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Efficacy Improvement of Flat Solar Air Collector Systems Varies With Structural and Material Modifications

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Abstract: This study was performed to evaluate the thermal parameters of solar air collectors in Vietnam. Three flat plate solar air collectors were fabricated and tested at Thua Thien Hue province, Vietnam. The research was comprised of three tilt angles, absorbent materials and height on the temperature of the outlet air, absorber plate surface and glass surface of the collectors. Similar, the variation of temperature was measured when collector structures and materials were changed at specific locations in the collector. Results show that the temperature of outlet air, absorber plate surface and glass surface was strongly affected by changing the structure and materials of the collectors. The outlet air temperature measured at the collector output increases (3°C) when the tilt angle of collector increases from 20o to 40o. However, there was no difference in collector using an absorbent sheet (V-groove black painted iron tole) as compared to V-groove black painted fibre-cement sheet. However, it is always higher than the collector using the non-painted fibre-cement sheet (up to 17ºC). Besides, the outlet air temperature increases with placing at a higher height of the collector. Thus, the results confirm that the thermal parameters of solar air collectors depend on collector structures and materials. The V-groove black painted fibre-cement sheet could be used as good absorber material for the design of the solar air collector and solar flat-plate air collectors.

Keywords: Solar air collector, fibre-cement sheet, solar energy, black painted iron tole, thermal parameter.

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1. Introduction

Solar energy is a clean, free and endless renewable energy (Guangul and Chala, 2019; Lehtola and Zahedi, 2019). It is applied in many areas of social life. Application of solar thermal has been used for a long time and is a promising technique to meet the world's energy demand while other thermal energy sources are rapidly exhausting (Farjana et al., 2018; Kannan and Vakeesan, 2016; Kumar et al., 2019; Prăvălie et al., 2019).

Vietnam lies from 23° to 8° North latitude and has an excellent solar radius. The areas with the highest potential for solar energy are the Central and the South of Vietnam. These areas are blessed with the excellent sun shines throughout the year (average total solar radiation of 5 kWh.m^{-2}/day) (Hoi et al., 2020; Sanseverino et al., 2020), with lowest during winter (3 - 4.5 kWh.m^{-2}/day) and increased during summer (4.5 - 6.5 kWh.m^{-2}/day). Average total sunshine hours ranged from 1,800 to 2,700 h per year (Phong, 2008). Solar energy in the Southern and Central regions in Vietnam can be used on average 300 days per year. Whereas, in the Northeast and Northwest region, the insolation is a bit lower during winter. However, still having high potential and can be used around 250 - 280 days per year (Phong, 2008).

Solar heater is a simple, cheaper and eco-friendly device used to harness solar energy for various purposes in agriculture and its products (Bisht et al., 2018; Fudholi and Sopian, 2019). Many solar air collectors have been studied and installed with many application areas such as hot air collectors for drying or heating, water heaters, etc. of which flat collectors

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are widely used due to its simple construction (Evangelisti et al., 2019;). However, it assesses in low efficiency, which is applicable in cases with medium or lower temperature differential requirements (El-Said, 2020; Mahboub et al., 2016; Salih et al., 2019).

Many studies have been conducted to study and assess collector efficiency such as the difference of absorbent material, increasing heat transfer area (Aboghrara et al., 2017; Chikurde et al., 2019; Gilani et al., 2017; Khawagianh et al., 2011), alteration of the airflow direction using the partitions (Singh and Dhiman. 2016; Yeh et al., 2000), varying number of air channels (Naphon, 2005; Menni et al., 2019), modification of the absorbent sheet material (Gao et al., 2017; Rajarajeswari and Sreekumar, 2016), altering the collector tilt angle and the collector height (Mohammed et al., 2019) and tilt optimization of solar air collector (Hocine Mzad et al., 2018), the study of surface geometry of the absorber plate affect to the thermal performance of the collector (Darici and Kilic, 2020). Through these studies, thermal parameters of the collector were determined, especially the airflow temperature. The results confirmed that the appropriate structure and materials of the constructor could improve collector efficiency.

In Vietnam rural areas, fibre-cement sheets widely used since the 1960s (Thuan, 2014; Duong, 2016) because this roofing sheet has many advantages such as being resistant to alkaline and acidic medium, well resistant to rain and sun, no ignition, no noise and low price. The fibre cement roof factories were built gradually. The year 2008 witnessed the highest yield of AC roof production at approximately 100 million m^2/year (Vietnam Roofsheet Association, 2017). After use, it can be disposed of indiscriminately without being treated, causing environmental pollution (Global Cement staff, 2014). Hence, if it is used in the absorbent material in the solar air collector are of significance in ecological pollution management and enhances the usability of this construction material.

In this study, fibre-cement sheets were used as absorption material in the solar air collector; thermal parameters of the collectors have been determined and compared with changing collector structure and height to confirm the usability of this material in the fabrication of solar air collector.

