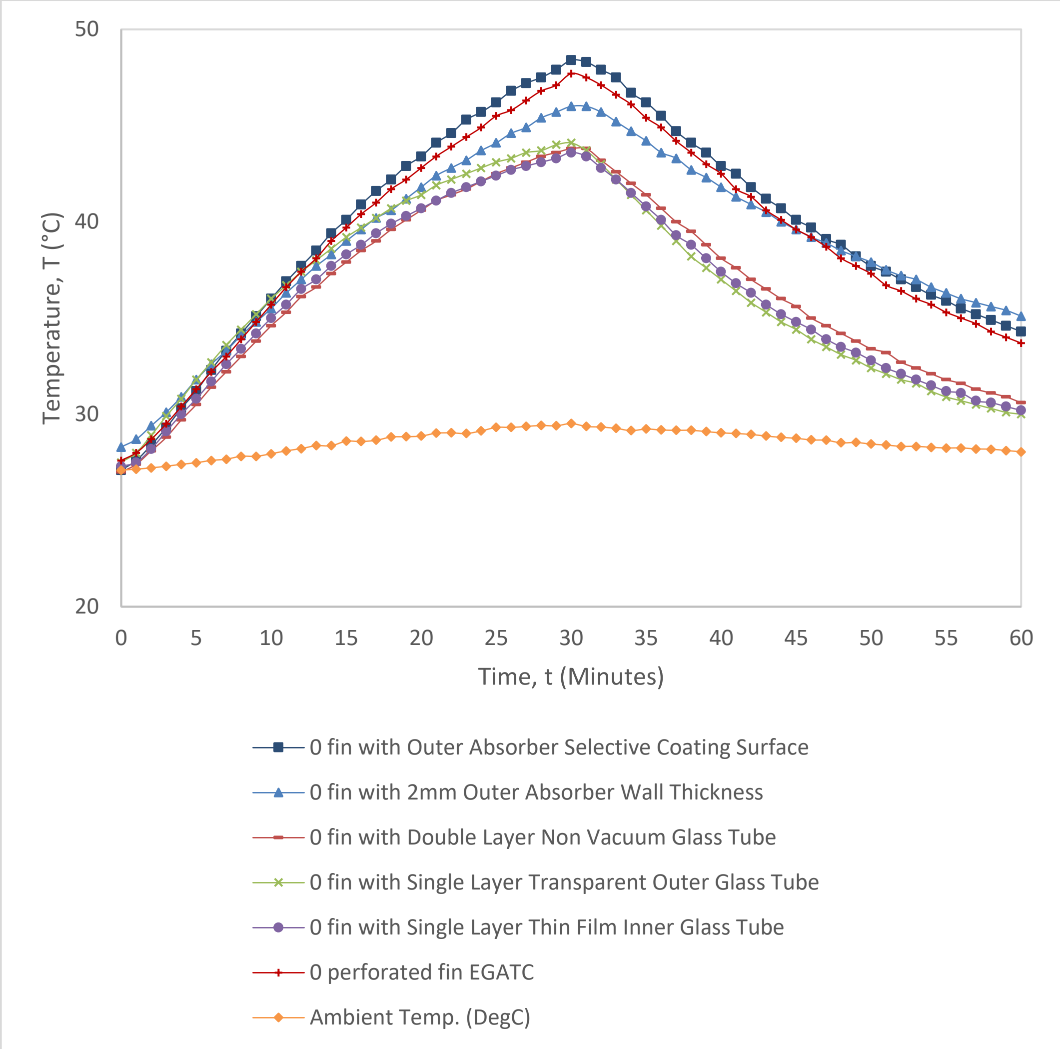


Fig. 9. Result of outlet temperature histories for parameter experiments on 0 fin with outer absorber selective coating surface, 0 fin with outer absorber wall thickness, 0 fin with double layer non-vacuum glass tube, 0 fin with single layer transparent outer glass tube and 0 fin with single layer thin film inner glass tube

