Modular Building Intergraded Solar-Thermal Flat Plate Hot Air Collectors

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Abstract
In this paper three different constructions of integrated flat plate hot air collectors are build and tested. These types are: (a) integrated hot air collector utilising an aluminium foil duct (b) integrated hot air collector with internal metal separators and (c) integrated hot air collector with a mild steel square tube duct. The produced hot air can be circulated either directly in a room to raise its temperature or be blended with the air of a central Heating Ventilation and Air-Conditioning (HVAC) system to increase the temperature of the circulating air in winter. The collectors were tested in a day with no clouds. The solar radiation incident on the collector as well as the temperatures of the air at the collector inlet and outlet were recorded. The efficiency of the systems, defined as the ratio of the useful energy collected during the day over the total solar energy falling on the collector aperture during the same time, was estimated. The calculated maximum efficiency is considered as favourable with respect to existing solar collector systems. Specifically, the results show that collector type (a) gives a calculated maximum efficiency of 85%, type (b) 80% and type (c) 80%. The simplest and cheapest construction is that of type (a). All types of collectors tested can easily be mounted on a new or an existing wall (retrofitting) and the air duct can be supplied directly to individual rooms of the building or integrated together and coupled to a central unit.

1. Introduction

The Renewable Energy Framework Directive sets a 20% target for renewables by 2020. Buildings account for 40% of the total primary energy requirements in the EU [1]. Therefore, developing effective energy alternatives for buildings, used primarily for electricity, heating, cooling and the provision of hot water, is imperative.

Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance, and sustainability. Integrating Renewable Energy Source (RES) systems to the building itself offers additional advantages in that a common building component is replaced by a RES one, which reduces the overall expenses and additionally, more area is available on the building for installing the RES system.

When these systems are used, architectural and aesthetic concepts have to be addressed for a good overall result. Additionally, practical issues need to be observed, such as rainwater sealing, over-insulation with increased cooling loads in summer etc.

A lot of work was performed in academic studies investigating various types of air collectors. A review on solar air heaters with storage materials is presented by Alkilani et al. [2]. They conclude that the recent designs of solar air heaters with thermal storage units reduce the cost and the volume when integrated in one product and that latent heat storage is more efficient than sensible heat storage.

Air type solar collectors have two drawbacks since (a) the air has low thermal capacity and (b) the absorber to air heat transfer coefficient is generally low. Therefore, different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air. In their study Karim et al. [3], investigated both experimentally and theoretically flat plate, finned and v-corrugated air heaters in order to improve the performance of conventional air heaters. The experiments showed that the v-corrugated collector was found to be the most efficient collector and the flat plate collector to be the least efficient. It was shown that the v-corrugated collector is 10–15 and 5–11% more efficient in single pass and double pass modes, respectively, compared to flat plate collectors.

Romdhane [4] performed a study on solar air collectors and showed that the introduction of suitable baffles in solar air collectors increases the efficiency and the outlet temperature. Baffles, placed in the air channel situated between the insulator and the absorber play the role of wings and improve the heat transfer from the absorber to the air. In this way, solar air collectors can become as efficient as the solar water collectors and have the same efficiency. The measurements showed that the efficiency reached 80% for the best type of chicanes.

In integrating the solar collectors to the building structure Hestnes [5] mentions that the solar systems become part of the general building design. They actually often become regular building elements due to the fact that integrating the solar systems in the building envelope make the systems economically feasible. Finally, Yang and Athienitis [6] study experimentally, a prototype open loop air-based building integrated photovoltaic thermal BIPV/T system. Furthermore, they develop a numerical control volume model to simulate the system. Simulation results indicate that an added vertical glazed solar air collector improves the thermal efficiency by about 8%, and the improvement is more significant with wire mesh packing in the collector by an increase of about 10%.

2. Construction of the integrated flat plate hot air collectors

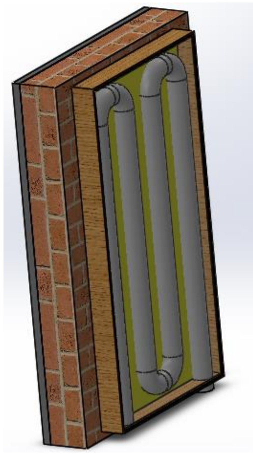
Modular intergraded solar-thermal flat plate collectors can act as a cover over a building façade or roof. As the units are modular they can be used across a range of domestic and commercial building structures and typologies. They can substitute common envelope elements in both existing or new structures and provide thermal insulation to the building. With appropriate connections, they can also provide direct thermal energy generated on site for either heating water or air and therefore can lower the energy requirements of the building.

