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Performance assessment of an unglazed solar thermal collector for envelope retrofitting

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Abstract

Present trends on solar thermal systems for building integration define the need of integrated solar technologies for façades. Although other possibilities exist for solar thermal systems in new buildings, solutions for a suitable integration of solar thermal systems into building retrofitting actuations are needed.
This paper presents a solar thermal collector system which hybridizes already existing ventilated façade cladding systems into a low temperature solar thermal collector. Numerical and experimental data is presented.

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Keywords: Solar thermal systems; Building envelopes; Integration; Integrated Solar Collector Envelopes;

1. Introduction

The development of building envelopes in the last decades has resulted in complex engineered systems. Part of this complexity is driven by energy procurement policies, targeting at the reduction of primary energy consumption of buildings, which also results in reduced energy costs.

Energy-related materials and technologies have been integrated, into building envelopes, which can be classified in two main paths: Energy conservation, and energy collection. Energy conservation measures target at the reduction of heat transfer across envelopes and other related passive measures, which ultimately reduce Heating, Ventilation

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and Air Conditioning (HVAC) energy needs in buildings. Energy collection covers technologies which harvest energy from various local sources, thus reducing the primary energy consumption of the building. Technologies such as ground source heat pumps, solar photovoltaic, and solar thermal systems can be classified in this last category.

When related to solar thermal systems, their integration in envelope systems is commonly limited by the complexity of its integration possibilities with other elements in the building (envelope, structure, systems, etc.). Furthermore, due to their aesthetic relevance in the overall design of the building, a purely engineered approach, is often in conflict with the architectural expression of the building. To the authors' belief, there is currently a small and limited variety of solutions for the architectural integration of solar collectors within façades, which together with their complex assembly process and high investment costs, are clear barriers to the generalization of solar thermal technology in building skins.

Within project BATISOL [1], an innovative solar thermal system is proposed, where solar collector units are designed as hybridized construction components without functional or formal differences when compared to their traditional counterpart.

This paper discusses results from ongoing research projects exploring strategies to integrate and/or hybridize solar thermal technology into building envelopes. A numerical and component-level performance assessment is performed.

2. Solar thermal technology

The final overall performance of a solar thermal system relates not only to the solar thermal collector, but is impacted by all elements in the solar system, and even by the heating loads in the building served by the system. The overall design of the system ultimately impacts on the performance of the system, and it must be performed considering building user needs, their energy consumption profile, and the fluctuation of the available solar energy. Thermal storage must be incorporated and sized accordingly in order to compensate for the seasonal discrepancy between supply and demand.

Several experiences from the field demonstrate that combined solar systems, if properly sized, provide a relevant increase in overall system efficiency. In [2] experience from simulation resulted in a CoP 30–40% higher than for regular air-source heat pumps. Within the 2Sol system, developed at ETH Zurich [3], low-temperature input from photovoltaic/thermal collectors is used to regenerate a seasonal ground heat storage, reaching a CoP above 8 in new buildings, and above 6 in retrofit [4].

Solar thermal systems are complex devices which absorb, transfer and store solar energy. Solar collectors themselves are only capable of performing the first of these functions, where a fluid is commonly used to transfer the absorbed heat to other elements in the system. Various solar collector technologies are available within the building HVAC framework, which perform differently. For a given solar radiation level and ambient temperature, performance is characterized by the average fluid temperature. Therefore, the efficiency of solar thermal collectors can be broadly defined according to their type (Fig. 1). Main technologies are vacuum tubes, glazed flat plate collectors and unglazed collectors.

In high temperature applications, vacuum tube collectors are the main technology. These collectors are composed by a set of glass tubes where an absorber is suspended and insulated within vacuum cavities. Within the reviewed alternatives, the most successful integration strategies incorporate the glass tubes into the design, at balcony parapets or similar locations.

Glazed flat plate collectors are the most commonly used technology in buildings. In this case, the absorber plate is insulated by a glazed assembly in its surface, and a rear insulation layer. A number of integration solutions for flat plate collectors are available in the market, commonly linked to specific cladding systems or lightweight façades.

Unglazed collectors are the simplest technology of solar thermal collector, consisting only on an absorber that can be either metallic or polymer-based. Unglazed collectors are only sufficiently performing for applications that deliver fluid at lower temperatures. Currently, they are typically used for swimming pool heating systems, low temperature space heating or pre-heating of domestic hot water.

