Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Evaluation of Different Glazing Materials, Strategies, and Configurations in Flat Plate Collectors Using Glass and Acrylic Covers: An Experimental Assessment

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P A P E R I N F O

Paper history:
Received 23 August 2021
Accepted in revised form 07 October 2021

Keywords:
Covering configurations
Covering strategy
Experimental study
Heat dynamics
Solar air heater
Thermal performance

A B S T R A C T

Glass plates have been commonly used as collectors' covers due to technical feasibility, high transmissivity in shortwave solar irradiation, and low transmissivity in long-wavelengths. However, they are vulnerable to stones and hail. Plastic plates have high transmissivity in shortwaves but also have transmission bands in the middle of the thermal radiation spectrum. The current study represents an experimental assessment of different covering strategies, including single acrylic-cover, single glass-cover, double glass- acrylic cover, and double glass-cover. Two solar air heaters (SAHs) prototypes were constructed for this study. The acquired experimental runs illustrated that the single glass-covered SAH represents higher thermal performance than the single acrylic-covered SAH due to the lower transmissivity of glass plates in long wavelengths. The double-covered SAHs have higher performance than the similar single-covered SAHs. In the double-covered SAHs, the convective-radiant heat loss is reduced. However, increasing the cover number improves the radiant resistance to solar irradiation and reduces the collector performance when solar irradiation is insufficient and the absorber temperature is low, especially at the beginning of daytime hours. The SAH using a double-glass cover is preferable; however, the heat dynamics of the double glass- acrylic-covered SAH are so close to the double glass-covered one, and the acrylic plate is more resistant to harsh ambient conditions.

***doi**: 10.5829/ijee.2021.12.04.03*

NOMENCLATURE

A	Collector area, m^2	w	Uncertainty
c_p	Specific heat, J/kg.K	**Greek Symbol**	
E	Energy, J	η	Efficiency
G	Solar irradiation heat flux, W/m^2	ρ	Desnity (kg/m^3)
k	Tehrmal conductivity, W/m.K	**Subscripts**	
$\dot{m}$	Mass flow rate, kg/s	a	Air
r	Equivalent thermal energy	el	Electrical
P	Parameter	in	Inlet
T	Temperature, ^{o}C	out	Outlet

INTRODUCTION

Providing sustainable and renewable energy sources is currently a primary subject in economic growth and industrial development. Solar energy is the most affordable, green, and sustainable energy source that attracts attention due to its pollution-free nature and inexhaustibility. Solar thermal collectors are a feasible technique for harvesting incident solar energy and turning it into accessible thermal energy [1, 2]. Solar air heaters

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Please cite this article as: M. Ameri, H. Farzan, M. Nobari, 2021. Evaluation of Different Glazing Materials, Strategies, and Configurations in Flat Plate Collectors Using Glass and Acrylic Covers: An Experimental Assessment, 12(4), pp. 297-306. Doi: 10.5829/ijee.2021.12.04.01

(SAHs) are thermal collectors that have been extensively used for space heating, food dehydration, and crop drying [3]. The air travels through channels installed inside SAHs and extracts heat from the hot absorber. Commonly transparent plates such as glass or acrylic sheets cover hot absorber plates, protect them, and remarkably reduce heat losses to ambient environments. Covering strategies, such as covers materials as single or double layers, are a crucial technical feature that can significantly affect the heat dynamics and thermal performance of SAHs. Single and double glass-covered strategies have been the most common techniques employed to improve the heat dynamics and thermal efficiency of SAHs [4, 5].

SAHs are immensely popular and interest many researchers due to their cost effectiveness, simple structure, and ease of application and maintenance [6, 7]. Numerous literature studied this type of solar air heaters to assess their performance and heat dynamics under different environmental and operational conditions [8, 9]. Samdarshi and Mullick [10, 11], Akhtar and Mullick [12] proposed analytical equations to obtain the heat loss factor of single and double-glazed flat plate collectors (FPCs) with sufficient accuracy. They reported that the convective/radiant heat transfer coefficient was reduced up to 50% by using the double-glazed cover instead of the single-glazed one. Das and Chakraverty [13] studied the efficiency of FPCs utilizing various glazing materials. They reported that double window glass collectors had a higher thermal performance than single window glass ones in two different air mass flow rates. A numerical study by Yang and Wang [14] investigated the performance of an absorption solar cooling system using single-glazed and double-glazed collectors. The acquired results proved that the double-glazed collector had higher efficiency than the single-glazed one. Maatouk [15] developed an analytical model to obtain the combined radiation, conduction, and convection heat exchange for a collector glazing that calculates the steady-state heat flux and temperature distribution within the glass cover. Natural convection in a vertical flat plate collector using single and double glazing were experimentally investigated considering airflow between the absorber plate and glass covers. This study illustrated that an air heater using two glass covers had maximum performance [16]. Tchinda [17] reviewed and classified various mathematical models to assess the number of glass covers, the shape of the absorber, and the presence of a packing bed. Giovannetti et al. [18] used theoretical methods to examine the effectiveness of highly transmitting and spectrally selective coating in the efficiency of uncovered, single-covered, and double-covered FPCs. A numerical approach was used to estimate the heat loss coefficient for the top cover of single and double glazed flat plate collectors with normal and small air gap spacing. The optimized design showed a 14% increase in outlet water temperature [19]. Akhtar and Mullick [20] analyzed the effects of solar radiation absorption in a glass cover on heat transfer coefficients in single and double-glazed solar collectors. Bahrehmand and Ameri [21] and Bahrehmand et al. [22] used mathematical models to investigate the heat dynamics of single and double glazed solar air heaters using artificial roughness. These studies evaluated crucial parameters on solar heaters' heat dynamics such as length, depth, and shape of used longitudinal fins.

