ISSN 2462-2052 *Journal of Science and Mathematics Letters*
DOI: https://doi.org/10.37134/jsml.vol11.1.11.2023 *Volume 11, Issue 1, 73-82, 2023*

RESEARCH ARTICLE

Mathematical Model Development of Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for Air Heating Application

Zairul Azrul Zakaria[1], Zafri Azran Abdul Majid[2,*], Muhammad Amin Harun[1], Ahmad Faris Ismail[1], Sany Izan Ihsan[1], Kamaruzzaman Sopian[3], Amir Abdul Razak[4], Ahmad Fadzil Sharol[4], Mohd Syahriman Mohd Azmi[5]

[1]Kuliyyah of Engineering, International Islamic University Malaysia,
Jalan Gombak, 53100 Kuala Lumpur, Malaysia
[2]Kuliyyah of Allied Health Sciences, International Islamic University of Malaysia,
25200 Bandar Indera Mahkota, Kuantan Pahang, Malaysia
[3]Solar Energy Research Institute, Universiti Kebangsaan Malaysia,
43600 Bangi Selangor, Malaysia
[4]Faculty of Mechanical Engineering Technology, Universiti Malaysia Pahang,
26600 Pekan Pahang, Malaysia
[5]Department of Physics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
*Corresponding author: zafriazran@yahoo.com

Received: 18 January 2023; **Accepted:** 19 March 2023; **Published:** 21 March 2023

ABSTRACT

For decades, solar energy as one of the endless energy sources has become the most public preference as a means to accommodate space heating. Various studies on solar thermal technologies have been worked out to replace outdated systems. However, conventional solar thermal systems offer two drawbacks such as diffuse solar radiation conditions that can lead to insufficient heating during winter and autumn, and limitations of the solar collector orientation that need to be opposed at a correct tilted angle towards maximizing the performance of the system. Previous studies have proposed an integrated design that consists of the evacuated tube and a preheating double-pass flow thermal absorber arrangement, namely, Evacuated Glass-Thermal Absorber Tube Collector (EGATC) to overcome these problems. Therefore, this research has discussed further on the formulated mathematical modeling of the design. EGATC components used to convert solar radiation into heat that stabilized and increased the outlet temperature were evacuated glass, thermal absorber, and working fluid. The equation related to each component was developed based on the first law of thermodynamics. The combination of the developed equations forms a solar thermal collector model for the system.

Keywords: EGATC, Mathematical modeling, air heating application

1. INTRODUCTION

Generally, the application of solar technology, either water or air heating, is limited due to weather conditions and system design. In Malaysia, the solar heating system is widely used for water heating and other applications, such as air heating, which is actively developed but still in research. Solar heating system, either water or air operation, is more efficient using a solar thermal collector compared to a photovoltaic (PV) system (Matuska & Sourek, 2017). Numerous types of solar thermal collectors, namely, flat plate collectors (FPC) and heat-pipe evacuated tube collectors (HP ETC), have been developed in various countries and have become increasingly important for integrated solar heating systems (Sabiha et al., 2015). However, conventional FPC had low thermal efficiency, and its energy efficiency decreased during the off-sunshine hours (Fudholi & Sopian, 2019). There are two common types of solar thermal collector applied as the low-medium temperature heating range. These types are the Flat plate collector (FPC) and the Evacuated tube collector (ETC). The FPC is uncomplicated in manufacturing and design, and its purchasing costs are lower. However, if considering the delivery cost, the FPC is more expensive due to the sizing of packaging. For the cost of operational ETC systems can attain a payback period less than the FPC systems (Nájera-Trejo et al., 2016). ETC has lower thermal losses than the FPC. This refers to the vacuum pocket between the outer and inner transparent glass tube of the thermal absorber that reduces conduction and convection heat losses.

The solar thermal collector used in this study, known as Evacuated Glass–Thermal Absorber Tube Collector (EGATC), was reported in a previous study by Zakaria et al. (2021). They were discussed on the performance study of EGATC and conclude that the design proves a better result compared to HP ETC on the outlet temperature and energy buffer storage for solar air heating applications. The thermal absorber was separated into two (2) particularly inner absorber and outer absorber. Inner absorber comprises of a small diameter pipe attached to zero (0) perforated fins, while the outer absorber has built in a slightly larger pipe diameter closed by one side end cap. Both absorbers were unified together inside the evacuated glass. Although the parameter experiment showed that there was no significant on the number of fins toward the design of a shortened evacuated tube collector (ETC), but for commercial purposes, the inner absorber was fitted with several fin-like Polyvinyl Chloride (PVC) saddles to uphold the inner absorber in its place. Instead of that, Razak et al. (2016) reported in their study that higher heat loss has occurred at the longitudinal fins attached at the upper and lower channel of the double pass solar air collector.