Table 1 shown the performance analysis based on the data obtained from parameter experiments involved in the study. The analysis on energy buffer between 0 perforated fin EGATC and 0 fin with outer absorber selective coating demonstrate that 0 perforated fin EGATC had better energy buffer, -0.00778 °C/s compared to 0 fin with outer absorber selective coating, -0.00783 °C/s. In term of energy store, Q_{Store}, 0 perforated fin EGATC also had an advantage with 4.46KJ compared to 0 fin with outer absorber selective coating with 4.12KJ. The outer surface of evacuated tube inner glass is coated by one-sided refraction/reflection characteristic coating (thin film-selective surface coated material) which allow the heat transfer via radiation and convection to the gap between inner glass and non-coating outer absorber. The material of non-coating outer absorber itself i.e. standard stainless-steel finishes increased the reflection rate toward the evacuated tube inner glass hence increase the energy store, Q_{Store} value and energy buffer value.

Table 1
Performance analysis based on the data obtained from parameter experiments involved in the study. Red dotted line indicates the comparison experiment

No.	Optimization Parameters	$\dot{Q}_{Collector}$ (KJ)	Q_{Store} (Daily) (KJ)	Tout @ mins 30 (°C)	Tout @ mins 60 (°C)	Temp. different (°C)	Energy buffer (°C/Sec)
1(a)	0 Perforated Fin EGATC (V=0.0 m/s @ 0.0v)	0.00	15.01	42.6	31.4	11.2	-0.00622
	0 Perforated Fin EGATC (V=0.7 m/s @ 4.2v)	17.83	4.81	47.0	34.4	12.6	-0.00700
	0 Perforated Fin EGATC (V=0.9 m/s @ 4.6v)	23.23	4.46	47.7	33.7	14.0	-0.00778
	0 Perforated Fin EGATC (V=1.1 m/s @ 5.2v)	27.55	3.59	46.4	32.8	13.6	-0.00756
	0 Perforated Fin EGATC (V=1.3 m/s @ 6.4v)	29.50	2.59	45.5	32.0	13.5	-0.00750
	0 Perforated Fin EGATC (V=1.5 m/s @ 8.1v)	31.28	1.87	44.4	31.2	13.2	-0.00733
	0 Perforated Fin EGATC (V=1.7 m/s @ 8.9v)	34.97	1.72	43.4	29.8	13.6	-0.00756
1(b)	7 Perforated Fins EGATC (V=0.0 m/s @ 0.0v)	0.00	16.19	42.4	30.9	11.5	-0.00639
	7 Perforated Fins EGATC (V=0.7 m/s @ 4.6v)	19.58	4.27	47.7	34.5	13.2	-0.00733
	7 Perforated Fins EGATC (V=0.9 m/s @ 5.2v)	23.87	3.42	48.0	34.2	13.8	-0.00767
	7 Perforated Fins EGATC (V=1.1 m/s @ 6.4v)	29.23	2.40	47.1	32.1	15.0	-0.00833
	7 Perforated Fins EGATC (V=1.3 m/s @ 8.1v)	31.44	1.62	45.7	30.7	15.0	-0.00833
	7 Perforated Fins EGATC (V=1.5 m/s @ 8.9v)	34.34	1.39	45.3	30.4	14.9	-0.00828
	7 Perforated Fins EGATC (V=1.7 m/s @ 11.5v)	37.44	0.92	44.3	29.2	15.1	-0.00839
2	0 FIN (Outer absorber selective coating surface) EGATC (V=0.9 m/s @ 4.6v)	24.17	4.12	48.4	34.3	14.1	-0.00783
3	0 FIN (2mm outer absorber wall thickness) EGATC (V=0.9 m/s @ 4.6v)	22.07	8.54	46.0	35.1	10.9	-0.00606
4	0 FIN (Double layer Non-Vacuum glass tube) EGATC (V=0.9 m/s @ 4.6v)	18.54	1.39	43.8	30.6	13.2	-0.00733
5	0 FIN (Single layer transparent outer glass tube) EGATC (V=0.9 m/s @ 4.6v)	17.07	0.44	44.1	30.0	14.1	-0.00783
6	0 FIN (Single layer thin film inner glass tube) EGATC (V=0.9 m/s @ 4.6v)	17.24	0.74	43.6	30.2	13.4	-0.00744