The constructed units utilise the face of an existing brick wall, facing south. Each unit was enclosed in a frame of approximately 1.8x1 m and in the frame an insulation layer was placed on the wall, which offers insulation both to the collector and the building itself. In front of the insulation an absorbing plate was placed as well as the appropriate ducting/tubing. Finally, the collector was covered with a 5 mm thinkness glass and the system was connected to a two-speed air fan for circulating the air through the collector.

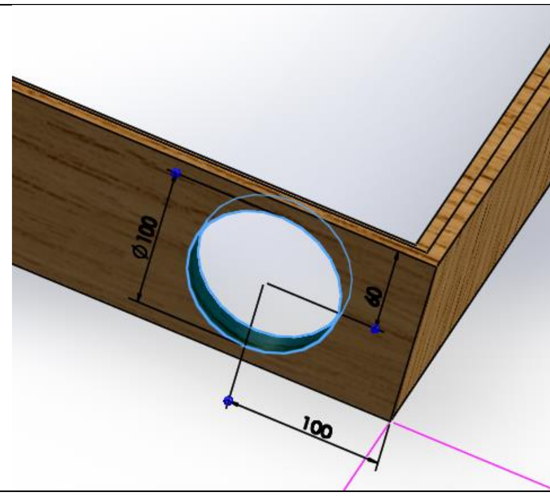
Existing building materials can act as the back plate of a flat plate collector. An integrated air collector can thus be built on a building façade or roof. Using air in ducts, the incident solar energy can be absorbed and transformed into heat. The units proposed can provide additional thermal insulation to the building, whilst producing useful amounts of hot air that could be used for the occupant needs and comfort. The hot air can be circulated either directly in a room to race its temperature or be blended with the air in a duct system.

2.1 Collector with flexible ducts

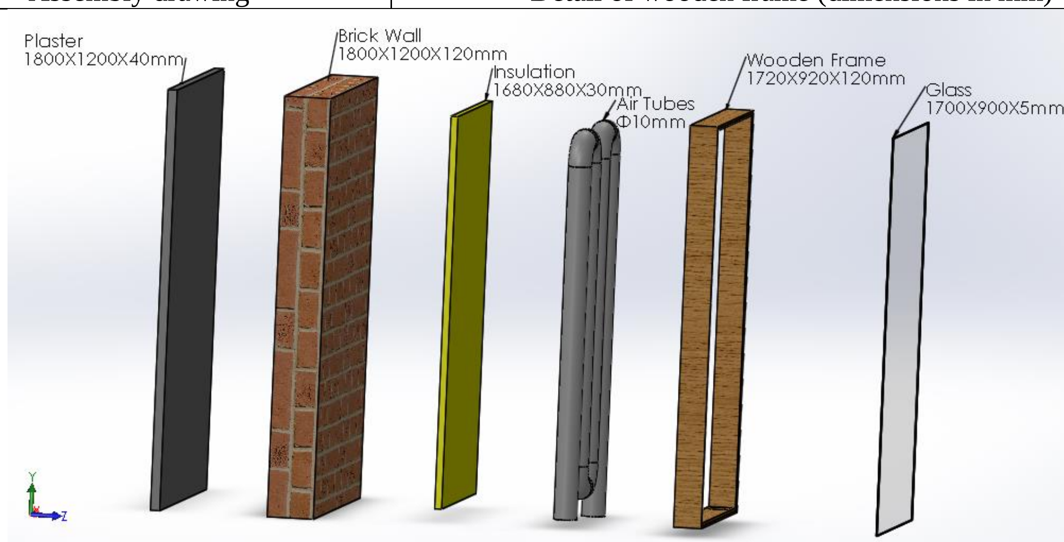
Engineering drawings were prepared for full size modules taking into account available construction and engineering material specifications and dimensions. The drawings were followed and the prototypes were fabricated according to specifications. Figure 1 shows the integrated hot air collector utilising flexible aluminium foil duct.