EGATC functions changed accordingly due to weather and environment changes. The concept of its development takes into account all mechanisms of heat transfer in thermal absorbers, namely, conduction, convection, and radiation. While its initial design considers the surface area of the thermal absorber, the maximum nature of radiation reflection and air convection to obtain the maximum efficiency. The mathematical model was developed based on the energy conservation principle from the 1st Law of Thermodynamics for each EGATC main component, as shown in Figure 1.

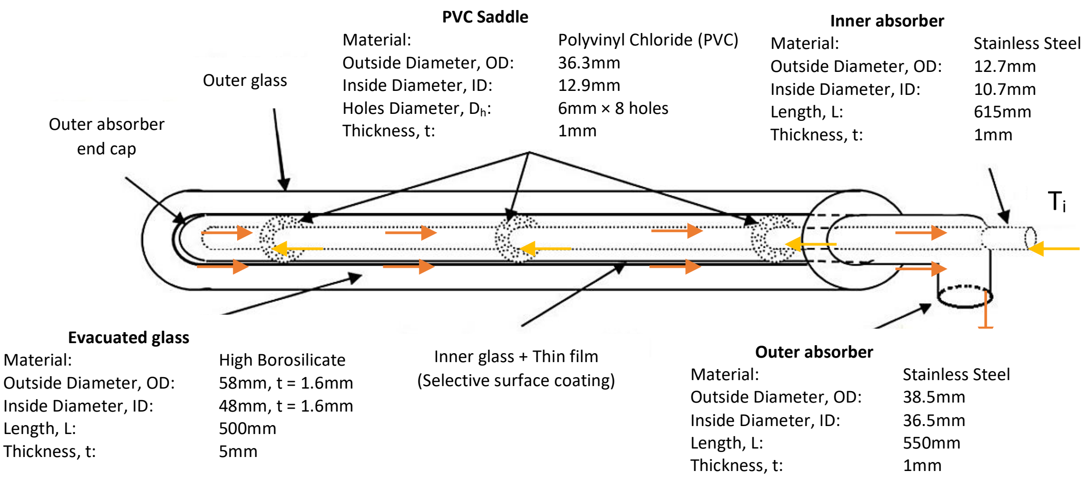

Figure 1. The Evacuated Glass – Thermal Absorber Tube Collector (EGATC) main components

The set of equations were derived based on the energy balance principle conducted by each of the main components of the EGATC. These main components are evacuated glass, outer absorber, inner absorber and working fluid. All main components correspond to the nodes of the model. Energy from the sun to the earth was in the form of radiation. Nevertheless, not all solar radiation reaches the earth's surface directly due to the mass of air in the atmospheric layer. The outer layer of EGATC, i.e., the evacuated glass, received solar radiation and converted it into heat. The design of EGATC makes the concept of greenhouse effect. Figure 2 shows the schematic diagram of the air flow through EGATC.

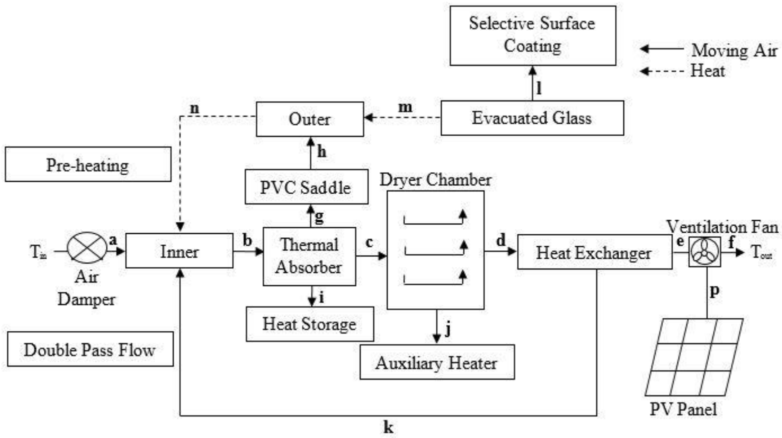

Figure 2. The schematic diagram of the air flow through EGATC

Solar radiation consists of long and short waves. EGATC consists of a thermal absorber inside an evacuated tube. The long wavelengths of the solar radiation reflected back to the environment while the short wavelengths penetrated the evacuated glass directly to the thermal absorber. It turns into a long wave and trapped inside the EGATC simultaneously raises the temperature of the air inside the respective solar thermal collector which will be used in the drying process. In order to facilitate the understanding and implementation as an air heater, Table 1 shows the details of the process of the air flow inside EGATC in air heating application.