Several studies have compared the thermal performance and heat dynamics of single and double-glazed plate collectors in recent years. These investigations reported significant improvement, around 20%, in the efficiency of double-glazed solar heaters compared to single-glazed ones [23, 24]. Dondapati et al. [25] and Singh et al. [26] assessed the effects of different glazing materials such as polyvinyl fluoride, polyethylene, polystyrene, polyester, polycarbonate, and glass on the performance of solar FPCs. They reported that collectors using polyvinyl fluoride as glazing materials represented the maximum thermal performance. Ganesh Kumar et al. [27] carried out an optimization study for choosing glazing materials among seven alternative options using TOPSIS (Multi-Criteria Decision Making Methodology). Renuka et al. [28] considered twelve alternative options and ten criteria for optimal selection of glazing materials. They suggested that the crystal glass had the best performance in assumed scenarios. Osorio and Rivera-Alvarez [29] extended glazing strategies to parabolic trough collectors (PTCs), studied the performance of PTCs using double glass envelopes and compared this collector type with traditional PTCs. Tekkalmaz et al. [30] used glass, Lexan, and acrylic to investigate the impacts of cover materials on heat transfer coefficients and cover temperature. The obtained numerical results proved that using acrylic covers is more advantageous than glass covers due to high heat loss by glass plates. Filipović et al. [31] utilized a numerical and experimental method to evaluate the heat dynamics of single and double-glazed solar collectors. This study's major contribution was developing a new approach to model the radiation mechanism in solar collectors. By literature review, early and recent studies emphasized using the double-glazing technique to improve collector performance and compared single and double-covered strategies. FPCs can use single and double covers made of transparent materials with different spectral transmissivities; they can also be placed in different configurations. However, less attention has been paid to cover materials, covers configurations with different materials, strategies, and their impacts on heat dynamics and thermal performance of SAHs. The present study attempts to concentrate on this crucial issue and assess different covering strategies and configurations to optimize the performance and extend the durability of SAHs. The considered scenarios include single acrylic-covered SAH, single glass-covered SAH, double glass-acrylic-covered SAH, and double glass-covered SAH.

The other contribution is to compare the heat dynamics of a strategy using a glass plate as an interior cover and an acrylic plate as an exterior cover with a strategy using a double-glass cover. To this aim, two SAH prototypes were constructed and experimentally tested under field conditions. Several sensors were employed to monitor the environmental conditions and heat dynamics of the constructed SAHs.

The heat dynamics and thermal performance of SAHs strongly depend on the types of covers and materials installed on collectors' top surfaces. These covers have been made of types of glass or transparent plastic that represent different spectral transmissivities. Furthermore, glass and plastic plates show different robustness against harsh ambient conditions or dust. The current study assesses the heat dynamics of the constructed SAH using different covering strategies to obtain the optimum thermal performance and extend the collector lifespan. It is worth noting that covering materials constitutes a small portion of the construction cost of a collector; however, covering strategy can significantly improve collector efficiency.

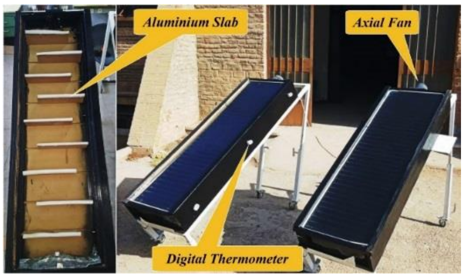
EXPERIMENTAL METHOD

Design and construction of SAH

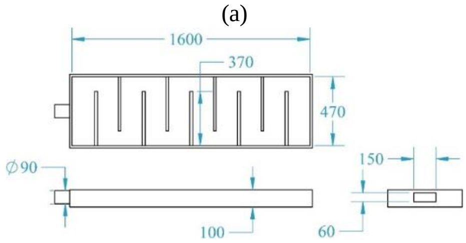
The experimental setup and the constructed SAH geometrical specifications are represented in Figures 1a and 1b. The constructed SAH consists of medium density fiberboards configured as a rectangular box with inner dimensions of 160 cm × 47 cm × 10 cm. Nine aluminum slabs were installed inside the collector to produce serpentine air channels and extend air travel inside the SAH. The aluminum slabs have outer dimensions of 30 cm × 10 cm × 1.5 cm. The absorber is a 5 mm thick corrugated aluminum plate coated black to maximize heat energy absorption. The collector was insulated with glass fiber wool to decrease the heat loss to the ambient. A 10 W axial fan was installed inside the outlet duct with a 9 cm diameter to provide a constant airflow rate. The setup was oriented toward the south at an angle of 30^o to receive the maximum solar irradiation.

