Modular Building Intergraded Solar-Thermal Flat Plate Hot Water Collectors

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Abstract

In this paper a small integrated flat plate hot water collector was built and tested. The purpose was to demonstrate its features and problems of this integration. The constructed unit utilises the face of an existing brick wall, facing south. The unit is enclosed in a frame of approximately 1.8x1 m and in the frame an insulation layer was placed on the wall, which provides insulation both to the collector and the building itself. As in conventional flat plate collectors, in front of the insulation an absorbing plate was positioned as well as the appropriate header and riser assembly for the water circulation. Finally, the collector was covered with a 5 mm glass and the system was connected to a hot water insulated tank for storing the hot water. The collector was tested during days with good solar radiation. The solar radiation incident on the collector the ambient temperature, as well as the temperatures of the water inlet and outlet during the day, were recorded. The efficiency of the system, defined as the ratio of the useful energy collected over the total solar energy falling on the collector aperture during the same experimental time, was estimated. Furthermore, a second experiment was carried out under stagnation conditions for the measurement of the maximum temperatures the system can attain, which could create fire issues. The calculated maximum efficiency for the system is 56% and is considered as favourable with respect to existing solar collector systems. The collector tested can easily be mounted on a new or an existing wall (retrofitting). Specific solutions for the required piping to and from the collector were also studied. These show that the piping does not present specific difficulties and in co-operation with the architects, the piping can easily be concealed in the construction.

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. One way to reduce fossil fuel dependence is the use of renewable energy systems (RES) which are generally environmentally benign. In some countries, RES and in particular solar water heating are used extensively. The benefits of such systems are well known but one area of concern has been their integration. Most solar components are mounted on building roofs and they are frequently seen as a foreign element on the building structure. Due to this fact alone and irrespective of the potential benefits, some architects object to this use of renewable energy systems. It is therefore necessary to find ways to better integrate solar systems within the building envelope, which should be done in a way that blends into the aesthetic appearance and form of the building architecture in the most cost effective way.

The Energy Performance of Buildings Directive (EPBD) requires that RES are actively promoted in offsetting conventional fossil fuel use in buildings. A better appreciation solar thermal systems (STS) integration will directly support this objective, leading to an increased uptake in the application of renewables in buildings, which is expected to rise dramatically in the next few years. This is further augmented by the recast of EPBD, which specifies that by the year 2020 the buildings in EU should be nearly zero energy consumption. Meeting building thermal loads will be primarily achieved through an extensive use of renewables, following standard building energy saving measures. STS are expected to take a leading role in providing the thermal energy needs respectively, as they can contribute directly to the building heating, cooling and domestic hot water requirements.

Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance, and sustainability. The systems that are usually employed in buildings are photovoltaics and solar thermal collectors. Photovoltaics can supply the electricity required to the building or the generated electricity can be fed/sold to the grid. Solar thermal systems can supply thermal energy for space heating, cooling and the provision of hot water for the needs of a house/building.

The advantages of building integration of STS are that more space is available on the building for the installation of the required area of the STS systems and that the traditional building component is replaced by the STS one, which increases the economic viability of the systems. In the case that this concept is employed, coupled with aesthetic and architectural challenges of building integration, many practical issues need to be resolved; such as rainwater sealing and protection from overheating (avoiding increased cooling loads during summer). As STS are latitude dependant, with respect to façade application and solar incidence angle effects, these needs to be considered as countries near the equator have high incidence angles (the sun is higher on the sky) but more energy is available compared to higher latitude countries.

The adoption of building integration of STS can fundamentally change the accepted solar installation methodologies that affect residential and commercial buildings throughout the world. Maybe the single most important benefit originating from this idea is the increased adoption of STS in buildings.

Various researchers presented building integrated solar thermal systems of various forms. A new concept of flat plate solar collector is presented by Motte et al. [2]. Its originality comes from its remarkable shape and from its integration into a rainwater gutter. The complete solar collector consists in several short modules connected serially. The same authors published in [3] the modelling of the system.

Zhang et al. [4] presented a review of building integrated solar thermal systems, whereas Hassan and Beliveau [5] presented the design, construction and performance prediction of integrated solar roof collectors using finite element analysis. Finally, Shia et al. [6] presented how solar water heating systems can be integrated in high-rise apartment in China.