Assembly drawing



Detail of wooden frame (dimensions in mm)



Expanded assembly showing details

Figure 1. Integrated hot air collector utilising an aluminium foil duct

The unit was enclosed in a wooden frame, with inside dimensions 1.72 m x 0.92 m and 170 mm deep, that was mounted on a vertical brick wall 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 30 mm thick, was placed on the wall. In front of the insulation an absorbing mild steel plate was placed, 0.4 mm thick, and 5 loops of aluminum tube (6 running lengths) of 100 mm in diameter and painted black. The enclosing frame was covered with a 5 mm glass. Additionally, the system was connected to a two-speed air fan for extracting the air from the collector.

2.2 Collector with air passages

Figure 2 shows the integrated hot air collector with internal metal separators. The unit was enclosed in a wooden frame, with inside dimensions of 1.635 m x 0.84 m and 76.6 mm deep, that was mounted on a vertical brick wall 200 mm thick, facing south and covered with 40 mm plaster on the backside.

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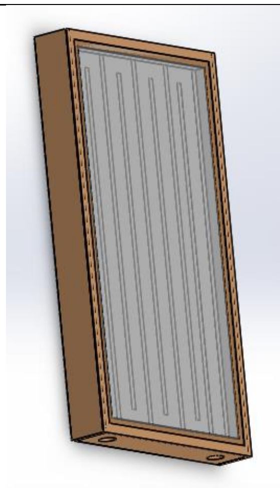
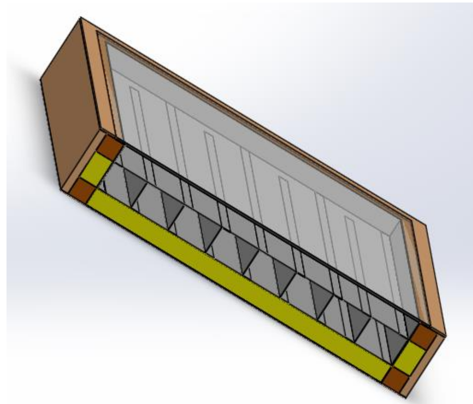
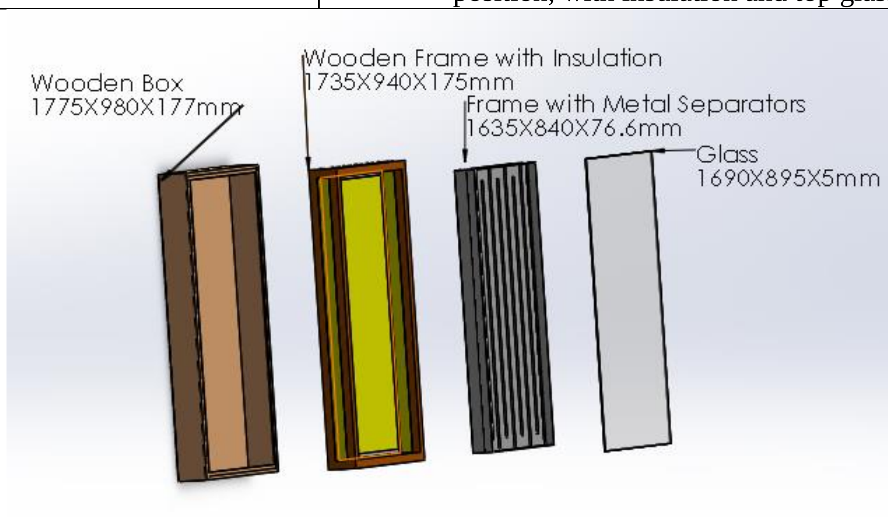
<tr><td></td><td></td></tr>
<tr><td>Assembly drawing</td><td>Section through the middle, showing separators in position, with insulation and top glass</td></tr>
<tr><td colspan="2">
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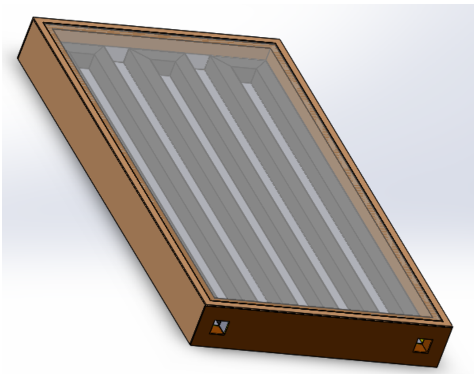
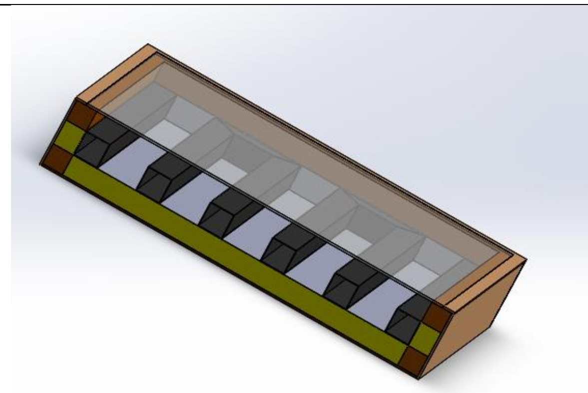
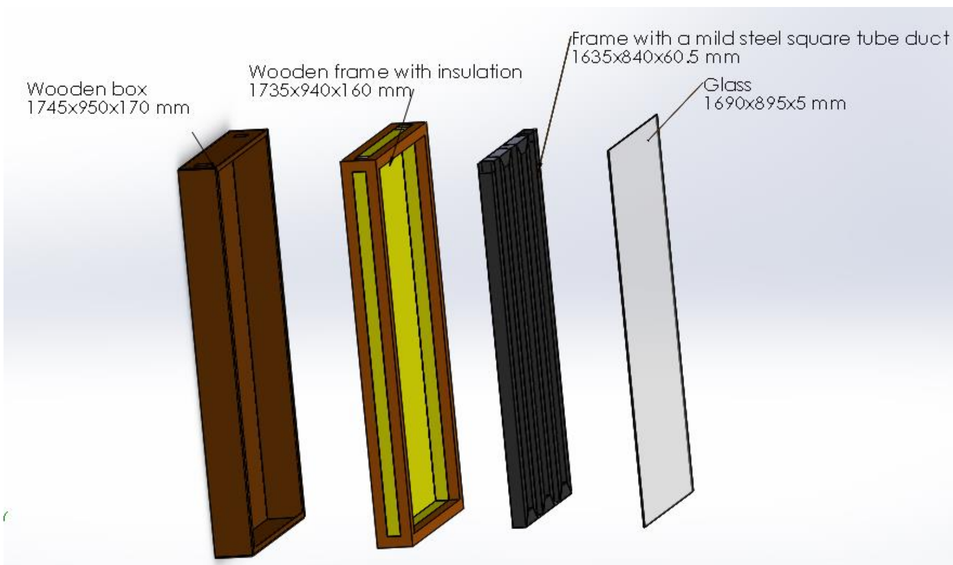
Figure 2. Integrated hot air collector with internal metal separators