Covering strategies and configurations

Covering strategy can significantly affect the heat dynamics and thermal efficiency of solar heaters. The covers installed on the SAHs' top surface are sensitive to solar wavelengths; hence, a portion of sun rays passes through transparent covers, and the remaining part is reflected ambient environments and absorbed by covers. The sun's energy portion passes through covers depending on the cover materials and wavelength. Figure 2 shows the spectral dependence of the spectral transmissivities of 4 mm thick glass and 3 mm thick acrylic plates. As shown in Figure 2, glass plates are almost opaque in long wavelengths and have lower



(a)



(b)

Figure 1. (a) Constructed experimental setup and (b) the SAH dimensions in milimeter

spectral transmissivity than acrylic plates. However, both glass and acrylic plates display the same pattern in short wavelengths and have high spectral transmissivity. This issue causes more thermal energy radiated from absorber plates in long wavelengths to pass through acrylic plates compared to glass plates. Hence, heat loss due to radiation in acrylic plates is more than in glass plates.

Various covering strategies are considered in the current study, including single-acrylic cover, single-glass cover, double-glass cover, and double-glass- acrylic cover. All glass and acrylic sheets used in this study have 4 mm and 3 mm thicknesses, respectively. Table 1 represents the thermophysical properties of glass and acrylic plates in summary. As stated in Table 1, acrylic plates are lighter and several times stronger than glass plates and thus more resistant to strokes, but the maximum service temperature in glass plates is higher than acrylic plates. Furthermore, acrylic plates have a low thermal conductivity that improves the thermal resistance to heat losses.

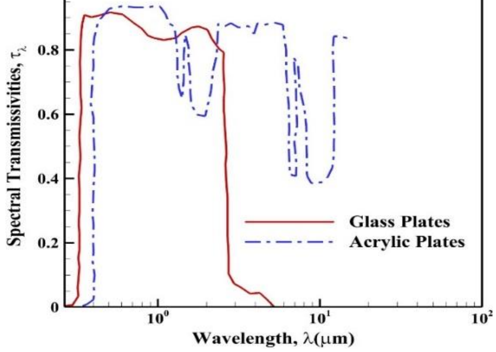


Figure 2. Spectral dependence of the spectral transmissivities of glass and plastic plates [32]

Table 1. Thermophysical properties of glass and acrylic plates

Cover Type	*k*	c_p	ρ	Rockwell Hardness (M Scale)	Maximum Service Temperature (ºC)
Glass	0.93	800	2530	5 to 6	200 - 230
Acrylic	0.21	1460	1180	100	80

Single and double glass covers are extensively used in commercial applications. However, these formations have some inherent drawbacks. The glass covers are vulnerable to thermal stress and external impacts. Nevertheless, glass covers are almost opaque and have much lower spectral transmissivities to long wavelengths than acrylic plates. On the other hand, the acrylic covers are resistant to harsh environmental conditions, but more thermal energy escapes with long wavelengths through acrylic covers due to higher spectral transmissivity. In the current study, four scenarios were considered to assess the effects of various covering strategies on the thermal efficiency of the constructed SAH. In other words, an optimum covering strategy can simultaneously increase the efficiency of SAHs and extend the lifespan of collectors. Figures 3a and 3b show the schematics of different converting strategies considered.

In the double-covered strategies, increasing the cover number improves thermal resistance. It is clear that the exterior cover in the double-covered SAH adds conductive, convective, and radiant resistances to the thermal network.

Expeimental setup sensors

Several sensors were used to monitor the heat dynamics of the constructed SAHs and measure environmental conditions. The crucial factors measured include ambient air temperature, solar irradiation, intake air temperature, exhaust air temperature, and airflow velocity. The Testo 405-V1 anemometer and the Kipp&Zonen CM6B pyranometer monitored the airflow velocity and solar intensity, while the Thermo TA-288 digital thermometers measured the ambient temperature and intake and exhaust airflow temperatures. The sensors' installation locations are shown in Figure 1a.

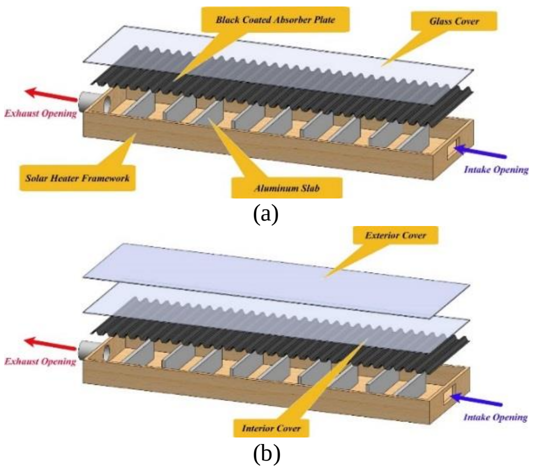


Figure 3. Schematics of the constructed (a) single-covered SAH, and (b) double-covered SAH

Test method

The experiments were performed in Kerman, Iran, located at 29.48° northern latitude, 57.64° eastern longitude. The experiments started at 10:00 A.M. and ended at 4:00 P.M., through July 2019. The fan speed was manually adjusted using a variable frequency drive to produce two constant air mass flow rates of 0.007 and 0.01 kg/s during the tests. The operational and environmental parameters were measured and recorded in 30 minutes intervals.