2. Materials and Methods

2.1. Experimental Setup

Three locally fabricated air collectors (1.0 × 0.5 × 0.1 m) were used to investigate their efficacy in terms of solar radiation intensity, temperature, and airspeed.

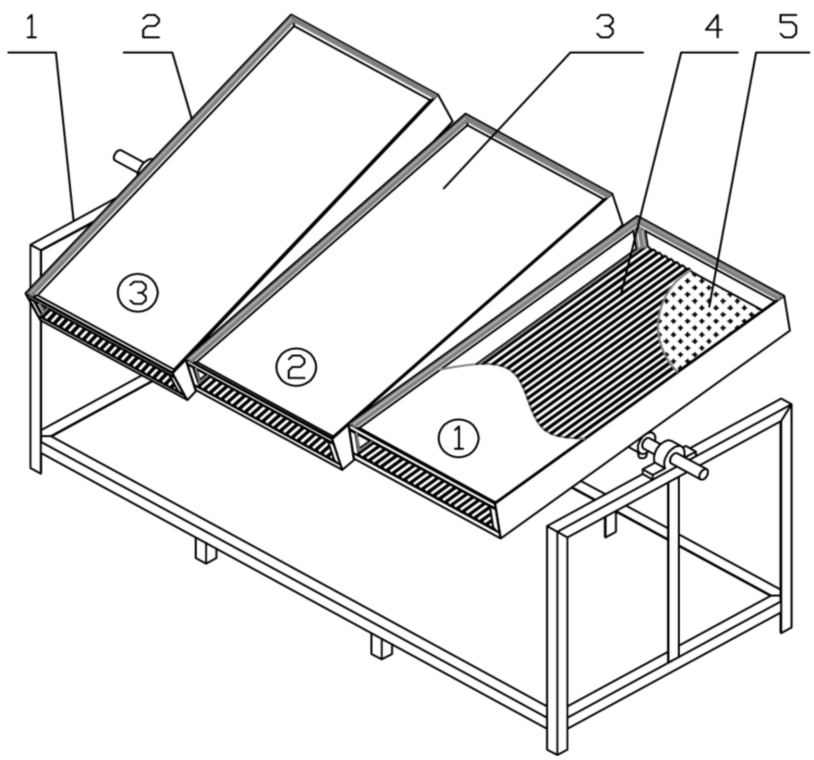

Fig. 1. Experimental system: 1. Main frame; 2. Collector frame; 3. Glass cover; 4. Absorbent plate; 5. Insulation sheet.

Collector materials included V-steel frames; insulation layer using 0.05m thick foam; absorbent plate material using V-groove black painted iron tole, V-groove black painted and unpainted fibre-cement sheet; transparent cover using 5mm-thick glass cover (Fig. 1).

2.2. Experimental design

The experiments were conducted at the College of Agriculture and Forestry, Hue University, Vietnam with geographical coordinates of 107°31 '- 107°38' East longitude and 16°30'-16°24' Northern latitude. Experimental data was recorded during daytime (9:00 to 16:30 h), August 22-24, 2018. Distribution factor and levels of the experiments are presented in Table 1.

Table 1. Factors and levels of the collectors during the experiments

Test code	Tilt angle (°)	Materials absorbent sheet	Heights (m)	Date
T1	20	V-groove black-painted iron tole	0.2	August 22, 2018
T2	30	V-groove black-painted iron tole	0.2	August 22, 2018
T3	40	V-groove black-painted iron tole	0.2	August 22, 2018
T4	30	V-groove black-painted iron tole	0.2	August 23, 2018
T5	30	V-groove black painted fibre-cement	0.2	August 23, 2018
T6	30	V-groove unpainted fibre-cement	0.2	August 23, 2018
T7	30	V-groove black-painted iron tole	0.2	August 24, 2018
T8	30	V-groove black-painted iron tole	0.6	August 24, 2018
T9	30	V-groove black-painted iron tole	1.0	August 24, 2018

The air collector was tilted toward South. The duration for each measurement was 30 minutes; used by temperature measuring device to measure the outlet air temperature of the collectors, the glass surface temperature and the absorbent plate surface temperature when the structure and materials of the air collectors are changed.

During the experiment, solar radiation intensity, temperature, and airspeed were determined using Tenmars TN-206 (Taiwan, ±0.1 Wm^{-2}); microclimate measuring device EN100 (Taiwan, ±1.2 °C); multi-function thermal sensor ADD81 (±0.1 oC); laser temperature measuring device (Sealey VS905, UK, ±0.1 °C) (Fig. 2).

Fig. 2. Measuring devices

2.3. Statistical analysis

Collected data sets were processed, and the graphical presentation was prepared using Microsoft Office Excel 2013.

3. Results and Discussions

3.1 The effects of the tilt angles on thermal parameters of the solar air collectors

Data was collected from 9:00 to 16:30 h; with 30 m average. The weather during data collection was sunny with an average radiation intensity of 610W.m-2, average ambient air temperature of 31°C. Results of thermal variation according to collector structure and solar radiation intensity are shown in Fig. 3, 4 and 5.