The innovative thermal absorber design of EGATC formed a preheating double pass flow at the inner absorber resultant in high cumulative temperature at the outlet (Zakaria et al., 2022). The outer glass tube of evacuated glass was made by transparent borosilicate glass intentionally to transmit solar radiation over the vacuum pocket directly to the inner glass tube. The inner glass tube which was coated by one-sided refraction/reflection characteristics (thin film-selective surface coating) allowed the heat transfer through radiation and convection to the gap between the inner glass tube and the thermal absorber (Kumar Singh & Samsher, 2020). The inner glass tube may transmit the short-wavelength of solar radiation but block the reflected long-wavelength irradiation to the vacuum pocket. This phenomenon, known as greenhouse effected, accumulates the heat energy inside the gap at the same timing, increased temperature of the outer absorber. Then the heat was transferred via convection to the inner absorber. The thermal absorber wall thickness acted as the heat storage material. These processes developed the cumulative heat gain of the solar thermal absorber design. Fundamentally, the evacuated tube collector (ETC) has proved that the combination of a selective surface coating and an effective convection suppressor resulted in good performance at high temperatures (ASHRAE, 2011). Figure 3 shows the heat transfer occurred inside the EGATC.

Therefore, this study aims to introduce a conceptual design of EGATC for air heating applications and provide a generic mathematical model of this unit. To the authors' best knowledge, the study has not been yet investigated. The findings may also deliver beneficial information on the performance enhancement of the EGATC systems.

Table 1. The detail process of the air flow inside EGATC in air heating application

Process	Description
p	1. The PV panel absorbs the solar radiation (radiation) 2. The PV panel converts the solar radiation into electricity, which was used as a power source for the ventilation fan
T_{in}	1. Air damper opened 2. Air damper trapped in the surrounding air into the inner absorber
a	1. Inner absorber receives air from the air damper 2. Inner absorber absorbs heat from the dryer chamber through the heat exchanger (convection/conduction) 3. Inner absorber absorbs heat from the outer absorber (convection/conduction)
b	1. Absorber (consists of an inner absorber, PVC fins/saddle, and outer absorber arrangement) receives air from the inner absorber 2. Absorber collects heat and then moves it to the inner absorber through the absorption of heat between the outer absorber and the inner absorber (convection) 3. Absorber collects heat and stores it as heat storage (convection/conduction)
c	Dryer chamber receives air from the absorber
d	Heat exchanger transfer heat from hot air through the dryer chamber (convection/conduction)
e	Ventilation can extract the air from the environment of tin and then discharge through T_{out}
f/T_{out}	T_{out} discharge the hot air from dryer chamber
g	PVC Saddle which located between the inner absorber and outer absorber does not affect the amount of heat flux received by inner absorber
h	Outer absorber blocked the transfer heat to PVC saddle (conduction)
i	Heat storage absorbs heat from the absorber for repository (convection/conduction)
j	Auxiliary heaters transfer heat to the dryer chamber (if necessary)
k	Hot air from the dryer chamber transfers heat to the inner absorber through Heat Exchanger (convection/conduction)
l	1. Thin Film assists in the absorption of shortwave solar radiation 2. Evacuated Tubes transmit incoming shortwave solar radiation but block the long-wave radiation emitted outwards by outer absorber (radiation)
m	Outer absorber collects heat from the evacuated tube (convection/conduction/ radiation)
n	Inner absorber collects heat from the outer absorber (convection/conduction)