UNCERTAINTY ANALYSIS

The uncertainty analysis provides a valuable tool for assessing uncertainties in an experimental measurement. The acquired measurements will be affected by errors, experimental conditions, methodology, and instrumentation during the experiment. Hence, the uncertainties highly depend on the accuracy and precision of used measurement instruments. The main parameters in the current study are shown in Table 2, and their associated uncertainties are given as follows [33]:

$$w_R = \left[\sum_{i=1}^{n} \left(\frac{\partial P}{\partial y_i} w_{x_i} \right) \right]^{1/2} \quad (1)$$

Here w_R and w_{xi} denote the uncertainties related to the parameter P and the independent variable y_i. n represents the number of independent variables. The measured data were employed to calculate the air mass flow rate, heat gain, and first law efficiency. The mean measured values during the experiments for ΔT, T_o, T_a, G, and v were 30.5 ºC, 60.2 ºC, 32 ºC, 950 W/m^2, 1.1 m/s, respectively. The uncertainty and accuracy of the critical measured and calculated parameters are shown in Table 2.

THERMAL ANALYSIS

Energy analysis has been extensively utilized to evaluate the daily thermal efficiency of an energy system and offer strategies to improve its performance. The daily thermal efficiency of the constructed SAH is defined as the ratio of the collected energy gain to the input energy. The daily thermal efficiency of the collector, η, is given as

$$\eta_{daily} = \frac{\dot{m} c_p \int_0^t (T_{air,out} - T_{air,in}) dt - \int_0^t E_{el,fan}}{A \int_0^t G dt} \quad (2)$$

Here, $\dot{m}$ is the air mass flow rate, and $T_{air,in}$, and $T_{air,out}$ denote the inlet and outlet air temperatures, respectively. G denotes the incident solar intensity, while A represents the total collector surface area. $E_{el,fan}$ is the consumed electrical power by the installed axial fan. The daily thermal efficiency was calculated using the overall test duration from the beginning to the end of the experimental run. In Equation (2), the first integral in the nominator is used to obtain the accumulated heat gain. However, the time interval is assumed one hour to calculate the accumulated heat gain.

It is obvious that in Equation (2), the critical factors such as the incident solar intensity, fan power, and thermal energy do not have the same worth and quality. One method for handling this problem is to equalize fan power with thermal energy. The equivalent thermal energy is found by introducing the electrical-to-thermal ratio as:

$$r=\frac{\dot{E}_{el}}{\dot{E}_{thermal}} \tag{3}$$

Coventry and Lovegrove [34] showed that the electrical-to-thermal ratio lies between 1 and 17 based on simple energetic and exergetic analyses. The energy analysis in the current investigation was carried out using the equivalent thermal energy and the electrical-to-thermal ratio. This ratio was assumed to equal 4, considering the energy market in Iran.

RESULTS AND DISCUSSION

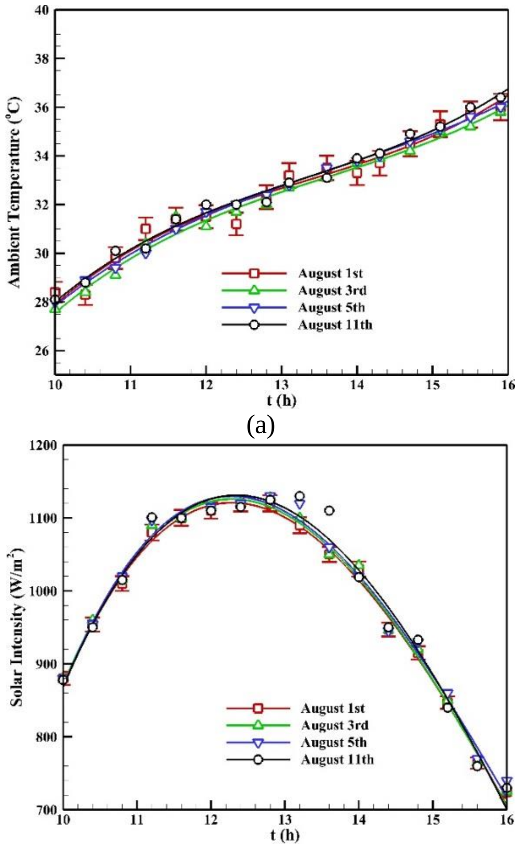
The current study analyzes the thermal performance of the constructed SAHs using numerous covering strategies. Hence, using a suitable covering strategy is a feasible and low-cost approach for improving the heat dynamics of SAHs without any requirement for sophisticated technical changes. Environmental conditions have a critical role in the dynamics of SAHs; therefore, the solar intensity and ambient air temperature were measured during the experiments. Figure 4 represents the measured ambient conditions from 10:00 A.M. to 4:00 P.M. for 6 hours. As shown in Figure 4, the solar intensity increased from 900 W/m^2 to a peak value of 1100 W/m^2 at 1:00 P.M., and then decreased to approximately 700 W/m^2 at 4:00 P.M. The mean average temperature was approximately 33 ^{o}C while increasing from 29 ^{o}C at 10:00 A.M. to 36 ^{o}C at 4:00 P.M. The environmental conditions remained unchanged for several consecutive days; therefore, an opportunity was created to evaluate the heat dynamics of the constructed SAHs at similar field conditions.