All types of buildings either residential, commercial or industrial should provide hot water for the occupant needs. Generally, the temperature for these needs does not exceed 50-60°C but depending on the use, large quantities may be required. In multi-storey buildings where there is a large number of occupants, adequate separate roof area for each owner, needs to be allocated for collectors and storage devices and for high buildings, even if this is available, the heat losses through the long pipes would be very problematic. A solution to this shortage of roof area and pipe losses, is to use Modular Building Intergraded Solar-Thermal Flat Plate Hot Water Collectors, that could use the appropriate wall areas and also serve as a design and construction element for reducing the material cost of the building.

A solar thermal collector can be installed on the facade of buildings. I such a case the collector consists of the usual parts found in stand-alone systems without the casing and the whole construction is set up in front of the brick of the normal wall. A good insulation is used to avoid transferring unwanted heat into the building, especially during the summer months. In view of the EPBD, which requires also the extensive use of thermal insulation, the above solution can be considered also for retrofitting applications, as external insulation applied to the external wall surface, protected with glazing. So the only extra element required is the collection element and glazing in order to convert the system into a thermal energy collection system.

2. Modular Intergraded Solar/Thermal Flat plate collector

Existing building materials can act as the back plate of a flat plate collector. An integrated water collector can thus be built on a building façade or roof. Using copper pipes and water as a circulating medium the falling solar energy can be absorbed and transformed into heat. The units are proposed to provide additional thermal insulation to the building, whilst producing useful amounts of hot water that could be used for the occupant needs and comfort.

The constructed unit utilises the face of an existing brick wall where an extra insulation is placed on the front face of the wall. A conventional copper plate with copper pipes is positioned in front of the insulation and the unit is framed in a wooden box and covered with glass. Using the same operating principle as a flat plate collector the unit heats domestic hot water by catching and storing solar energy. The working Heat Transfer Fluid (HTF) is water, that can be stored in an insulating vessel and be used when needed. It can also be used as a circulating fluid of the heat exchanger of a hot water cylinder.

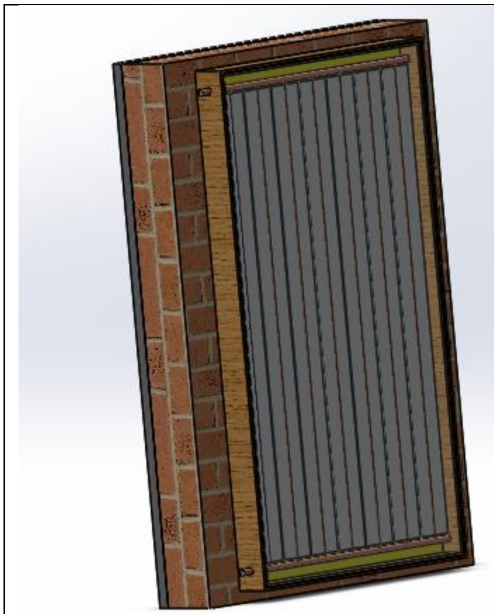
The modular façade integrated Solar/Thermal Flat plate collector, as all other similar BISTS, is designed to:

- Reduce building cooling loads in warm climates and heat loss in cool climates by providing additional insulation to the building fabric
- Provide direct thermal energy generated on site by either heating water or air and therefore lower the power requirements of the building
- Reduce the carbon footprint of the building by using renewable energy

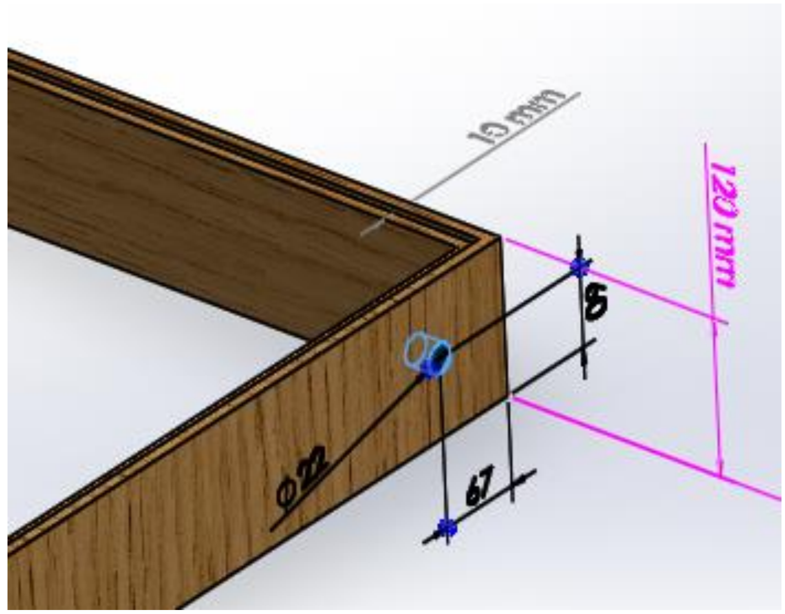
The units being modular can be used in the façade or roof of a building. These units can be used across a range of domestic and commercial building structures and typologies, substituting common envelope elements in both existing or new structures.