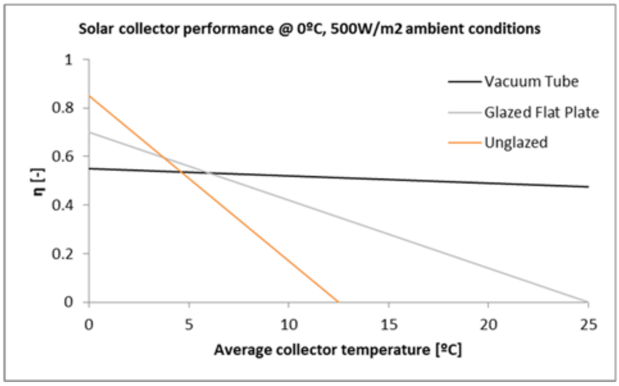

Fig. 1 Efficiency of solar collectors depending on collector temperature for given ambient conditions.

The efficiency of thermal systems is mostly related to the temperature at which heat is delivered. For combined solar thermal systems, those designed and sized to minimize high temperature needs commonly succeed in achieving better overall energy output of solar panels. For a given technology, energy output is mainly related to solar gain (related to solar radiation), and heat loss (related to a collector-ambient temperature gradient). Solar systems with reduced collector temperature perform with reduced heat loss, resulting in greater energy output.

In broad terms, the temperature of a solar heating system in a building is related to the services covered by this system. Figure 2 contextualizes the service temperature of a HVAC system. For heating applications, Domestic Hot Water systems require high temperatures, while space heating applications can be supplied with various service temperatures depending on the type of terminal units. Other types of heat use such as pool heating and domestic hot water heating are serviced at temperatures close to their set service temperatures. For the case of solar cooling systems, temperatures commonly above 100 ºC are recommended for thermally driven chiller systems.

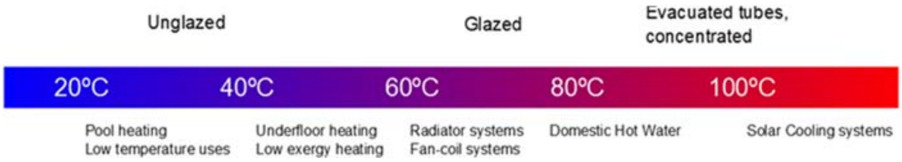

Fig. 2 Temperature levels of solar collector technologies, compared to HVAC services in buildings

Unglazed collectors are limited in their operational temperature by their relatively high heat loss. Nevertheless, this technology presents opportunities regarding their integration into flat envelope components. Their relatively low operational temperature (Fig. 2) imposes the use of heat pumps, storage tanks and/or other auxiliary devices in order to ensure that delivered fluid temperatures suit space heating or domestic hot water loads in the building.

3. Architectural impact of solar technology in building skins

Technical barriers are still relevant for the massive adoption of solar thermal technologies in building envelope projects. However, to the authors' belief, the main issues limiting the adoption of building integrated solar thermal systems are not technology-related. Aesthetics and adaptability to each specific building project are key issues. The implementation of solar systems requires a large envelope surface, resulting in a noticeable impact in the architectural expression of the building. Regarding their level of integration in the buildings, there already are systems with different degrees of integration, which can be classified as follows:

- Addition to the envelope: No consideration is given to the impact of thermal systems on the architectural quality of the building. Solar collectors are engineered as standalone elements and mechanically assembled over the building envelope. The system does not include a solution for its connection to the elements and systems of the building.

- Integration in the envelope: Solar thermal systems are integrated within modular structures such as cladding systems or curtain walls, allowing for some dimensional flexibility in order to match the grid and composition of the façade. Collectors are usually glazed, and designed to conceal pipework and connections.
- Hybridized envelope: Façade assemblies are hybridized with active thermal systems, by incorporating unglazed solar collectors within external renders and claddings. A neutral aesthetic impact is achieved, where users cannot differentiate between hybridized and ordinary building skins. These solutions are commonly combined with advanced HVAC systems, in which solar systems are connected with thermal storage, heat pumps, and/or low energy delivery systems such as radiant floors or thermal mass activation.

Despite the availability of an increased number of solutions for the architectural integration of solar systems, these are still not widespread in the solar collector market. Most solutions result in a technification of the appearance of the façade, as only glazed or metal finishes are available. An extensive research on the architectural integration of solar systems in façades was carried out in [5].

In recent years, several research projects have been targeted at achieving hybrid building envelope solutions, with active envelopes within systems with neutral aesthetical impact. Within [6] a steel façade cladding system was adapted for the integration of water-based capillary tubes on its internal side. Within [2] a façade system was developed based on external thermal insulation systems, in which capillary tubes were integrated within the external render finish, coupling the system with a heat pump for decentralized space heating.