The obtained outlet temperature profile is a critical factor that specifies the performance of a SAH. In other words, at the same environmental conditions, the higher the outlet temperature, the higher the performance. Figures 5a and 5b represent the obtained outlet temperature for two air mass flow rates of 0.007 and 0.01 kg/s during the experimental runs in the single-glass, single-acrylic, and double-glass strategies.

As shown in Figures 5a and 5b, at both air mass flow rates considered, the obtained exhaust temperature in the SAHs using a single cover, including the single glass-covered SAH and the single acrylic-covered one, are lower than the outlet temperature of the SAH using a double-glass cover except at the beginning of the

Table 2. The accuracy and uncertainty of main parameters

Parameter	Accuracy	Uncertainty
Inlet Air Temperature	0.5 ^{o}C	5%
Outlet Air Temperature	0.5 ^{o}C	5%
Ambient Air Temperature	0.5 ^{o}C	5%
Solar Intensity	10 W/m^2	3%
Air Velocity	0.01 m/s	5%
Air Mass Flow Rate	N.A.	0.91%
Heat Gain	N.A.	1.87%
First Law Efficiency	N.A.	2.14%



(b)

Figure 4. Variation of the ambient conditions (a) ambient temperature (b) solar intensity

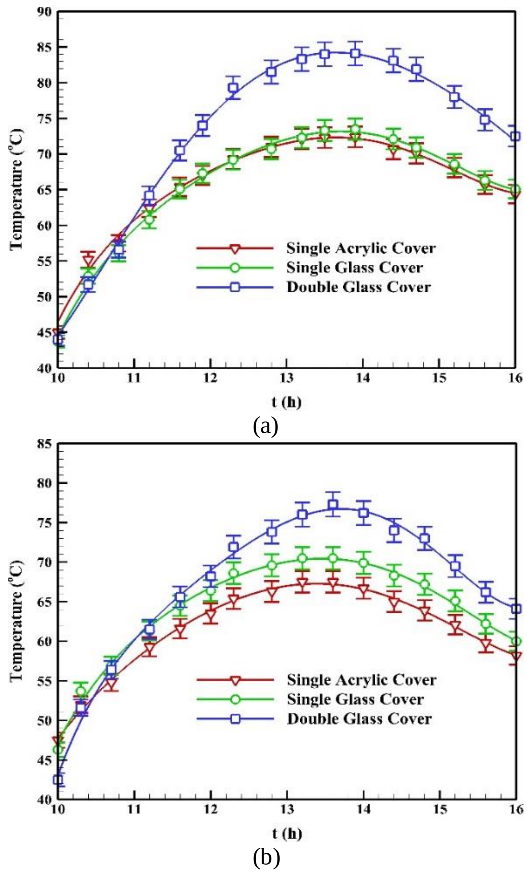


Figure 5. Variation of outlet temperatures measured in single-glass, single-acrylic, and double-glass scenarios at the mass flow rates of (a) 0.007 kg/s and (b) 0.01 kg/s

experimental tests. At the start of the experiments, the absorber temperature and heat losses to ambient environments were low. On the other hand, due to the high transmissivity of acrylic plates, more thermal energy was allowed to enter the collector. Hence, at the beginning of the tests, the single-acrylic SAH had better performance than the single-glass and double-glass collectors.

In the double-glass strategy, the air gap between the exterior and interior covers serves as an insulator. Hence, this technique reduces conductive, convective, and radiant heat losses to ambient environments and increases the acquired outlet temperature. However, increasing the cover number improves the radiant resistance to incident solar radiation, reducing input energy to the collector. As shown in Figure 5, the measured outlet temperature obtained by the double-glass SAH was lower than the single-covered ones at the beginning of the experimental runs. Since the absorber had a low temperature by starting the tests, the convective/radiant heat loss to the surroundings was also low. On the other hand, the exterior cover in the double-glass cover acted as a radiant resistance and reduced solar energy passing through the cover. This fact causes the obtained outlet temperature in the double-glass collector to be lower than the single-covered ones at the beginning of the tests.

At the air mass flow rate of 0.007 kg/s, the air residence time inside the collector was longer, and the traveling air had more time to exchange heat with the hot absorber plate. Therefore, the outlet air temperature at a lower mass flow rate of 0.007 kg/s experienced higher temperatures than the outlet temperature at the mass flow rate of 0.01 kg/s.