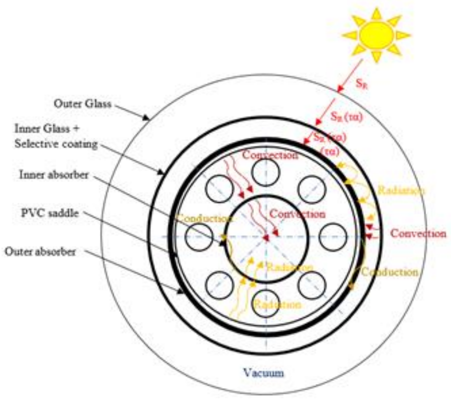

Figure 3. The heat transfer mechanism inside the thermal absorber of EGATC

2. MATERIALS AND METHODS

The physical component models of the collector were described by the Eq. 1 to Eq. 13. Four (4) nodes models for each main collector component level were selected starting with evacuated glass, outer absorber, inner absorber and working fluid inside the absorber. For each node, an equation related to the respective components was developed based on the first law of thermodynamics which describes the energy conservation equations. The combination of the developed equations ~~forms~~ a solar thermal collector model for the system. The proposed model is considered as the distributed parameters of the thermal collector. The method was based on solving the energy conservation equation for the evacuated glass, both outer and inner absorbers, and working fluid. Listed below were the assumptions for modeling purposes: (a) The air flow from inlet to outlet was in steady state conditions, (b) The convective heat transfer coefficient and thermal conductivity of the thermal absorber was constant along the path of the working fluid, (c) The thermal loss via convection around the evacuated glass tube was eliminated and can be neglected, (d) The wall thickness of the evacuated glass tube (T=1.6mm) was small and can be neglected, (e) The thermal collector was assumed as a short collector (≤ 1 meter) (Ong, 1995), (f) The temperature gradients in the direction of flow can be neglected, (g) Lumped type analysis was used for the evacuated tube.

2.1. Energy balance of EGATC

In a steady state system with a single inlet and outlet entrance, the flowing in mass flow rate was identical to flowing out of the control volume, where;

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m} \qquad \text{(Eq. 1)}$$

With changes of kinetic and potential energy introduced into or out of the control volume considered as negligible, the energy balance of the system was described by the changes of the fluid temperature as defined in Equation 2;

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} \qquad \text{(Eq. 2)}$$

The amount of energy entered into the control volume is equal to the energy leaving the control volume. Hence, the difference of energy entering and leaving the control volume will equal the total energy change within the control volume as illustrated in Figure 4.

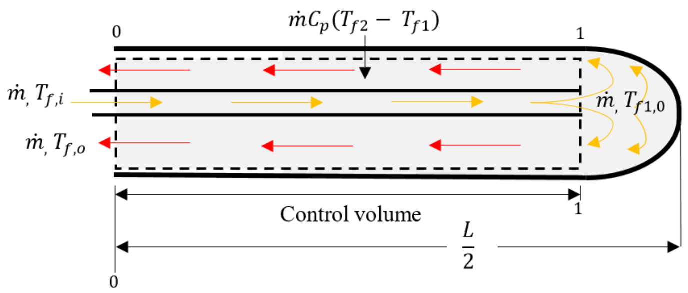

Figure 4. Energy balance in control volume

It is assumed that the constant heat transfer occurred between the thermal absorber and the fluid along the length of the heater, L. This assumption suggests the fluid temperature varies linearly along the short collectors (less than 10 m), as proposed by Fudholi et al. (2013). Thus, the mean temperature can be obtained based on the following:

$$T_f = T_{f1,0} = \frac{T_{f,i} + T_{f,o}}{2} \qquad \text{(Eq. 3)}$$

Hence, the defined boundary condition for the fluid temperature is given as follows:

$$T_{f1}\left(0 < x < \frac{L}{2}\right) = \frac{T_{f,i} + T_{f1,0}}{2} \qquad \text{(Eq. 4)}$$

$$T_{f2}\left(\frac{L}{2} < x < L\right) = \frac{T_{f\,1,0} + T_{f,o}}{2} \qquad \text{(Eq. 5)}$$

Figure 5 illustrates the schematic diagram of heat transfer in EGATC system, where the energy balance equation is derived. Each evacuated glass element was lumped into one node since the difficulties of temperature measurement at the vacuum pocket. Njomo & Daguenet, 2006 also had neglected the heat exchange between the two covers in their mathematical model study. The energy balance equation based on the four nodes, as indicated earlier, is written in the following:

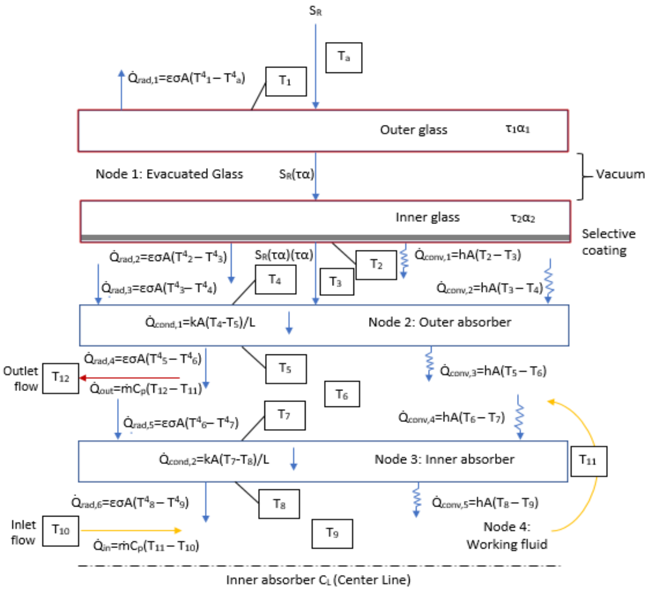

Figure 5. Schematic diagram of heat transfer coefficient

Energy balance is divided into four components of the collector, which are evacuated glass, outer absorber, inner absorber and air flow. Boundary conditions of the model are assumed that steady air flow is occurred along the solar thermal collector, with convection and radiation heat transfer as well as the thermal conductivity of the thermal absorber are constant along the solar thermal collector length. Based on the assumption, the energy analysis based on the 1st law of thermodynamics is presented as follows:

For evacuated glass, energy in to the outer glass = Energy out of inner glass;

$$S_R + S_R(\tau\alpha) = \dot{Q}_{rad,1} + \dot{Q}_{rad,2} + \dot{Q}_{conv,1} \quad \text{(Eq. 6)}$$

$$G_tA_c + G_tA_c(\tau\alpha) = \varepsilon\sigma A_s({T_1}^4 - {T_a}^4) + \varepsilon\sigma A_s({T_2}^4 - {T_3}^4) + hA_s(T_2 - T_3) \quad \text{(Eq. 7)}$$

For outer absorber, energy in to the outer absorber = Energy out of outer absorber;

$$S_R(\tau\alpha)(\tau\alpha) + \dot{Q}_{cond,1} + \dot{Q}_{rad,3} + \dot{Q}_{conv,2} = \dot{Q}_{rad,4} + \dot{Q}_{conv,3} \quad \text{(Eq. 8)}$$

$$G_tA_c(\tau\alpha)(\tau\alpha) + \frac{kA(T_4-T_5)}{L} + \varepsilon\sigma A_s({T_3}^4 - {T_4}^4) + hA_s(T_3 - T_4) = \varepsilon\sigma A_s({T_5}^4 - {T_6}^4) + hA_s(T_5 - T_6) \quad \text{(Eq. 9)}$$

For inner absorber, energy in to the inner absorber = Energy out of inner absorber;

$$\dot{Q}_{cond,2} + \dot{Q}_{rad,5} + \dot{Q}_{conv,4} = \dot{Q}_{rad,6} + \dot{Q}_{conv,5} \quad \text{(Eq. 10)}$$

$$\frac{kA(T_7-T_8)}{L} + \varepsilon\sigma A_s({T_6}^4 - {T_7}^4) + hA_s(T_6 - T_7) = \varepsilon\sigma A_s({T_8}^4 - {T_9}^4) + hA_s(T_8 - T_9) \quad \text{(Eq. 11)}$$

For working fluid, energy in to air = Energy out of air;

$$\dot{Q}_{in} = \dot{Q}_{out} \quad \text{(Eq. 12)}$$

$$\dot{m}C_p(T_{11} - T_{10}) = \dot{m}C_p(T_{12} - T_{11}) \quad \text{(Eq. 13)}$$

where,

S_R	:	Solar energy (W)	T_a	:	Ambient temperature (K)
G_t	:	Solar radiation (W/m^2)	k	:	Thermal conductivity (W/m.K)
A_c	:	Surface area of collector (m^2)	A	:	Cross-sectional area (m^2)
τ	:	Surface transmittivity	L	:	Length (m)
α	:	Surface absorptivity	$\dot{m}$	:	Mass flow rate (kg/s)
ε	:	Surface emissivity	C_p	:	Specific heat capacity for air (KJ/Kg.K)
σ	:	Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^2.K^4)	$T_1, T_2, T_4, T_5, T_7, T_8$	:	Surface temperature (K)
h	:	Convective heat transfer coefficient (W/m^2.K)	$T_3, T_6, T_9, T_{10}, T_{11}, T_{12}$	:	Convection air temperature (K)
A_s	:	Surface area (m^2)			

