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Performance assessment of façade integrated glazed air solar thermal collectors

Roberto Garay Martinez[a,]*, Julen Astudillo Larraz[a]

[a] *Tecnalia, Sustainable Construction Division, C/ Geldo s/n, Edificio 700, 48160, Derio, Bizkaia, Spain*

Abstract

Present trends on solar thermal systems for building integration define the need of integrated solar technologies for façades. The integration of solar systems in façades allows for the direct connection of solar systems to heated spaces, and automated air solar collectors based on the trombe-mitchell provide a suitable technology for its adoption in multi-rise buildings with decentralized-individual HVAC systems in Central-European and Mediterranean heating dominated climates.
This paper reviews the main principles of such building envelope components, and the construction and design considerations of two air-based solar thermal collectors. Full scale preliminary prototypes of these systems were tested at the KUBIK by Tecnalia test facility in an Oceanic Climate (Koppen Geiger Cfb zone). The observed thermal performance is analyzed, and the process of a full scale installation in a real building envelope retrofitting process of a building in Spain is reviewed.

Peer-review under responsibility of the organizing committee of AREQ 2017.

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

1. Introduction

With energy efficiency and an ultimate need to reduce primary energy consumption of buildings towards sustainability, energy systems are increasing its presence in building envelopes. Solar energy systems such as solar thermal and photovoltaic systems are being implemented in buildings, boosted by energy procurement policies and user/owner will to reduce the overall energy costs in buildings.

* Corresponding author. Tel.: +34 667 178 958; fax: +34 946 460 900.
E-mail address: roberto.garay@tecnalia.com

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Solar thermal systems are commonly used as a heat source for Heating Ventilation and Air Conditioning (HVAC) systems in buildings, in such a way that the need for electricity or fossil fuels in the building is reduced. Also, a large fraction of solar energy is commonly used for Domestic Hot Water (DHW) heating. These systems can be classified as indirect systems, as solar energy flows to the building use across the HVAC/DHW system.

In direct systems, solar heat is directly used in the building, without the need for its connection to HVAC networks in the building. These systems are commonly air-driven systems, where indoor air is circulated across the collector and introduced back into the building with a certain heat gain. Depending on various possible air loops, other circulations are possible, such as heating of outdoor ventilation air prior to its introduction to the building.

In [1], a Passive solar collector module for building envelope is proposed, which provides a flexible air circulation in the collector, with up to 4 different circulation schemes (trombe wall, parieto-dynamic wall, solar chimney, ventilated façade). In this paper, two engineered solutions of this concept are detailed and their performance assessed.

Due to increased requirements in the use of solar energy in buildings, an evenly increasing building envelope surface is required. This implies that the impact of solar thermal technologies in the overall aesthetics of the building also increases. For this reason, solar systems in buildings are evolving from “technical kits” to building envelope systems. The seamless integration of these technologies in buildings is required to ensure that building owners accept their integration in their property.

The presented solution integrates the solar thermal system within a curtain wall scheme, suitable for retrofit or new-constructed buildings, which also facilitates dimensional adaptation to construction projects.

2. Air solar collectors

Air solar collectors are relatively easy constructions where solar energy is absorbed and transferred to an air stream. Depending on the particular type of collector, the air stream is forced by a fan, or created by the thermal buoyancy of the air as it is heated.

Most commonly referred solar collectors are glazed constructions, where a glass cover is used to generate a channel over the absorber. The glazing serves the dual purpose of allowing solar radiation into the collector, and insulating the collector and the heated air from outdoor conditions.

In its most simple configuration, air solar collectors are created with the erection of a glazed pane in front of a brick wall, and the perforation of venting holes on the upper and lower edges of the wall. This constructions, when installed in irradiated façades (South façades in the Northern hemisphere), will serve to heat the building. However, the performance of this system would be substantially increased with some control of the otherwise completely natural and uncontrolled ventilation. Airflow control by means of operable ventilation grilles will avoid overheating of the served building, and also cooling phenomena in cold, non-irradiated periods (e.g. winter nights).

Although the concept is relatively simple, a modern implementation of such a system should incorporate a set of properties to ensure the proper formal integration of the system in buildings, a seamless and confortable operation, and reduced user disturbance when it is installed in retrofit projects.