Figures 6a and 6b represent the obtained outlet temperature for two air mass flow rates of 0.007 and 0.01 kg/s during the experimental runs in the double-covered strategies. Two double-covered scenarios were considered in the current study, including double-glass SAH and double glass- acrylic SAH. The double glass-acrylic collector used the glass plate as the interior cover, while the acrylic plate was located on the top of the glass plate as the exterior cover. Glass plates are nearly opaque in long wavelengths, which causes a decrease in the radiant heat loss. However, acrylic plates have low thermal conductivity than glass plates, reducing the conductive heat loss to ambients. Acrylic plates are lighter and stronger than glass plates and thus more resistant to strokes. However, acrylic plates have a lower maximum service temperature, and they should be located at an appropriate distance from hot absorber plates. Hence, the acrylic cover served as the exterior cover in the constructed double glass- acrylic SAH. Interestingly, the available double-covered SAHs represent close outlet air temperature profiles at both air mass flow rates of 0.007 and 0.01 kg/s during the experimental runs.

On the other hand, acrylic plates show higher resistance to harsh environmental conditions such as dust and impacts. Using an acrylic cover as an exterior cover and a glass cover as an interior cover is an affordable technique that simultaneously increases the thermal efficiency of the constructed SAHs and extends the lifespan of the collectors. In other words, the interior cover is opaque to long wavelengths radiated by the absorber plate. Simultaneously, the exterior acrylic cover protects the interior cover from harsh environmental conditions and reduces more conductive, convective, and radiant heat losses to ambient environments.

Due to the higher transmissivity of the acrylic cover compared to the glass cover, the incident solar radiation should pass through a higher thermal resistance in the double-glass collector compared to the double glass-acrylic one. In other words, the higher the thermal resistance, the less the input solar energy. Therefore, at the beginning of daytime hours, when the absorber plate had a low temperature and heat losses to the ambient, the lower input energy caused the obtained outlet temperatures in the SAH using double-glass cover was lower than the collector using cover double glass- acrylic. This fact is clearly illustrated in Figures 6a and 6b at the beginning of the experimental runs. By increasing the

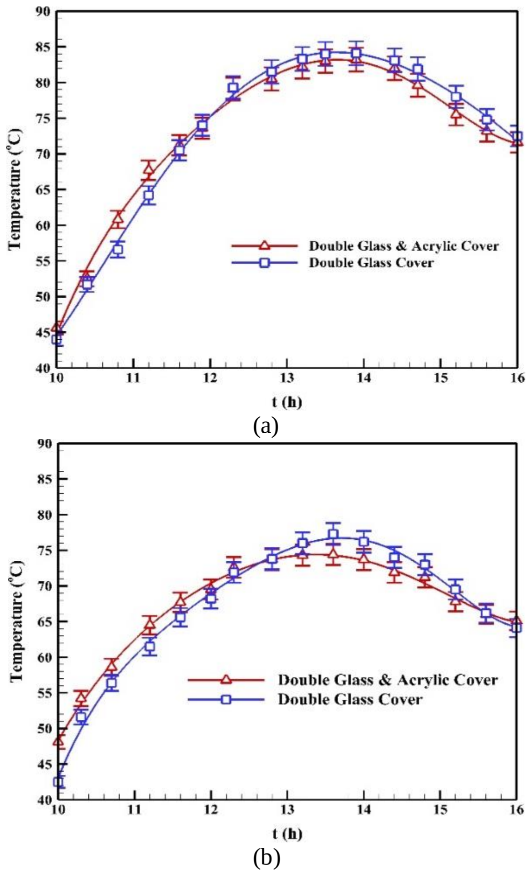


Figure 6. Variation of outlet temperatures measured in double covered scenarios at the mass flow rates of (a) 0.007 kg/s and (b) 0.01 kg/s

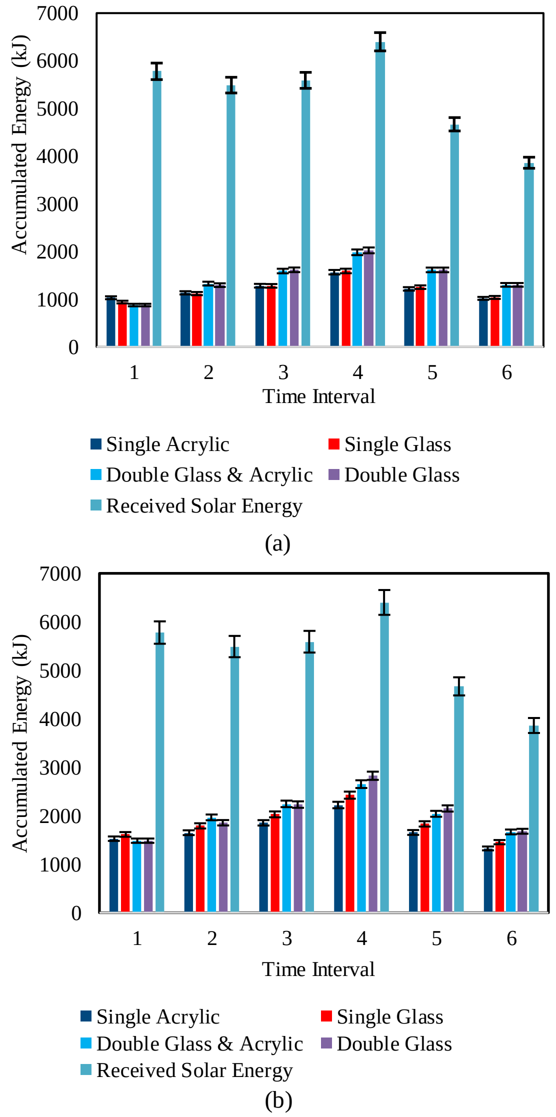


Figure 7. Variation of accumulated heat gains in different scenarios considered at the mass flow rates of (a) 0.007 kg/s and (b) 0.01 kg/s in on-hour intervals