2.2. Theoretical Solution Method

Several researchers were studied on solar collector modelling which includes a detailed numerical model such as Tchinda (2009), Parker et al. (1982) and Hollands & Shewen (1981). A numerical solution for the collector with an assumed adequately short collector under steady-state (Choudhury et al., 1995) is sufficient in solving the theoretical model for EGATC. During the initial stage, all required constants and parameters need to be determined. These include surrounding conditions such as solar radiation, ambient temperature, physical properties of the evacuated glass, both outer and inner thermal absorbers, thermophysical of the working fluid, and dimensions of the solar thermal collector. The design parameters at evacuated glass are τ = 0.92, α = 0.05 (high borosilicate glass), ε_1 = 0.02, σ = 5.67 x 10^{-8} W/m^2.K^4 , A_s = 0.0455m^2, ε_2 = 0.05, h = 250 W/m^2.K; at outer absorber are τ = 0.3, α = 0.67(thin film- selective surface coating), k = 15 W/m.K, A = 0.0615m^2, L = 0.5m, ε = 0.05, A_s = 0.0308m^2 , h = 250 W/m^2.K, A_s = 0.0333m^2 , h = 720 W/m^2.K; at inner absorber are k = 15 W/m.K, A = 0.0199m^2, L = 0.5m, , ε = 0.05, A_s = 0.0122m^2 , h = 720 W/m^2.K and at working fluid are $\dot{m}$ = 0.0005 kg/s, C_p =1.005 kJ/kg.K. The energy conservation equations were developed for each node, i.e., evacuated glass, outer absorber, inner absorber and working fluid based on the first law of thermodynamics. The value obtained from the respective experiment was stated while computing the energy conservation equations (Eq. 6 - 13). Microsoft Excel® software is used for solving the equation. The solution needs to ensure the amount of energy entered into each node should equal to the energy leaving the node during charging. The temperature value which meets the process criteria will then be used to compute the thermal performance of the solar thermal collector. The theoretical thermal performance was validated with another actual experimental value with similar arrangement. Algorithm flowchart for the theoretical solution process is outlined in Figure 6.

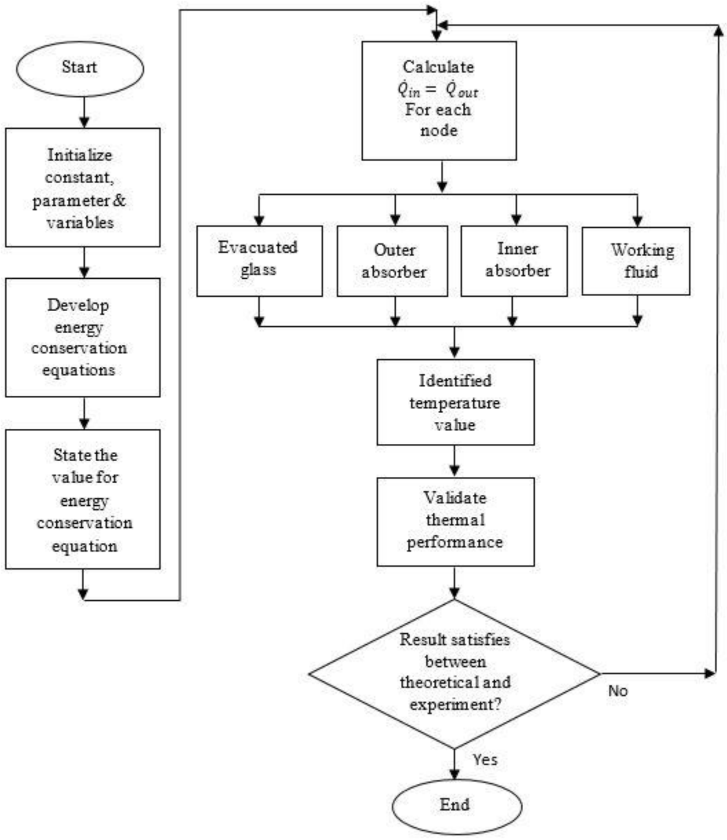

Figure 6. Flow chart for theoretical solution process

3. RESULTS AND DISCUSSION

The results of energy conservation (Eq. 6 to Eq. 13) obtained from Microsoft Excel® software are stated in Table 2. The total difference in the percentage of 4.7% shows the model at each node is valid. The temperature value which meets the process criteria is used to compute the thermal performance of the solar thermal collector for the validation process. The theoretical thermal performance was validated with another actual experimental with similar arrangement. From the Figure 7, it can be visibly seen that the efficiency of the collector increases with temperature differences (T_{out}-T_{in}) along the experiment for those mathematical modeling and experimental. The efficiencies of all types increased during the charging period with the same experimental arrangement, i.e., 1mm thickness of non-coated absorber, solar radiation = 700 W/m^2, wind speed = 0.9 m/s @ 4.6v for both 0 Fin EGATC and 3 Fins EGATC. From the results obtained, the collector and storage efficiency for both 0 Fin EGATC and 3 Fins EGATC are 71.2% and 71.0%, respectively. It can be clearly seen that the efficiency depends on the number of fins. The more the fins affect, the lower the collector and storage efficiency. The finding was similar to Razak et al. (2016). They proposed that longitudinal fins attached inside the respective double-pass solar air collector design as the performance lowering factor, as per higher heat loss has occurred at the fins.