Fig. 3 shows the effects of the tilt angle of collectors to outlet air temperature during the daytime. The intensity of solar radiation increases continuously and rapidly increases from 9:00 to 12:30 h and begins to decrease from 13:00 to 16:30 h gradually. The highest solar radiation intensity was 945$W.m^{-2}$. Further, results revealed that the temperature variation of outlet air of the collectors depends on the tilt angle: the more elevated temperature varied from 9:00 to 11:30 h for 30°.

Heating achieved from 12:00 to 16:00 h was higher at outlet air of the collectors for 40° tilting angle; whereas lowest heating was achieved with outlet air collectors at 20° compared to 30° and 40° tilting angles of the collectors. The ambient air temperature also showed an increase from 9:00 to 13:00 h then gradually decreased from 13:30 to 16:30 h, with a daily average of 30°C and very low wind speed (average 0.2 $m.s^{-1}$).

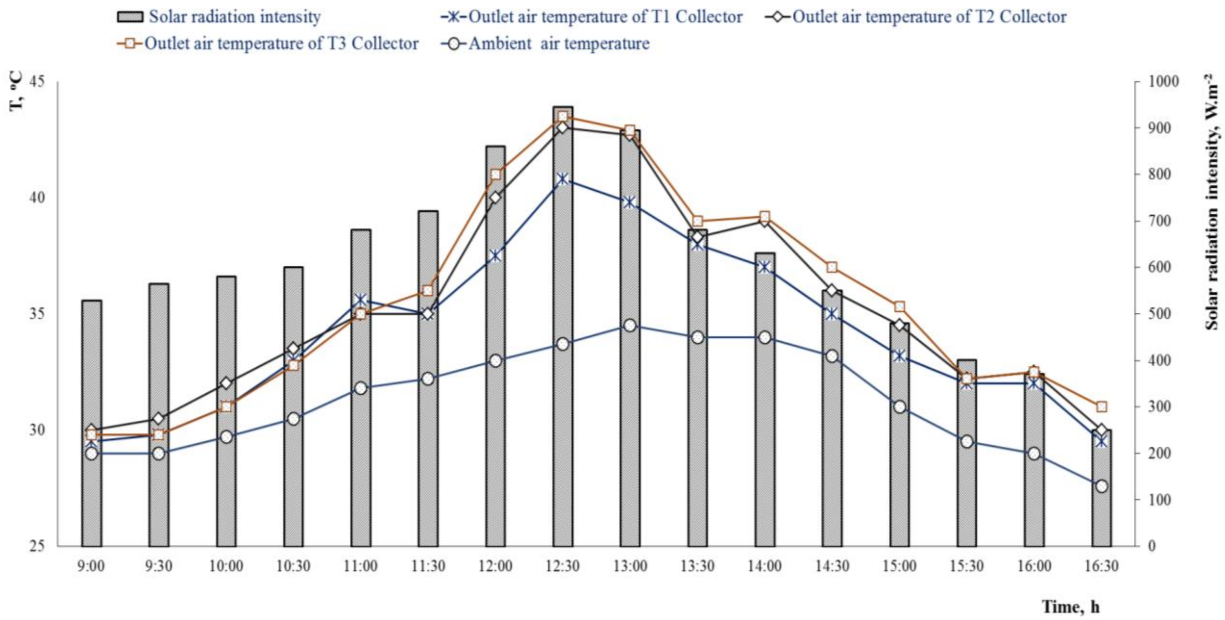

Fig. 3. The effects of the tilt angle of collectors to outlet air temperature during the daytime.

The temperature measured at the glass surface also varies with the intensity of solar radiation during the day (Fig. 4). The results showed that the glass surface temperature is highest when the tilt angle of the collectors was 20° and decreased with the increasing tilt angle. However, this difference was not significant, especially in the early morning or late afternoon in the day.

The experiment also conducted to measure the temperature at the absorbent plate surface of the collectors. The results showed that the highest temperature measured was 78.2 °C, higher than the ambient air temperature up to 45 °C. A significant difference in the heating between the absorbent plates (around 5 °C) was recorded at 12:30 h and gradually decreased with the reduction in the radiation intensity.