3. The Tecnalia passive air solar collector system

In European Patent [1], a modular passive solar collector system is presented which presents a suitable root for the development of several air solar thermal collector systems. This concept is underpinned on a high quality curtain wall Aluminum frame, where the collector is housed.

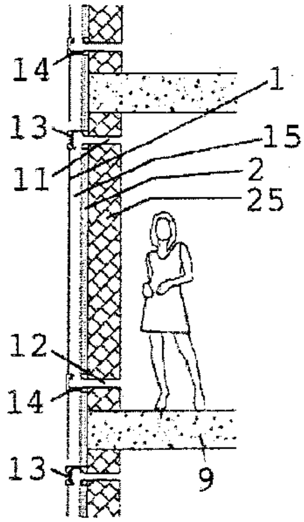

Fig. 1. Schematics of the air solar collector in a building [1].

The proposed system is compatible with a modular curtain wall system in new-built constructions, and with wall overcladding solutions in building energy retrofits. In this later case, the system is suitable for installation over unglazed walls, with additional thermal insulation of the wall.

The system incorporates a set of operable louvres where the ventilation scheme of the air channel can be modified. These louvres are three way actuators which rotate according to manual or automatic systems. Figure 2 depicts the louvre system and some of the possible ventilation schemes.

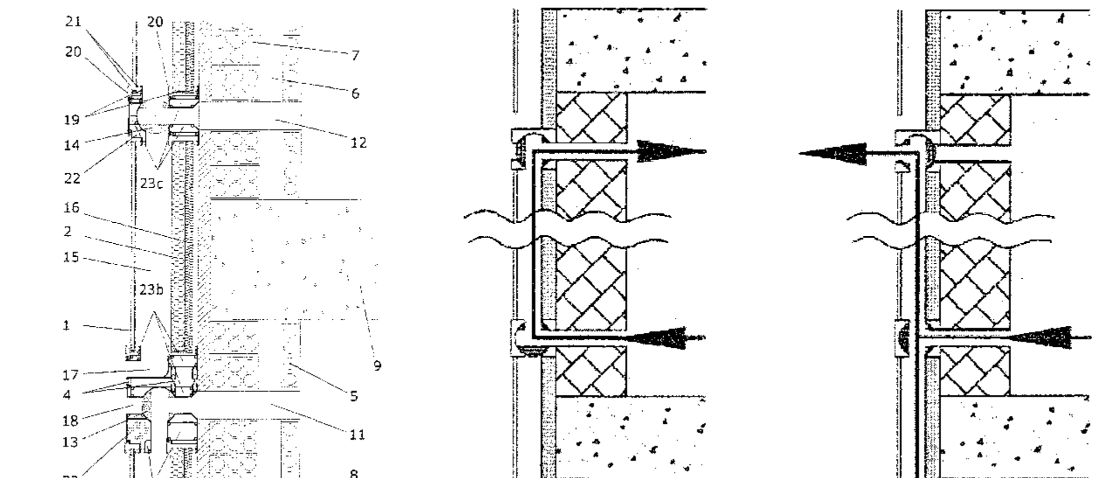

Fig. 2. (a) Detail of the T-shaped louvre system. (b and c) Ventilation schemes [1].

4. Implementations

Several implementations of this system have been produced, with variants related to the final purpose of the system, and available degrees of freedom for the design.

4.1. Common Engineered parts

Both systems are rooted in the same platform, consisting in a set of conventions. The following elements are the common key elements:

- Aluminum frame system: An aluminum frame was designed, manufactured and tested for assembly. The resulting concept is tested for structural integrity, and a manufacturing protocol is available, which facilitates to focus design on specific variables related to the thermal performance of the system and its variants. Although specific mechanical validations might be necessary, the system is validated for large dimensions, with tentative heights above 3m, and widths larger than 1m.
- Actuator system: An actuator system was defined which allows the T-shaped louvre to rotate up to 270º. Cone gears were used, and a chassis defined to allow for the integration of the louvre system, the rotation axis, and a standard HVAC rotational actuator. All the assembly is designed to fit within a tubular frame in de main Aluminum frame system. A tray for ventilation fans is also defined, based on low profile, ventilation fans commonly used for electrical cabinets.
- Louvre system: The louvre system, compatible with the previously mentioned actuator and frame assemblies. The louvre system consists on plastic rotational elements within a plastic housing. The relatively smooth assembly ensures that minimal air leaks are produced in the junctions. Based on the same assembly concept of fixed envelope and rotational core, T, I and L-shaped variants allow for different degrees of freedom in the design of ventilation loops.
- Glazing and blind: A double pane, Low-emissive glazing is used in the standard configuration; a roller blind is installed in cases where summer overheating is possible.