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 water collector drawings. The unit was enclosed in a wooden frame, with dimensions 1.72 m x 0.92 m and 120 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. The absorbing plate consists from seven, 1.6 m x 0.15 x 0.4 mm thick, corrugated copper strips on which 7 copper pipes of 15 mm in diameter were welded. The absorber was placed in front of the insulation and covered with a 5 mm glass. In this case the system was connected to a hot water cylinder allowing the system to work with natural convection. Figure 2 shows the prototype construction of the integrated hot water collector.

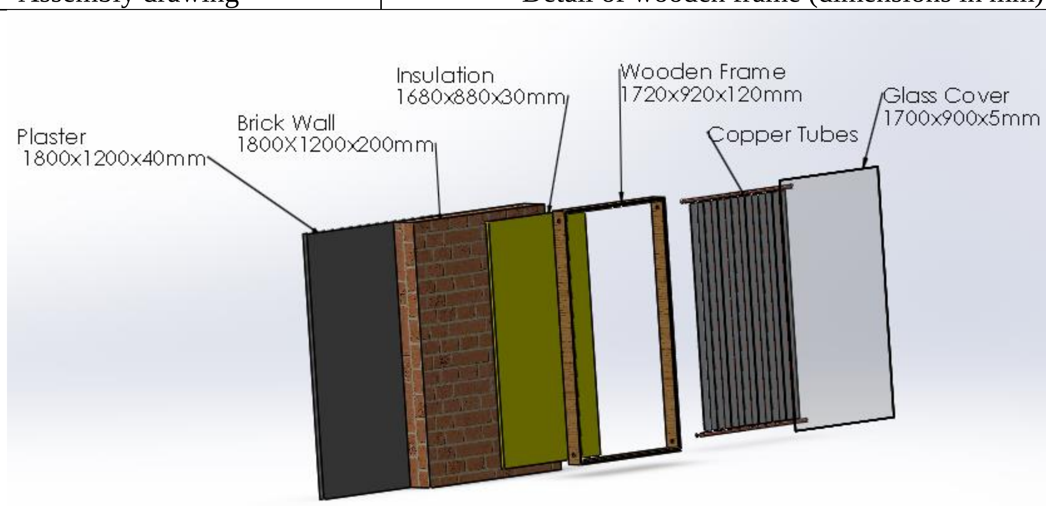
Once all parts were placed inside the frame and painted black, thermocouples were positioned at the appropriate places for monitoring the system temperatures. A pyranometer and water flow meters were also placed in the right places for carrying out the performance test.



Assembly drawing



Detail of wooden frame (dimensions in mm)



Expanded assembly showing details

Figure 1. Engineering drawings of the Modular Intergraded Solar/Thermal Flat plate collector

Figure 2. Prototype construction of the integrated hot water collector

3. Efficiency of the constructed prototype unit

In this section the tested results of the integrated hot water collector are presented. The collector was tested during a day with ample radiation. The solar radiation incident on the collector as well as the temperatures of the collectors were recorded as shown in Figure 3.