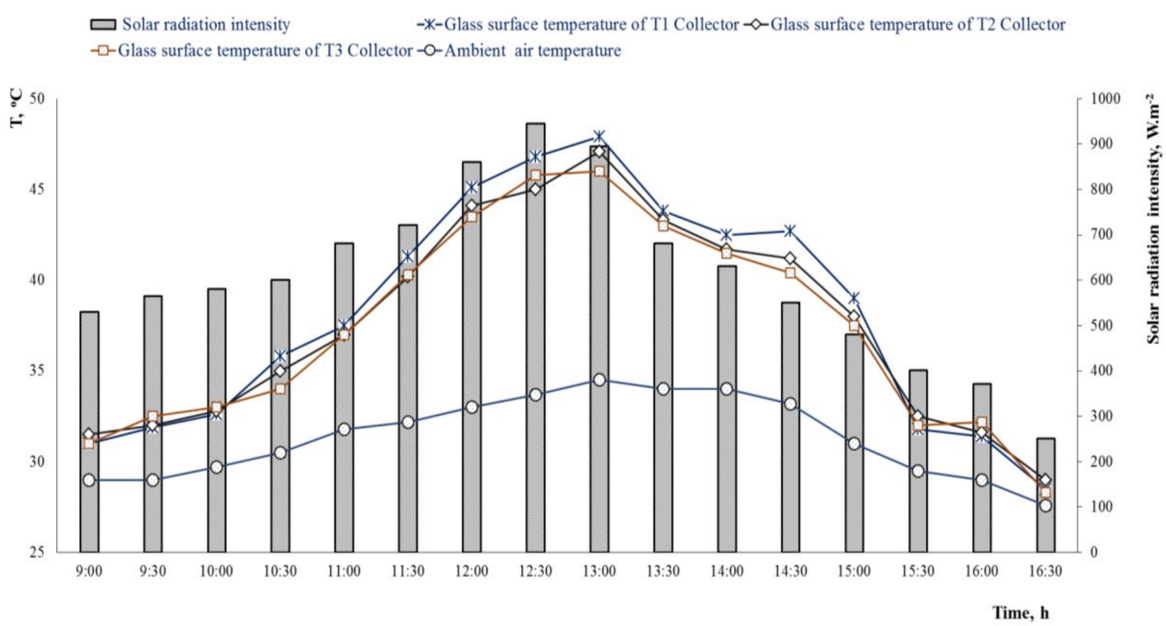

Fig. 4. The effects of the tilt angle of collectors to glass surface temperature during the daytime

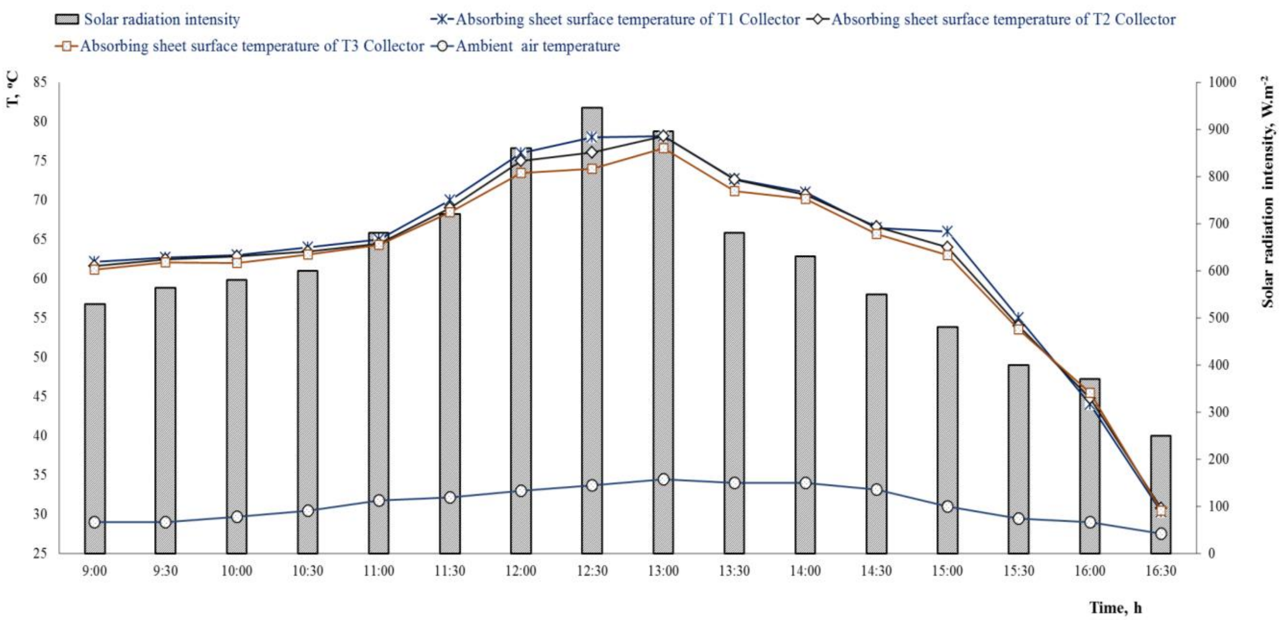

Fig. 5. The effects of the tilt angle of collectors to absorbent plate surface temperature during the daytime

Surfaces of the absorbent plate of the collector with a narrow tilt angle (20°) achieved the highest warming and were lowest for the collector with a wider tilt angle (40°). Greater heat exchange between the airflow and absorbent plate surface can be potentially due to the higher natural convection rate in the collector with a tilt angle of 40° is higher, and the higher airflow temperature was obtained by decreasing the absorption plate temperature. Contrarily, collectors with a narrower tilt angle (20°), higher temperature of absorption plate surface were observed, mainly due to the lower convection airflow, leading to limited heat exchange between the airflow and the absorbing plate. This difference was negligible in the early morning and late afternoon.