Table 2. The result of energy conservation equation

Node	Sum of energy (Watt)		Different (Watt)	Percentage (%)
	In	Out		
Evacuated glass	590.69	564.23	26.46	4.5
Outer absorber	7009.19	7482.92	473.73	6.3
Inner absorber	2043.80	2073.98	30.18	1.5
Working fluid	0.0775	0.0799	0.0024	3.0
Total	9641.75	10121.20	479.45	4.7

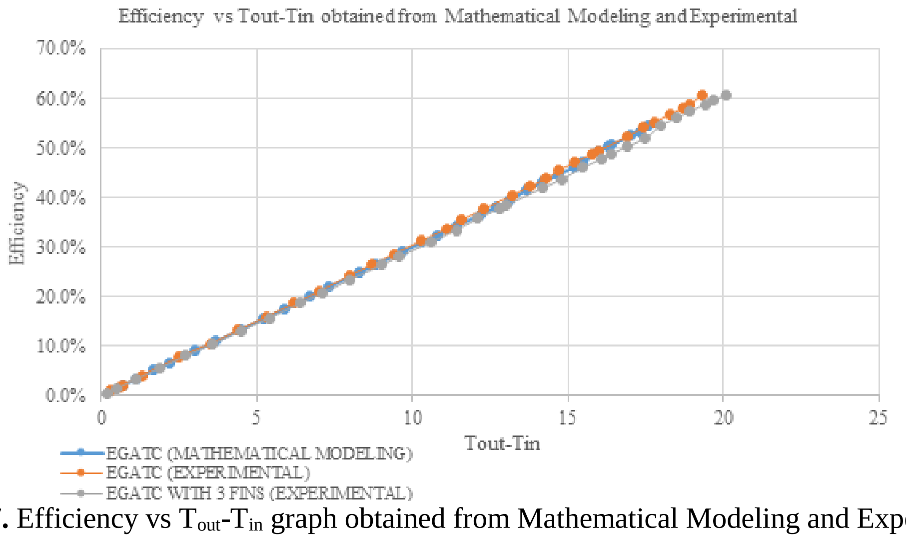

Figure 7. Efficiency vs T_{out}-T_{in} graph obtained from Mathematical Modeling and Experimental

On the other hand, Table 3 shows the results obtained to validate the mathematical modeling with experimental. The collector efficiencies for both mathematical modeling and experimental are 30.5% and 33.1%, respectively. However, the collector storage efficiencies are 68.7% and 71.2% for mathematical modeling and experimental. Despite the fact that the errors of collector efficiency and collector storage efficiency between those mathematical modeling and EGATC experimental are 7.9% and 3.5%, respectively. It was found that both theoretical and experimental results were in good agreement.

Table 3. The results obtained from the algorithm through Microsoft Excel® software

Description	EGATC (Mathematical Modeling)	EGATC (Experimental)	EGATC with 3 FINS (Experimental)
Experiment details	Heat Transfer Experiment at 01/04/2020; 10:12 (1mm NC absorber, 0 Fin EGATC, S_R = 700 W/m^2, Wind Speed = 0.9 m/s @ 4.6v)	Experiment No. 11 at 12/11/2020; 13:55 (1mm NC absorber, 0 Fin EGATC, S_R = 700 W/m^2, Wind Speed = 0.9 m/s @ 4.6v)	Experiment No. 15 at 16/11/2020 (1mm NC absorber, 3 Fin EGATC, S_R = 700 W/m^2, Wind Speed = 0.9 m/s @ 4.6v)
G_t hour/day	0.33	0.32	0.33
$E(G_tA_c)$ (kJ)	33882.62	33262.27	34536.96
E ($\dot{Q}_{collector}$) (kJ)	10337.88	11006.94	11416.19
Efficiency (Collector) (%)	30.5	33.1	33.1
Q store (Daily) (kJ)	12942.97	12671.36	13099.66
Efficiency (Collector + storage) (%)	68.7	71.2	71.0

4. CONCLUSION

The mathematical equation related to each component of EGATC was analytically formulated based on the first law of thermodynamics. The combination of the developed equations forms a solar thermal collector model for the system. The total difference in the percentage of 4.7% shows the model at each node was valid. The performance curves of the Evacuated Glass-Thermal Absorber Tube Collector (EGATC) for those 0 fins (mathematical modeling), 0 fin (experimental), and 3 fins (experimental) were obtained. The results show that the efficiency (collector + storage) is affected by the number of fins. The efficiency (collector + storage) was 68.7%, 71.2%, and 71.0%, respectively.