On 0 fin with 2mm Outer absorber wall thickness experiment, the comparison on energy store, Q_{Store} show 0 perforated fin EGATC attained 4.46KJ and 0 fin with 2mm Outer absorber wall thickness attained 8.54KJ while on energy buffer both attained -0.00778 °C/s and -0.00606 °C/s respectively. Thicker thermal absorber wall thickness increased the mass thus improved high heat energy storage and energy buffer applications. On the others experiments, the energy store, Q_{Store} for 0 fin with double layer non vacuum glass tube 1.39KJ, 0 fin with single layer transparent outer glass tube 0.44KJ and 0 fin with single layer thin film inner glass tube 0.74KJ compared to 0 perforated fin EGATC 4.46KJ. On energy buffer, there are -0.00733 ºC/s, -0.00783 ºC/s, -0.00744 ºC/s compared to -0.00778 ºC/s, respectively. The vacuum pocket of evacuated glass eliminated the heat loss through convection and conduction between the absorber and ambient, therefore the collectors can operate at higher temperatures hence increased the outlet temperature and improved the energy store and energy buffer application.

4. Conclusions

The investigation on thermal energy storage proves better thermal performance enhancement of EGATC for solar air heating applications with integration of several parameter. The analysis was carried out through indoor experiment, under the artificial solar radiation, by recorded solar charging and discharging heat rate. Based on the experimental investigation, some conclusions are made, as follows

i. Wind speed 0.9 m/s performed better since the wind speed is inversely proportional with energy store, Q_{Store} in the meantime gain the highest outlet temperature at minutes 30. A lower mass flow rate was preferred for the high outlet temperature of the air [35]. This is because, at lower mass flow rate, the higher residential time of the flowing air around the surface of thermal absorber increases the heat transfer amount between them [36]. On the other hand, at higher mass flow rate, due to shorter residential time, the small amount of heat transfer in between the flowing air and the thermal absorber led to a prolonged cooling time of the absorber simultaneously increase the thermal inertia of the thermal absorber.

ii. Zero (0) perforated fin obtained the better energy store, Q_{Store} value compared with seven (7) perforated fins. Seven (7) perforated fins may produce turbulence air flow hence built up the outlet temperature [37] at minutes 30 but lowering the energy store, Q_{Store} value. In the other side, zero (0) perforated fin with laminar air flow produce a little bit lower outlet temperature at minutes 30 but gain better energy store, Q_{Store} value. The less differential on outlet temperature (0.3°C) show there is no significant on the number of fins toward the design of shorten evacuated tube collector (ETC) and in cases where the fins were placed inside an enclosed chamber with air flow.

iii. Non-coating outer absorber showing better energy store, Q_{Store} value and energy buffer compared to Outer absorber selective coating surface. The outer surface of evacuated tube inner glass is coated by one-sided refraction/reflection characteristic coating (thin film-selective surface coated material) which allow the heat transfer via radiation and convection to the gap between inner glass and non-coating outer absorber. The material of non-coating outer absorber itself i.e. stainless steel increase the reflection rate toward the evacuated tube inner glass hence increase the energy store, Q_{Store} value and energy buffer value [38].

iv. Outer absorber with 2mm wall thickness obtained high energy store, Q_{Store} and energy buffer. Thicker thermal absorber wall thickness increased the mass therefore gained high heat energy storage and energy buffer applications [39].

As per reporting of evacuated tube parameter, it can be concluded that

v. Double layer vacuum glass tube showing better compared with Double layer non-vacuum glass tube, Single layer transparent outer glass tube and Single layer thin film inner glass tube since it showed better outlet temperature at minutes 30 and energy store, Q_{Store}. It was aligned with the theoretical that the vacuum pocket of evacuated glass eliminated the heat loss through convection and conduction between the absorber and ambient, therefore the collectors can operate at higher temperatures [34].

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