In the frame an insulation layer of glass wool, 50 mm thick, was placed on the wall. In front of the insulation a mild steel plate was placed, 1.0 mm thick. On the plate seven vertical mild steel separators were glued with high temperature silicone. In this way 8 linked compartments were created, forming a continuous tube. On top, an absorbing mild steel plate 0.6 mm thick was glued with high temperature silicone. The absorbing plate was then painted black. The enclosing frame was covered with a 5 mm glass. The sites of the wooden frame in this case, were also insulated. Additionally, the system was connected to a two speed air fan for extracting the air of the collector.

2.3 Collector with rectangular ducts

Figure 3 shows the integrated hot air collector with a mild steel square tube duct. The unit was enclosed in a wooden frame, with inside dimensions 1.635 m x 0.84 m and 60.5 mm deep, that was mounted on a vertical brick wall 200 mm thick, facing south and covered with 40 mm plaster on the backside. In the frame an insulation layer of glass wool, 50 mm thick, was placed on the wall.

	
Assembly drawing	Section through the middle, showing tube sections in position, with insulation and top glass



Expanded assembly showing details

Figure 3. Integrated hot air collector with a mild steel square tube duct

In front of the insulation a mild steel absorber plate was placed, 0.5 mm thick. On the plate a continuous welded pipe, made of six vertical mild steel runs of square tube 6 cm x 6cm x 1.5mm thick, were placed. The absorbing plate and the tube was then painted black. The enclosing frame was covered with a 5 mm glass. Additionally, the system was connected to a two-speed air fan for extracting the air of the collector.