absorber temperature, the acrylic cover caused more heat losses to ambient environments than the glass plate due to the higher transmissivity of the acrylic plate in long wavelengths.

Figures 7a and 7b show the accumulated heat gains by the constructed collectors in different scenarios for two considered air mass flow rates of 0.007 and 0.01 kg/s. As shown in Figures 7a and 7b, the double glass-covered collector has the optimum performance in heat extraction among the available collectors. However, the SAH using double glass- acrylic-cover shows close performance to the double glass-covered SAH. The received solar energy is also represented next to the accumulated heat gains by the collectors. This factor provides the chance to fairly compare the amount of heat accumulated by the constructed SAHs with the maximum possible heat gain.

It is interesting to note that the heat gains by the double-covered collectors were lower than the single-covered ones at the beginning of the experimental runs. As discussed previously, the exterior covers in the double-covered collectors improved the thermal resistance to incident solar irradiation. This caused the double-covered collector to gain less thermal energy than the single-covered ones at the beginning of the experiments when incident energy was required to heat the absorber. In other words, increasing the cover number has some drawbacks, such as increasing the thermal resistance to incident solar radiation when the absorber plate temperature is not sufficiently heated. So, the input incident energy decreases when the heat loss is not significantly high.

The accumulated heat gains and daily thermal performances in two considered airflow rates are represented in Table 3. As data summarized in Table 3, increasing the air mass flow rate from 0.007 to 0.01 kg/s, that is, by almost 50%, increased the total heat accumulation by an average of almost 40%.

Table 3 shows that the single glass-covered SAH has higher daily thermal performance than the single acrylic-covered SAH, and as was expected, the double glass-covered SAH has a daily thermal performance as high as the double glass- acrylic covered SAH. However, the acrylic plate is more resistant to harsh ambient conditions. Furthermore, increasing the air mass flow rate improves the daily thermal performance of the constructed SAH. Indeed, increasing the air mass flow rate improves the convective heat transfer coefficient and reduces air residence time and heating duration inside the collector. These factors cause two opposing effects on the air heat dynamics; however, eventually, the daily thermal performance of the constructed SAHs improves by increasing the mass flow rate.

From an economic point of view, covers only constitute a small portion of the total cost required to construct a collector. However, acrylic plates are 50% to 60% more expensive than glass plates with the same thickness. At the same time, only 8 to 10% of the total cost was allocated to the covers in the current study. Therefore, covering strategy is an efficient and cheap approach to improve collectors' efficiency.

Table 4 illustrates that using a double-glazed collector improves the thermal performance of the SAHs. Interestingly, numerous studies suggested double-glass covers; however, the current study shows the double glass- acrylic cover have approximately the same thermal efficiency, but the exterior acrylic cover is more resistant to harsh ambient conditions than the glass cover.

Furthermore, as shown in Table 4, the collectors' design, type, air mass flow rate, and coating strategy are other crucial factors that significantly affect the collector's thermal efficiency.

Table 3. Total accumulated heat gain and daily thermal performance in different considered scenarios

Collector Type	0.007 kg/s		0.01 kg/s	
	Total Accumulated Heat Gain	**Thermal Efficiency**	**Total Accumulated Heat Gain**	**Thermal Efficiency**
Single Acrylic-Covered SAH	7218 kJ	22.7%	10235 kJ	32.2%
Single Glass-Covered SAH	7246 kJ	22.8%	11148 kJ	35.1%
Double Glass-Acrylic-Covered SAH	8694 kJ	27.3%	12056 kJ	37.9%
Double Glass-Covered SAH	8728 kJ	27.4%	12228 kJ	38.4%

Table 4. Comparison between daily thermal efficiencies in different covering strategies

Reference	Air Mass Flow Rate	Glazing Strategy	Efficiency (Strategy)
Das and Chakraverty [13]	0.1 kg/s	Using single window glass (SG), double window glass (DG), and polymethyl methacrylate (PMMA)	42% (SG), 46% (DG), 36.5% (PMMA)
Giovannetti et al. [30]	0.05 kg/s	Using single-glazed and double-glazed glass coated with transparent conductive oxide (TCO)	45% (Single-glazed), 60% (Double-glazed)
Manikandan and Sivaraman [23]	0.0125 kg/s	Using single window glass (SG), double window glass (DG),	SG (49%), DG (54%)
Current Study	0.01 kg/s	Using single-glass cover, double-glass cover, and double glass - acrylic cover	Single-glass (35.1%), Double-glass (38.4%), Double glass - acrylic (37.9%)