On the other hand, the tilt angle of the collector has effects to the angle of incidence of solar radiation to the collector surface, which affects the thermal parameters of the collectors (Danuta and Sławomir, 2017). Orientation and tilt angle of a solar collector significantly influences its heating potential. Abdulkadir et al. (2015) also reported that the tilt angle of the collector affected the efficiency of the South faced solar air collectors. It can be utilizing maximum solar energy through the optimum tilt.

3.2. Effect of absorbent plate materials on thermal parameters of the solar air collectors

The experiment was also conducted in the same collectors tilt angle of 30° and a height of 0.2 m. The temperature of outlet air, glass surface and absorbent plate surface were measured by changing three kinds of absorbent plate materials (V-groove black painted iron tole, V-groove black painted and unpainted fibre cement sheet) of the collectors. The highest solar radiation intensity is measured of 980 $W.m^{-2}$, the ambient air temperature was 30 °C, and the natural wind speed was $0.2 m.s^{-1}$ and changed continuously.

There was a significant difference in the temperature at outlet air of the collector when the absorbent plate materials differ (Fig. 6). The outlet air temperature in the collectors using V-groove black painted iron tole was higher than that of the collectors using black painted fibre cement sheets in AM then it is lower in PM, the difference in temperature is around of 3°C while the difference in outlet air temperature between the collector using V-groove black painted fibre-cement (or V-groove black-painted iron tole) and the unpainted fibre-cement sheet was significant (8°C).

Similarly, the results obtained the outlet air temperature of the collector using the black fibre-cement absorbent plate was higher than the V-groove black painted iron tole considering after 13:00 h, this is indicating the higher heat storage capacity of the fibre cement sheet than the V-groove black painted iron tole. These results suggest that fibre-cement sheets could be applied in the manufacturing of solar air collectors; especially this material is cheaper, durable and widely available in Vietnam.

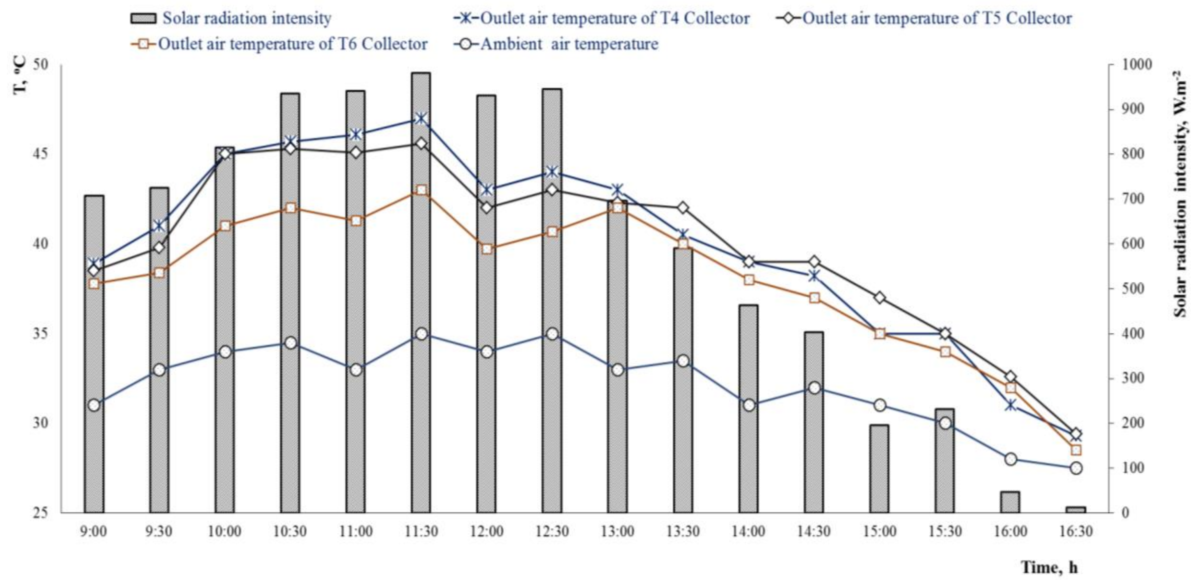

Fig. 6. **The effect of absorbent material of the collectors to outlet air temperature during the daytime.**

The temperature of the glass surface was measured by time of the day (Fig. 7), the highest temperature in a surface glass is observed in the collector using a V-groove black painted fibre-cement plate and the lowest temperature in the collector using unpainted fibre cement sheet plate. However, these differences are not significant (around 4°C).