2.4 Final collectors

The various collectors were fabricated in the way described above and installed on a small brick wall constructed for this purpose. It should be noted that the wall was a simple brick wall without any finishing, as in an actual system the collector glass will be the finishing surface. Figure 4, shows the tree types of ducts inserted in the integrated hot air collectors. The small collector assemblies described above and shown in Figure 4, were constructed in order to be able to measure the performance of the collector as installed on site.

Once all parts were placed inside the frames and painted black, thermocouples were positioned at the appropriate places for monitoring the system temperatures. Finally, the units were sealed with the glass covers. Pyranometers and air flow meters were also placed in the right places for carrying out the performance tests. Figure 5, shows the monitoring instruments in position for testing the performance of the integrated hot air collector utilising an aluminium foil duct.

		
Aluminium foil duct in the integrated hot air collector	Internal metal separators in the in the integrated hot air collector	Mild steel square tube duct separators in the integrated hot air collector

Figure 4. Duct details in the three types of integrated hot air collectors

Figure 5. Pyranometer, air flow meter and temperature sensors in position for testing the performance of the integrated hot air collector utilising an aluminium foil duct.

3. Performance evaluation of the constructed prototype units

In this section the specific tested results of the three units are given.

3.1 Integrated hot air collector utilising an aluminium foil duct

The collector was tested with a mean air fan speed of 2.1 m/s. With this flow the time needed for the stabilisation of the output temperature was about 260 seconds, in which time the temperature dropped from an initial value of 48°C to a steady temperature of 45.5°C. The test was performed at an incident solar radiation of 461 W/m^2. Figure 6 shows the efficiency of the collector at this fan speed.

The same test was repeated with a low speed of 1.9 m/s. The test was performed at an incident solar radiation of 560 W/m^2. Figure 7 shows the efficiency of the collector at this fan speed.

Both results show a high efficiency of the system. As for space heating the collector draws ambient air (low temperature) which is heated in the collector and supplied in the building, the collector is very effective and can be used directly for space heating.

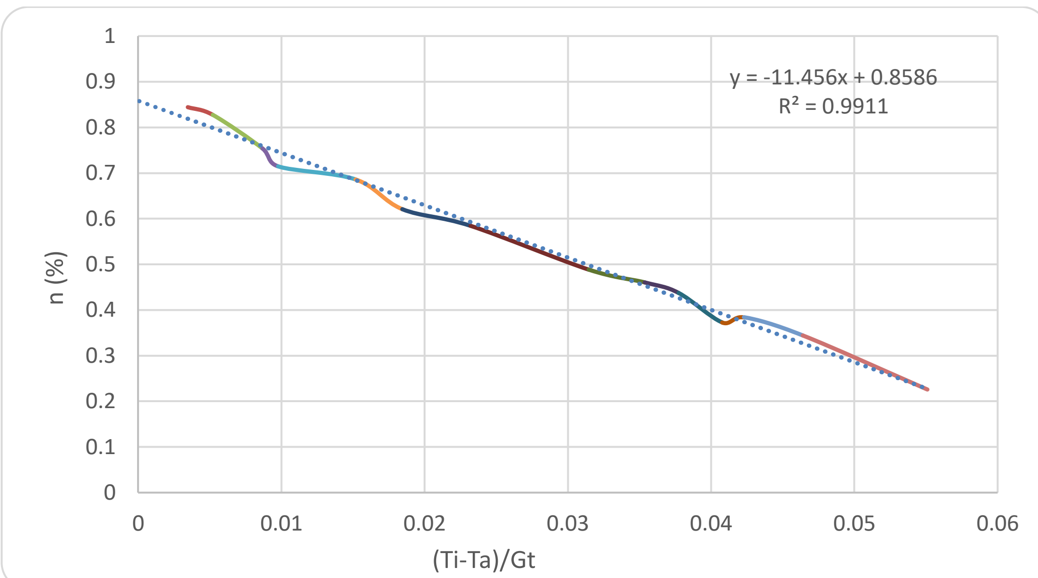


Figure 6. Efficiency of the integrated hot air collector utilising an aluminium foil duct, with a fan speed of 2.1 m/s and an incident radiation of 461 W/m^2. Abbreviations: n= efficiency, Ti= initial air temperature (°C), Ta= air temperature of environment (°C), G_t= solar radiation (W/m^2)