CONCLUSION

Collector covers have different spectral transmissivities to incident solar intensity and significantly affect the heat dynamics of SAHs. Hence, the covering strategy can be a feasible, efficient, and low-cost technique to improve the thermal performance of SAHs. The current study assesses the heat dynamics and thermal performance of SAHs in different covering strategies. To this end, two SAH prototypes were constructed, and an experimental setup was developed to analyze the heat dynamics of the SAHs in the different scenarios, including the single acrylic-covered SAH, single glass-covered SAH, double glass-acrylic-covered SAH, and double glass-covered SAH. The acquired results illustrate that using the double-covered strategy increases the efficiency of the constructed SAH by an average of 5%. The double-glazed collectors obtained a 12ºC hotter outlet temperature on average. Indeed, the air gap between the exterior and interior covers serves as an insulator that reduces the heat losses to the ambient. However, the exterior cover in the double-covered collectors improves radiant thermal resistance to incident solar radiation. At the beginning of the experimental runs, this drawback is highlighted when the absorber temperature is not high enough, while solar irradiation as input energy is required to heat the absorber. In other words, the added thermal resistances by the exterior cover do not allow solar irradiation to pass through the exterior cover as input energy when the heat loss is not high due to the absorber's low temperature.

The double glass-covered has the highest daily thermal performance among the considered scenarios since the glass plates are nearly opaque to long wavelengths radiated by the hot absorber plates. However, glass covers are vulnerable to harsh ambient conditions and may be damaged. Acrylic covers are more resistant to environmental conditions, but they have higher spectral transmissivities to long wavelengths compared to glass covers. This issue is proven in the scenarios using a single acrylic or glass cover, when the SAH using a single acrylic cover shows lower daily thermal performance than the SAH using a single glass cover. The double glass - acrylic-covered collector show similar heat dynamics and daily thermal performance to the double glass-covered collector with the maximum obtained performance. Using double glass- acrylic-cover is an affordable approach to simultaneously improving collector resistance to harsh ambient conditions and boosting the daily thermal performance of SAHs. Such a method can be used in other types of collectors as well. The results obtained in this study can be summarized as:

- Increasing the mass flow rate from 0.007 to 0.01 kg/s reduces the maximum outlet temperature while increasing the daily thermal performance by approximately 10%.
- The double-glazed collectors obtained a higher outlet temperature by an average of 12 ºC than the single-glazed collectors.
- Using the double-glazing strategy improves the collector performance by an average of 5% compared to the single cover strategy.
- The double glass- acrylic-covered SAH has a close daily thermal performance to the double glass-covered SAH. However, acrylic plates as an exterior cover are more resistant to harsh ambient conditions than glass plates.

ACKNOWLEDGEMENT

The authors would like to thank Shahid Bahonar University and the Higher Education Complex of Bam for their supports.

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Persian Abstract

چکیده

شیشه به دلیل سهولت کاربری، ضریب عبور بالا در طول موج‌های کوتاه و ضریب عبور پایین در طول موج‌های بلند به شکل متداول به عنوان پوشش گرمکن‌های خورشیدی مورد استفاده قرار گرفته است. اگرچه شیشه‌ها نسبت به عوامل خارجی مانند سنگ و تگرگ آسیب پذیر هستند. صفحه‌های پلاستیکی دارای ضریب عبور بالا در طول موج‌های کوتاه و طول موج‌های میانی طیف انرژی گرمایی خورشیدی هستند. در این مطالعه یک روش تجربی برای ارزیابی رویکردهای مختلف پوششی گرمکن‌های خورشیدی شامل پوشش تک اکریلیک، پوشش تک شیشه، پوشش دوگانه شیشه-اکریلیک و پوشش دوگانه شیشه بررسی شده است. برای این منظور دو گرمکن خورشیدی هوایی ساخته شده است. آزمایش‌های تجربی نشان می‌دهند گرمگن با پوشش تک شیشه به علت ضریب عبور کمتر شیشه در طول موج‌های بلند بازتابشی از صفحه جاذب، راندمان حرارتی بالاتری نسبت به گرمکن با پوشش تک اکریلیک دارد. گرمکن‌های با پوشش دوگانه به دلیل کاهش اتلاف حرارتی جابجایی-تابشی دارای راندمان بالاتری نسبت گرمکن‌های با پوشش تک گانه هستند. اگرچه افزایش تعداد لایه‌های پوششی، مقاومت تابشی در مقابل انرژی خورشیدی را افزایش می‌دهد و راندمان حرارتی گرمکن را به ویژه در زمان‌های ابتدایی صبح که مقدار تابش و دمای صفحه جاذب کم است، کاهش می‌دهد. نتایج بدست آمده نشان می‌دهند گرمکن‌هایی با پوشش دوگانه شیشه مطلوبترین حالت پوشش است، اگرچه پاسخ حرارتی گرمکن دوگانه شیشه-اکریلیک بسیار نزدیک به پوشش دوگانه شیشه است، اگرچه پوشش اکریلیک نسبت به شیشه در مقابل شرایط محیطی سخت بسیار مقاومتر است.