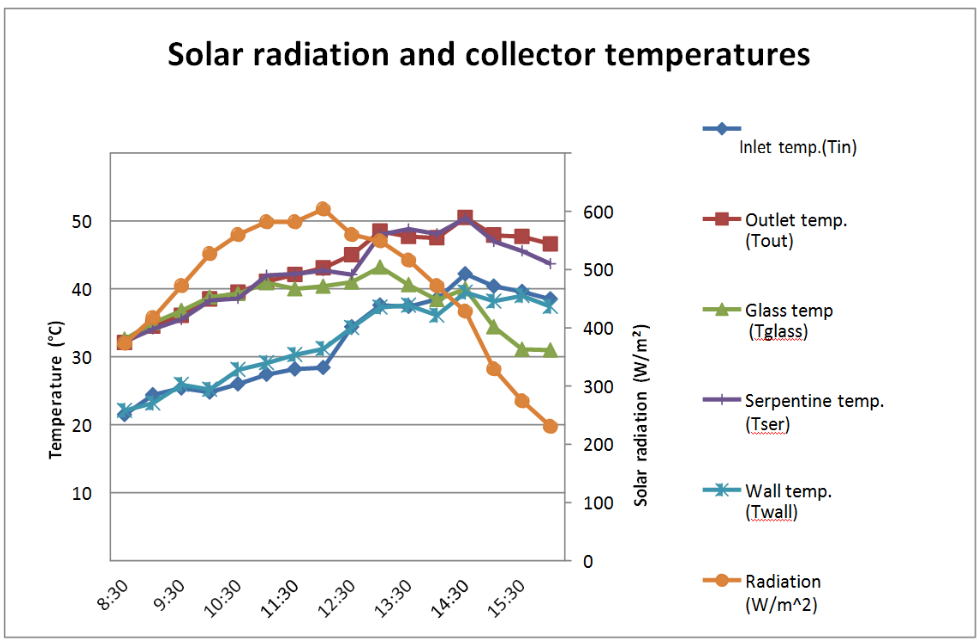


Figure 3. Integrated hot water collector. Solar radiation and collector temperatures during the test hours of the day

The efficiency of the system is defined as the quotient of the useful energy collected during the day over the total solar energy falling on the collector during the same time. The collected useful energy stored was calculated to be 8952 KJ. The total energy incident on the area of the collector during the testing time (from

8:30 to 16:00) was 16180 KJ. The calculated efficiency thus, is 55.7%, which is considered as favourable in respect to existing solar collector systems. It should be noted that the system tested works thermosiphonically (without a circulating pump).

Furthermore, a second experiment was carried out under stagnation conditions for the measurement of the maximum temperatures the system can attain, which could create fire issues.

For this reason, a gate valve was fitted on the collector water outlet and the temperatures at the back side of the insulation (T_{ins}), the temperature of the absorbing plate (T_{ab}) and the temperature of the front glass (T_g) were recorded. The results are shown in Table 1. The maximum recorded temperature is 60.1 °C, showing that there is no danger of fire resulting from this construction.

Table 1. Recorded temperatures (°C) under stagnation conditions, at various parts of the collector.

Time	Back of insulation - T_{ins}	Absorber plate -T_{ab}	Front of glass - T_g
9:00	23.2	39.2	27.4
10:00	39.2	71.2	39.1
11:00	50.4	89.5	46.8
12:00	54.0	100	50.7
13:00	60.0	99.6	48.3
14:00	60.1	97.5	48.4

4. Modular configuration

The operation of the building integrated flat plate collectors was conceived to be modular with the configuration of the units in either series or parallel. Figure 4, shows an example of how a set of two coloured flat plate collector array can change the appearance of a building facet and Figure 5, shows one of the possible interconnections of the building integrated flat plate collectors. The full-scale systems could provide heat tailored to a building load and occupant needs.

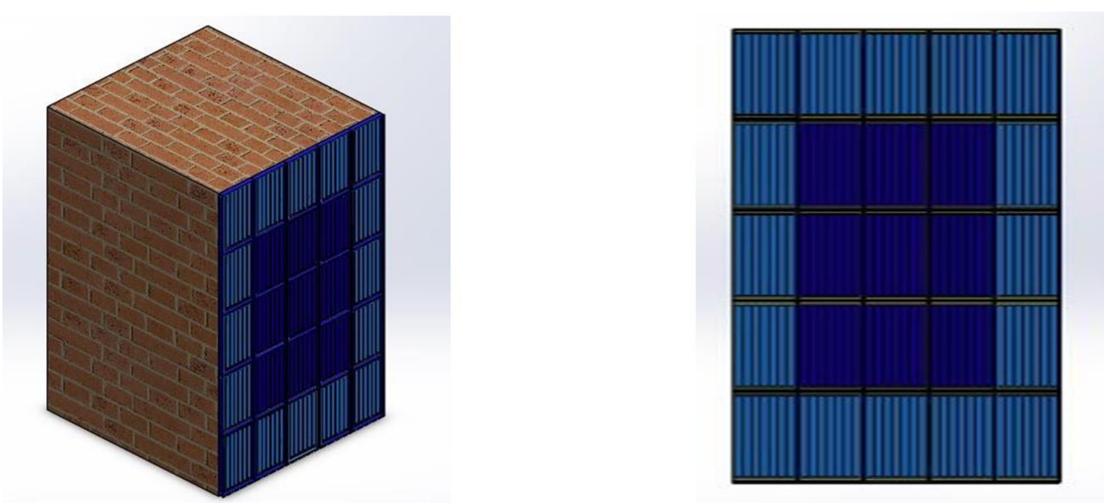


Figure 4: A system of two coloured flat plate collectors covering a building facet (side and front view).