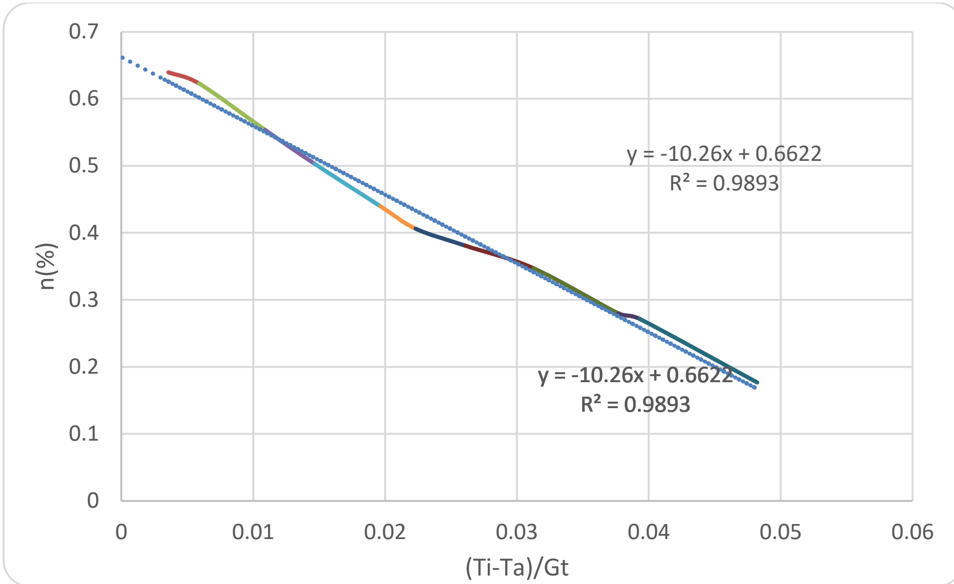


Figure 7. Efficiency of the integrated hot air collector utilising an aluminium foil duct, with a fun speed of 1.9 m/s and an incident radiation of 560 W/m^2. Abbreviations: n= efficiency, Ti= initial air temperature (°C), Ta= air temperature of environment (°C), G_t= solar radiation (W/m^2)

3.2 Integrated hot air collector with internal metal separators

In this case also, the collector was tested during a day with no clouds. The solar radiation incident on the collector as well as the air temperature of the outlet were recorded as shown in Figure 8. Together with other recordings the efficiency of the collector was estimated. Its value is high, varying during the testing period, from a minimum of 63 to a maximum of 82%. It should be noted that although the radiation was measured from 11am until 16pm the performance was measured from a smaller interval as shown.

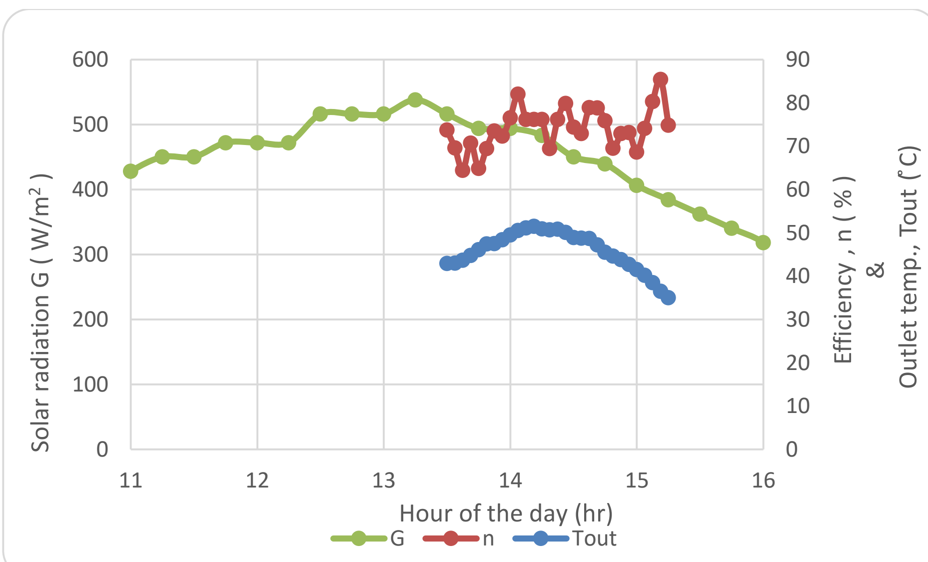


Figure 8. Efficiency of the integrated hot air collector with internal metal separators, varying during the testing period, from a minimum of 63 to a maximum of 82%.