Fig. 3 Capillary tubes within a render finish [2]

4. Proposed Unglazed solar collector design

An unglazed solar thermal collector has been designed within project BATISOL. At the same time, this collector has been conceptualized as a cladding tile compatible with ventilated façade substructures. The pursued target was the total integration with metallic cladding systems such as composite Aluminum-plastic components.

The BATISOL collector is composed by an absorber surface coated with a selective paint, a plastic body, where circulation channels are carved, and hydraulic connections. Although various dimensions are possible, 1200mm x600mm and 1000mm x500mm configurations are the most suitable dimensions due to architectural compatibility with similar cladded systems.

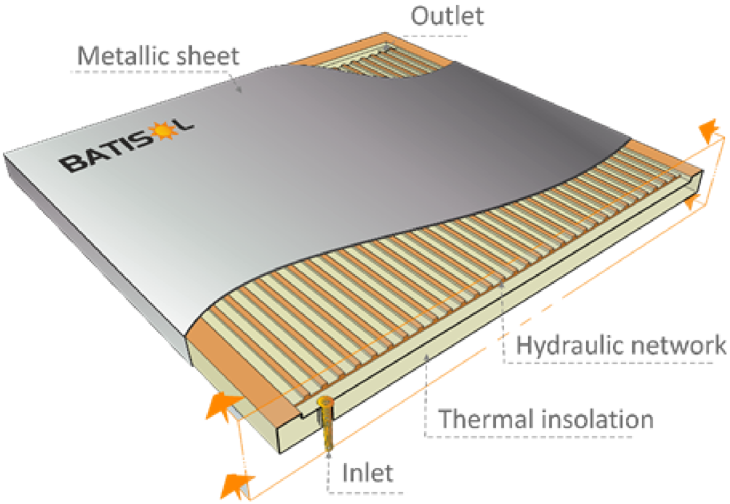

Fig. 4 Conceptual design of the BATISOL collector

5. Numerical performance assessment

Several numerical models were generated to evaluate the performance level of the solar collector under various assumptions. The selected numerical code for this work was COMSOL [7]. 2+1D and 3D models were conducted.

In the 2+1D model, a 2-dimensional finite element model of the section was computed and its solar absorption and heat loss obtained. These parameters were then applied over a fluid line of a given length, and the results calculated for various pipe lengths. Figure 5 presents the cross section of the modelled geometry.

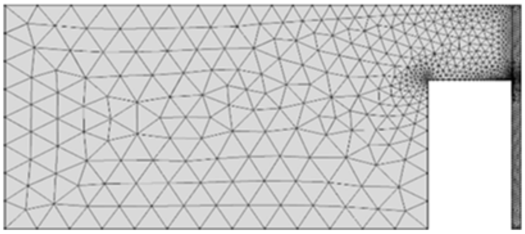

Fig. 5 2D Finite element model of one channel of the BATISOL solar collector

The 3D model consisted on a full finite element model of the collector. No relevant difference between these two modelling approaches was found in the results, and the 2+1D approach was used for the numerical study.

In order to assess the relevance of each of the design variables, a sensitivity study was conducted based on the MORRIS methodology [8-10]. Table 1 depicts the relevance of each parameter.

Table 1. Influence of parameters.

Parameter	Influence		
	Thermal performance	Weight	Head loss
Thickness of metal absorber	0.03	0.15	0
Thickness of body	0.85	1	0
Length of channel in series	0.85	0.01	0.4
Depth of channel	1	0.01	1
Distance between channels	0.57	0.01	0

The thickness of the absorber was found to be of little influence in the thermal performance of the collector, while the thickness of the body was found to be relevant due to its role as insulator in the rear face of the collector. The geometry of the channels was found to be critical, especially its depth, as it impacts in the equivalent hydraulic diameter, and the resulting convective heat transfer coefficient.

The performed sensitivity study allowed to select a geometrical design which was prototyped for experimental assessment. In table 2, the performance of this geometry is shown for various surface emissivity and external convection cases.

Table 2. Collector performance.

Case			Performance
Solar absorptivity, α	Surface emissivity, ε	Surface convection coefficient, W/m^{2}K	
0.6	0.2	5	0.576-7.44*ΔT/I
0.6	0.2	15	0.549-16.2*$\Delta T/I$
0.95	0.95	5	0.899-10.9*$\Delta T/I$
0.95	0.95	15	0.855-19.3*$\Delta T/I$

As it can be observed on table 2, cases representative of galvanized steel (α =0.6 ε =0.2), have a relatively smaller intercept (η=0.55) when compared to black-painted (α =0.95 ε =0.95) cases. However, for highly convective situations, the lower emissivity of galvanized steel provides a better overall performance at large ΔT/I situations.