Meanwhile, the temperature at the absorbent plate surface also changes over time of the day (Fig. 8) when changing the material of the absorbent plate. The temperature is highest (78.2°C) in the collector using V-groove black-painted iron tole, and it is lowest (58°C) in the collector using unpainted fibre cement sheet.

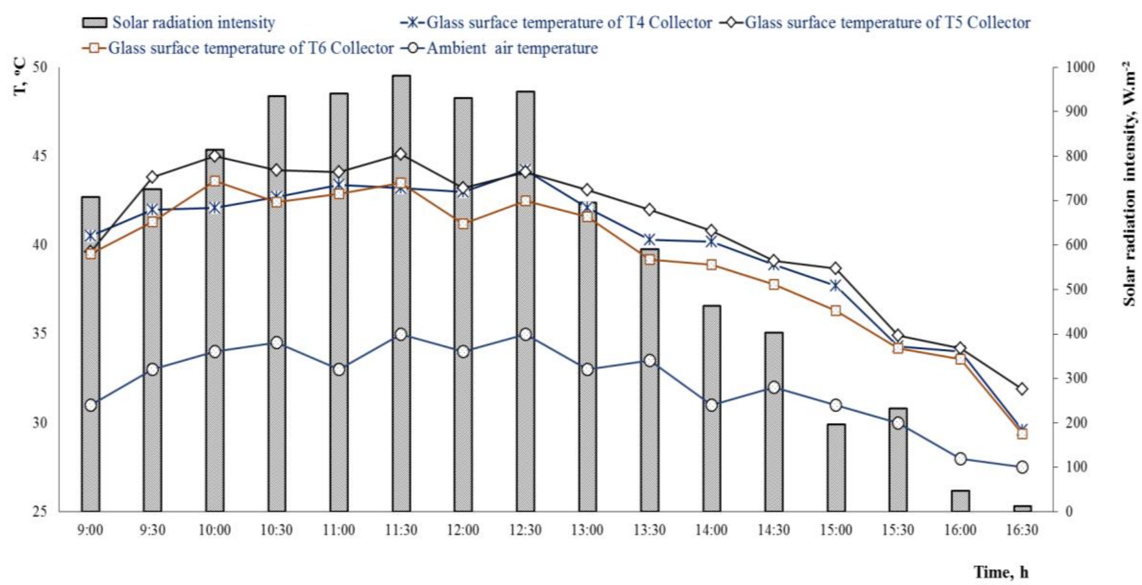

Fig. 7. The effect of absorbent material of the collectors to glass surface temperature during the daytime.

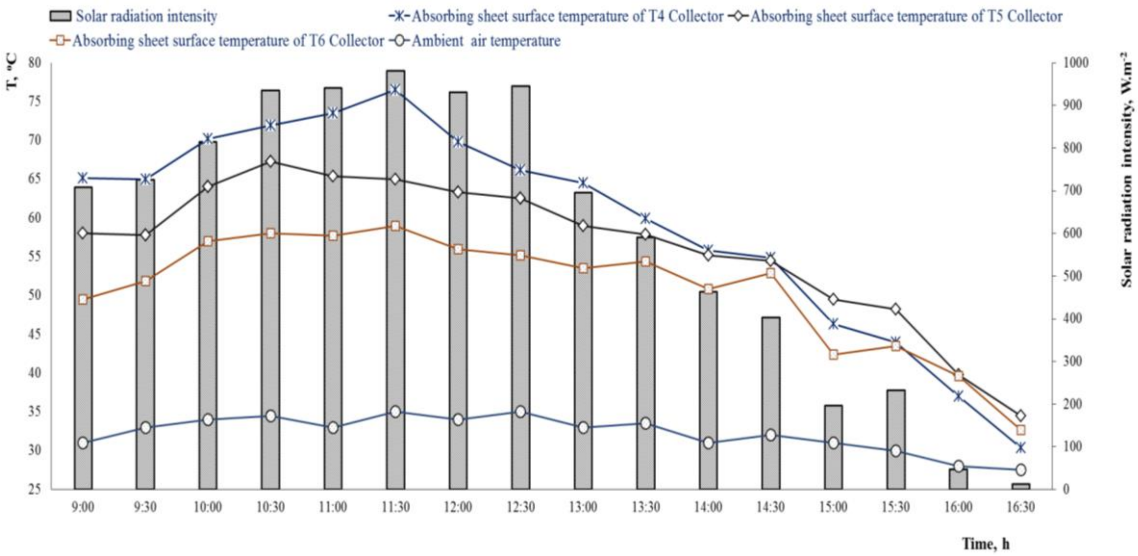

Fig. 8. The effect of absorbent material of the collectors to absorbent surface temperature during the daytime.

When the intensity of solar radiation decreases (after 12:30 h), the absorbent plate surface temperature of black-painted fibre cement plate is higher than that of V-groove black painted iron tole and unpainted fibre cement sheet, this is because the fibre cement sheet can retain heat longer than iron tole, this result may be noted in the use of the solar air collectors using fibre cement sheet as the absorbent material in the air heater systems in drying equipment which the drying time may be extended when the intensity of solar radiation decreases.