Figure 3 shows two phases in the assembly process of the aluminum frame, louvre system and actuator in project RETROKIT, “Toolboxes for systemic retrofitting” [3].

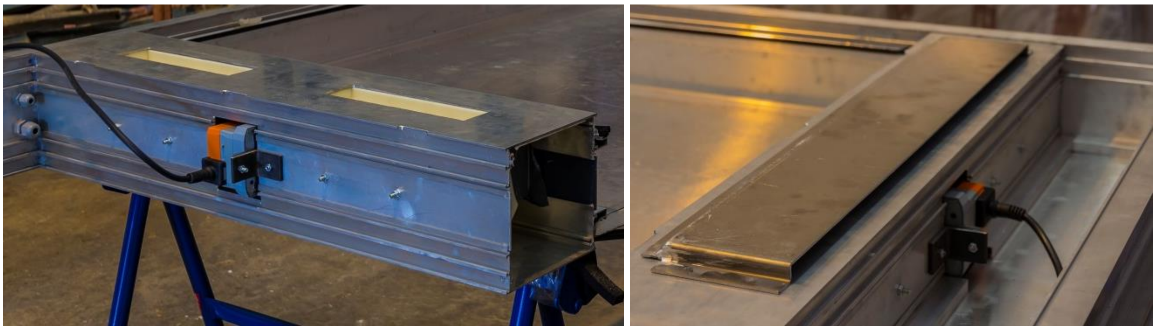

Fig. 3. Aluminum frame, louvres and actuators in the assembly process.

4.2. MeeFS air solar collector system

In EU project MeeFS, “Multifunctional Energy Efficient Façade System” [2], an air solar collector was implemented, where Phase Change Materials were installed to smooth the temperature output of the system along the day. This system is capable of providing the 4 main ventilation schemes due to its two L-shaped louvres (figure 4).

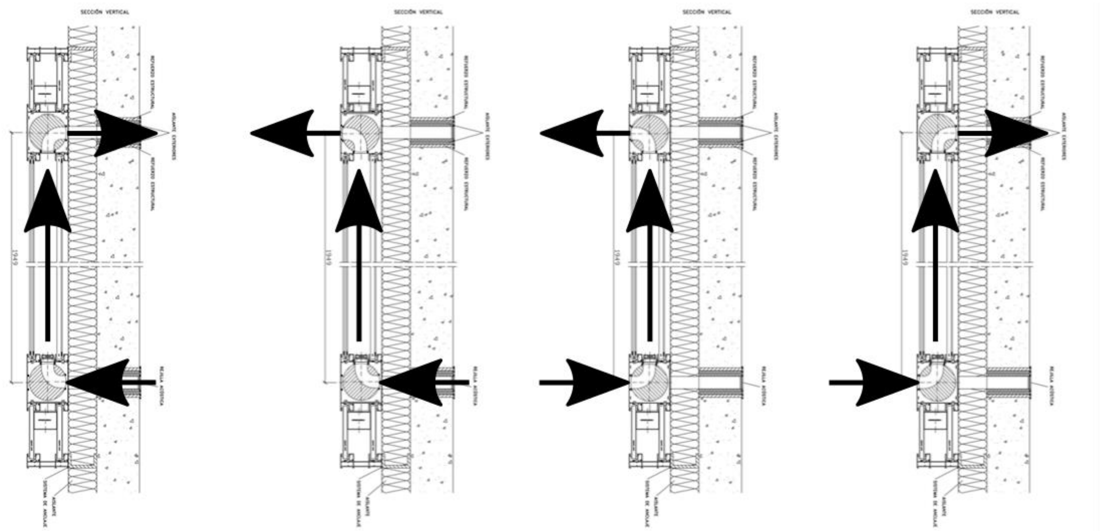

Fig. 4. Venting schemes of the air chamber in the MeeFS solar collector.