3.3 Integrated hot air collector with a mild steel square tube duct

In this case the collector was also tested for evaluating its performance. The solar radiation incident on the collector as well as the air outlet temperature were recorded as shown in Figure 9. The efficiency of the collector was high, varying during the testing period, from a minimum of 68 to a maximum of 80%. Again here it should be noted that although the radiation was measured from 11am until 16pm the performance was measured from a smaller interval as shown.

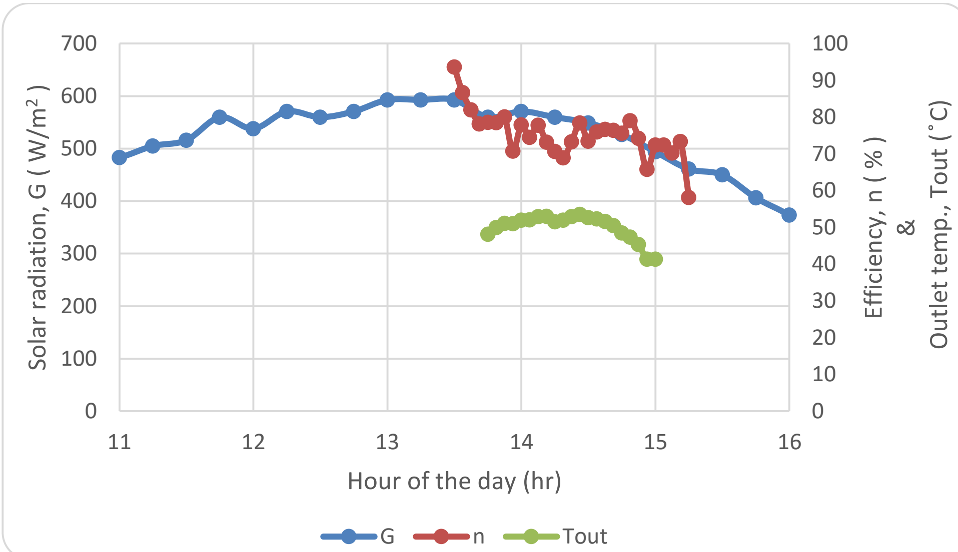


Figure 9. Efficiency of the Integrated hot air collector with internal metal separators, varying during the testing period, from a minimum of 68 to a maximum of 80%.

4. Conclusions

Hot air produced in building integrated air collectors can be circulated either directly in a room to raise its temperature or be blended with the air of a central Heating Ventilation and Air-Conditioning (HVAC) system, to increase the temperature of the circulating air in winter. In this paper three different collectors, (a) an integrated hot air collector utilising an aluminium foil duct, (b) an integrated hot air collector with internal metal separators and (c) an integrated hot air collector with a mild steel square tube duct, were build and tested. The constructed units utilise the face of an existing brick wall, facing south. Each unit was enclosed in a frame of approximately 1.8x1 m and in the frame an insulation layer was placed on the wall, which offers insulation both to the collector and the building itself. In front of the insulation an absorbing plate was placed as well as the appropriate ducting/tubing. Finally, the collector was covered with a 5 mm glass and the system was connected to a two-speed air fan for circulating the air through the collector.

The calculated maximum efficiency is considered as favourable with respect to existing solar collector systems. Specifically, the results show that collector type (a) gives a calculated maximum efficiency of 85%, type (b) 80% and type (c) 80%. The simplest and cheapest construction is that of type (a). All types of collectors tested can easily be mounted on a new or an existing wall (retrofitting) and the air duct can be joint directly to individual rooms of the building or integrated together and coupled to a central unit.

To commercialise the building integrated flat plate collectors is not difficult because of the large-scale production of the common flat plate collectors. Readymade components can easily be found and the tailored-made parts can simply be manufactured with standard industrial processes. Various materials can also be interchanged (e.g. the wooden frame with plastic or aluminium material) without affecting the efficiency.

References

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