3.3. The effect of installation height on thermal parameters of the solar air collectors

The temperature of the airflow at outlet air of the collector, glass surface and the absorption plate surface are determined when the height of collectors is changed. The results are shown in Figs. 9-11. Fig. 9 shows that the outlet air temperature depends on the collector height. The temperature obtained at outlet air of collector was highest in the height of 1.0 m, while lowest in the collector for 0.2 m. However, results agreements that no much change in the early morning and late afternoon in the day.

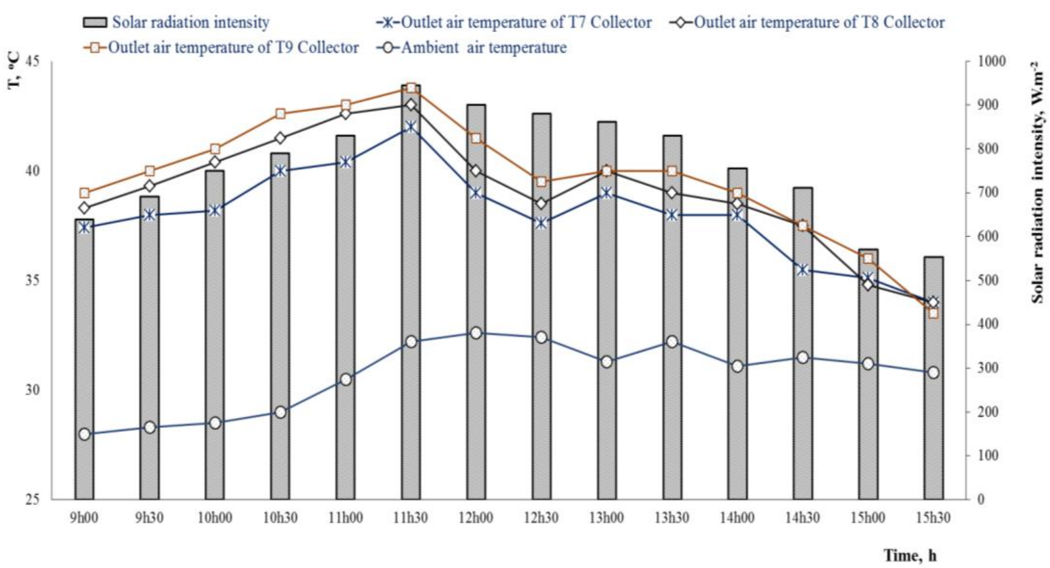

Fig. 9. Effect of installation height of the collectors to outlet air temperature during the daytime.

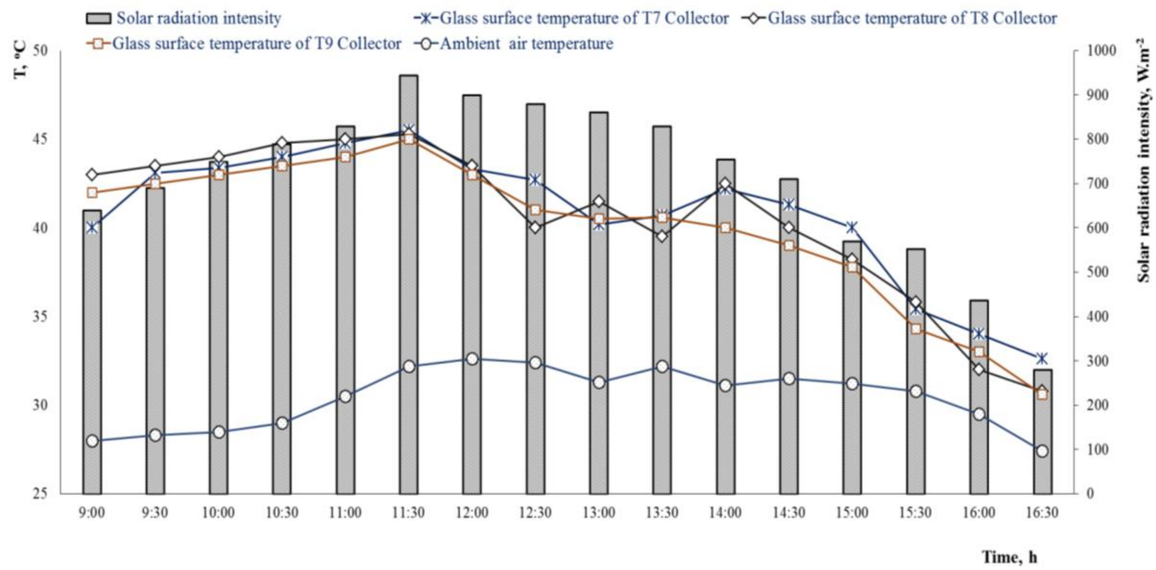

Fig. 10. The effect of installation height of the collectors to glass surface temperature during the daytime.