6. Experimental performance assessment

An experimental test bench was constructed where 1000mm x350mm prototypes were experimented. The experimental test bench was constructed with a double-reservoir system, where a circulation pump circulated water to the upper vessel, with stabilized water level. The water flow control was performed by gravity-height difference between both reservoirs (~2m). Temperature and mass flow measurements allowed assessing the performance of the collectors installed in the system.

The test bench was constructed in a portable assembly for its use with SOL500 solar bulbs, or at outdoor exposure conditions. For indoor conditions the homogeneity of the irradiance was verifier by multiple radiation measurements with pyranometers.

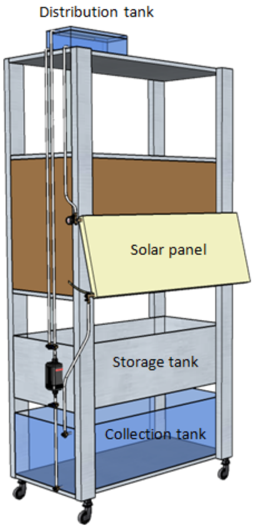

Fig. 6 Schematic of the test bench

The performance of the collector was obtained under various experimental conditions, for various prototypes. Table 3 provides an overview of experimental variables. In Figure 7, experimentally obtained performance curves are shown.

Table 3. Experimental conditions.

Surface type	Galvanized Steel, Black paint
Survace convection	No wind (estimated, 5W/m2K), moderate wind (estimated, 15 W/m2K)
Flow	8, 15, 20 and 30 l/h.
Inlet water temperature	Text, Text +5°C
Solar radiation	500 W/m².

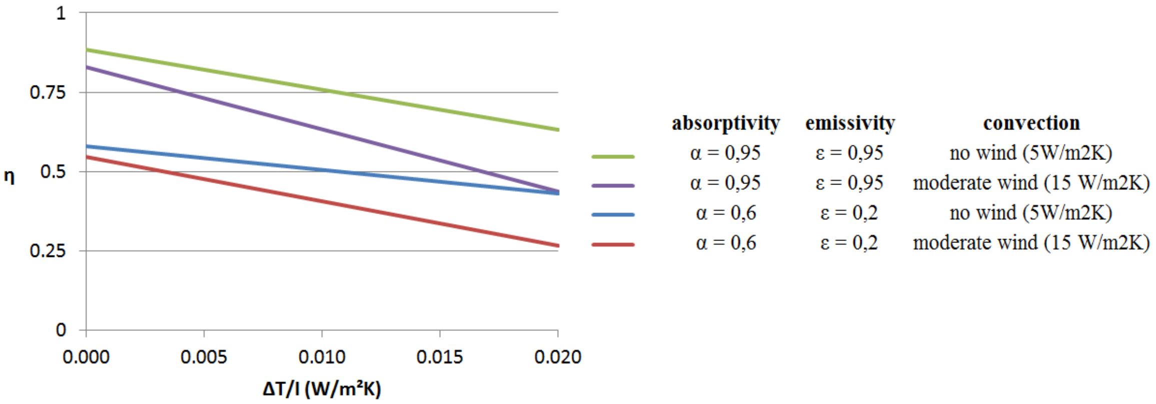

Fig. 7 Experimentally obtained performance curves of the solar thermal collector.

7. Discussion

The presented solar thermal collector system is a promising solution for low-temperature solar integration in building envelopes. Regarding its integration, it is suited for any building with metallic envelopes. Particularly buildings with ventilated façade substructure present the best integration frame for such collectors. A numerical and experimental performance assessment has been made, and the results seem to be in good agreement. The overall performance of the system results in a rapid performance reduction fort high collector temperature, and windy convective conditions. These conclusions are in good agreement with previous knowledge of unglazed solar collector systems.

Overall, the obtained performance is compatible with the intended use as heat source for heat pump systems. In these systems, the heat pump provides heat to the building, and no temperature levels are imposed to the collector field. Overall, the performance of this system will provide a stable heat source several ºC above ambient temperature, allowing for improved heat pump COP.

8. Future works

The modeling and experimental work presented in this paper defines the thermal performance of the collector system in isolation. This assessment will be complemented by a coupled system testing at full scale. This test will comprise several inter-connected envelope cladding elements connected to a combined solar thermal system, with a Heat Pump. This system will be used to heat an indoor space in an office building, and provide Domestic Hot Water to it. Approximately 20 m2 of active solar collectors will be installed and a relatively-poor insulated office of 80m2 will be serviced.

This test will serve to obtain operational performance figures of the collector, define operational temperature, validate control algorithms to avoid dangerous frosting and stain situations at façade level.

Acknowledgements

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