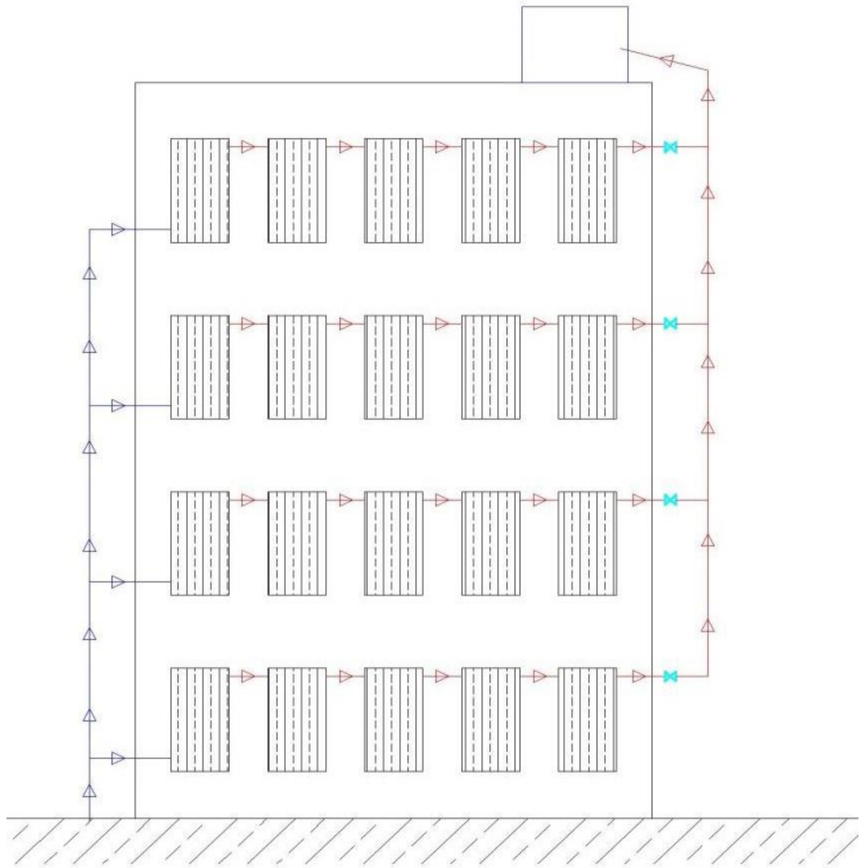


Figure 5: One of the possible interconnections of the building integrated flat plate collectors

5. Conclusions

In this paper an integrated small flat plate hot water collector was built and tested. The constructed unit utilises the face of an existing brick wall, facing south. The unit was enclosed in a frame of approximately 1.8x1 m and in the frame an insulation layer was placed on the wall, which provides insulation both to the collector and the building itself. As in conventional flat plate collectors, in front of the insulation an absorbing plate was positioned as well as the appropriate header and riser assembly for the water circulation. Finally, the collector was covered with a 5 mm glass and the system was connected to a hot water insulated tank for storing the hot water.

The collector was tested during days with good solar radiation. The solar radiation incident on the collector the ambient temperature, as well as the temperatures of the water inlet and outlet during the day, were recorded. The efficiency of the system, defined as the ratio of the useful energy collected over the total solar energy falling on the collector aperture during the same experimental time, was estimated as 55%. Furthermore, a second experiment was carried out under stagnation conditions for the measurement of the maximum temperatures the system can attain, which could create fire issues, which indicated that the construction is safe.

The collector tested can easily be mounted on a new or an existing wall (retro fitting). Specific solutions for the required piping to and from the collector were also studied. These show that the piping does not present specific difficulties and in co-operation with the architects, the piping can easily be concealed in the construction.

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.

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