In practice, the installation height of solar air collector was usually divided into two groups. First, low-set collector group for natural convection of the hot air using in solar air heating devices to reduce the overall height of the equipment. Whereas, second for high-set collector group (upper 1.0 m) for solar air heating devices using forced convection type. In the latter case, the solar air collector usually set up at the bottom of the drying chamber. These results indicate that the increase in the installation height of the collectors increases the outlet air temperature of the collectors.

The temperature of glass surface was highest obtained at 0.2 m height comparing with 0.6 and 1.0m heights, the difference in temperature at the glass surface in the case of height of 0.6 and 1.0m is not apparent. The temperature at the surface of the absorbent plate was measured with three installation heights of the collectors. The observed temperature was lowest when the collector was installed at the height of 0.2 m, while the temperature is highest in the case of installation height of 1.0 m.

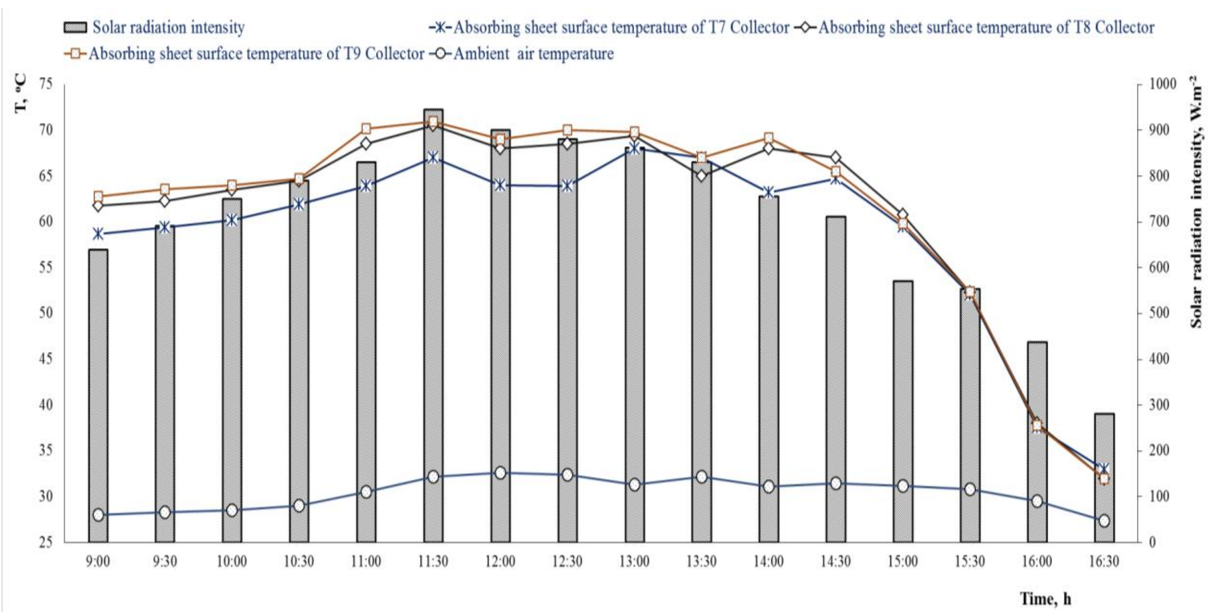

Fig. 11. The effect of installation height of the collectors to absorbent plate temperature during the daytime

4. Conclusions

The study was conducted to investigate the effect of material and structure to the thermal parameter of solar air collectors. The outlet air temperature increased with the increase in collector tilt angle from 20°, 30°, 40°; the highest temperature determined during the time from 9:00 to 11:30 h for collector tilt angle is 30°. However, the highest temperature of outlet air is observed for a tilt angle of 40° during the time from 12:00 to 16:00 h. The temperature of the absorbent plate surface decreased while the glass surface temperature is not different when the tilt angle increased. With the same tilt angle and height, the highest temperature of outlet air observed in collector using V-groove black painted iron tole. At the same time, it was lowest in the collector using a V-groove unpainted fibre-cement sheet. The temperature at the absorbent plate is also highest for the V-groove black painted iron tole collector, and it is lowest for unpainted fibre-cement sheet collector. However, the heat-retention capacity of V-groove black painted fibre-cement sheet collector is higher. It shows that a collector with the fibre-cement sheet can extend the heater time. Besides, the outlet air temperature of the collector increased when the height of the collector is increased. The results recommended that the increase in the tilt angle of the collector up to 40°, the increase in the height and black painted of the absorbent plate can improve outlet air temperature. The results also indicated that fibre-cement sheets could be used as good absorbent material in the manufacture of solar air collectors. These results have to be considered in the design and manufacture process of solar air collectors.

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Author's Contribution: The authors have equal contribution to the planning, conduction and writing of the research article. The authors have thoroughly read and approved the final manuscript.

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