Declaration of Interest

The authors declare that there is no conflict of interest.

Acknowledgement

The researchers wish to express their appreciative acknowledgement to International Islamic University Malaysia and Solar Energy Research Institute, Universiti Kebangsaan Malaysia for lab facilities besides Lestari Energy Sdn. Bhd. for financial provision.

REFERENCES

Ashrae. (2011). The American Society Of Heating, Refrigerating And Air-Conditioning Engineers (Ashrae) Handbook - Hvac Applications. In Www.Ansi.Org American Society Of Heating, Refrigerating And Air-Conditioning Engineers, Inc.

Choudhury C, Chauhan PM, Garg HP. (1995). Design Curves for conventional solar air heaters. *Renewable Energy*, 6(7), 739-749.

Fudholi A, Sopian K. (2019). A review of solar air flat plate collector for drying application. *Renewable and Sustainable Energy Reviews*, 102, 333-345.

Fudholi A, Sopian K, Gabbasa M, Bakhtyar B, Yahya M, Ruslan MH, Mat S. (2015). Techno-economic of solar drying systems with water based solar collectors in Malaysia: a review. In Renewable And Sustainable Energy Reviews.

Fudholi A, Sopian K, Ruslan MH, Othman MY. (2013). Performance and cost benefits analysis of double-pass solar collector with and without fins. *Energy Conversion and Management*, 76, 8–19.

Hollands KGT, Shewen EC. (1981). Optimization of flow passage geometry for air-heating, plate-type solar collectors. *Journal of Solar Energy Engineering, Transactions of the Asme*, 103(4), 323.

Kumar Singh A, Samsher. (2020). Analytical study of evacuated annulus tube collector assisted solar desaltification system: a review. *Solar Energy*, 207, 1404-1426.

Matuska T, Sourek B. (2017). Performance analysis of photovoltaic water heating system. *Int. J. Photoenergy*, 1, 1–10.

Najera-Trejo M, Martin-Domínguez IR, Escobedo-Bretado JA. (2016). Economic feasibility of flat plate vs evacuated tube solar collectors in a combisystem. *Energy Procedia*, 91, 477-485.

Njomo D, Daguenet M. (2006). Sensitivity analysis of thermal performances of flat plate solar air heaters. *Heat and Mass Transfer/Waerme- Und Stoffuebertragung*, 42(12), 1065-1081.

Ong KS. (1995). Thermal Performance of solar air heaters: mathematical model and solution procedure. *Solar Energy*, 55(2), 93-109.

Parker BF, Colliver DG, Walton LR. (1982). Sensitivity Analysis Of Solar Air Heater Design Parameters. In Unknown Host Publication Title, pp 361-371.

Razak AA, Majid ZAA, Azmi WH, Ruslan MH, Choobchian S, Najafi G, Sopian K. (2016). Review on matrix thermal absorber designs for solar air collector. *Renewable and Sustainable Energy Review*s, 64, 682-693.

Sabiha MA, Saidur R, Mekhilef S, Mahian O. (2015). Progress and latest developments of evacuated tube Solar collectors. *Renewable And Sustainable Energy Reviews*, 51, 1038-1054.

Tchinda R. (2009). A review of the mathematical models for predicting solar air heaters systems. *Renewable and Sustainable Energy Reviews*, 13(8), 1734-1759.

Zakaria ZA, Majid ZAA, Harun MA, Ismail AF, Ihsan SI, Sopian K, Razak AA, Sharol AF. (2021). Experimental investigation of integrated energy storage on the thermal performance enhancement of evacuated glass-thermal absorber tube collector (Egatc) for air heating application. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 96(1), 137–152.

Zakaria ZA, Majid ZAA, Harun MA, Ismail AF, Ihsan SI, Sopian K, Razak AA, Sharol AF. (2021). Investigation on the thermal performance of evacuated glass-thermal absorber tube collector (Egatc) for air heating application. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 79(2), 48-64.