4.3. RETROKIT solar collector and ventilation module

In EU project Retrokit [3], a ventilation module was implemented with solar air pre-heating. This system is used to heat outdoor air only. This system is capable of selecting the most suitable intake to the ventilation system. One T-shaped louvre system selects outdoor air, or air from the collector according to a pre-defined algorithm.

5. Experimental assessment

The thermal performance of the systems presented in this project was tested at the KUBIK $_{\text{by Tecnalia}}$ [4] test facility within 2013, 2014 and 2015. KUBIK $_{\text{by Tecnalia}}$ is a multi-rise building aimed at realistic testing of building concepts, for which it provides a fully adaptable environment (internal boundary conditions, HVAC system layout, adaptation of building envelopes, fully customizable building automation & control). It is located in Derio, on the Atlantic coast of Spain, which exhibits a Cfb climate based on the Koppen climate classification system [5]. The Cfb climate characterizes most of central and West Europe, including the British Islands, and some locations in the Mediterranean Coast. The KUBIK test facility is designed and operated as a test facility to bridge the gap between laboratory testing and full scale deployment, and is customized on a case-by case basis to meet the specific needs of each project.

A section of the South façade of the building was used for the experimentation of both systems. The MeeFS system was installed and tested in mid 2013, while the RETROKIT substituted the previous prototype in late 2014. In figure 5, South views of the experimental collectors are presented.

(a) (b)

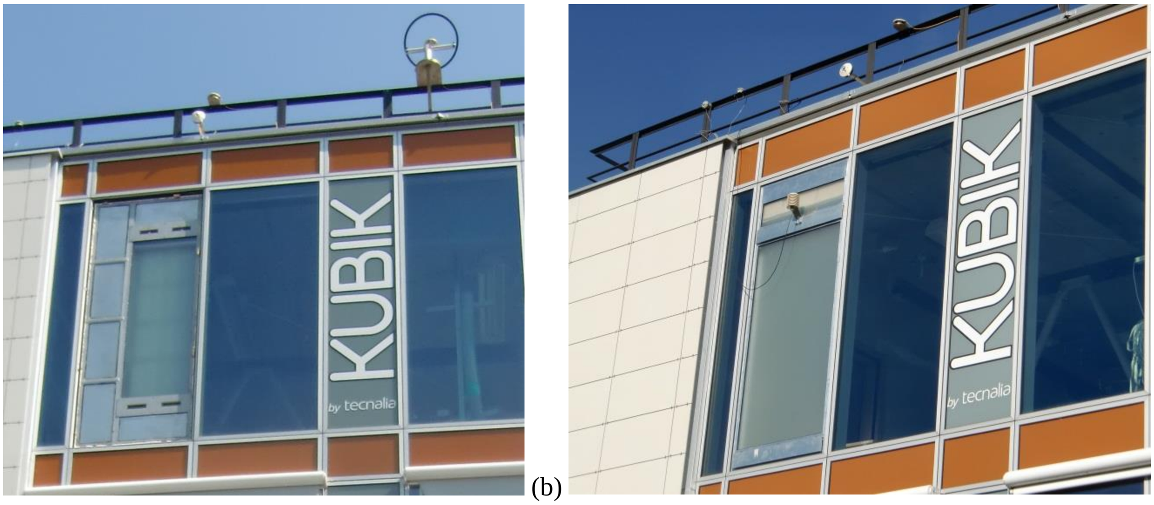

Fig. 5. Proof of concept MeeFS (a) and RETROKIT (b) solar collector modules in the South Façade of the KUBIK building

Both test set-ups were sensorized with similar criteria. Solar radiation and ambient conditions were recorded by the central meteorological station setup in Kubik. Additionally, ambient temperature was measured in the vicinity of the prototypes with local sensors. Internally, air temperature and collector surface temperature were measured at three different heights inside the solar collector. Indoor measurements consisted on ambient air temperature, radiant temperature and relative humidity. In figure 6, details of the sensor scheme used in the MeeFS experiment can be found.

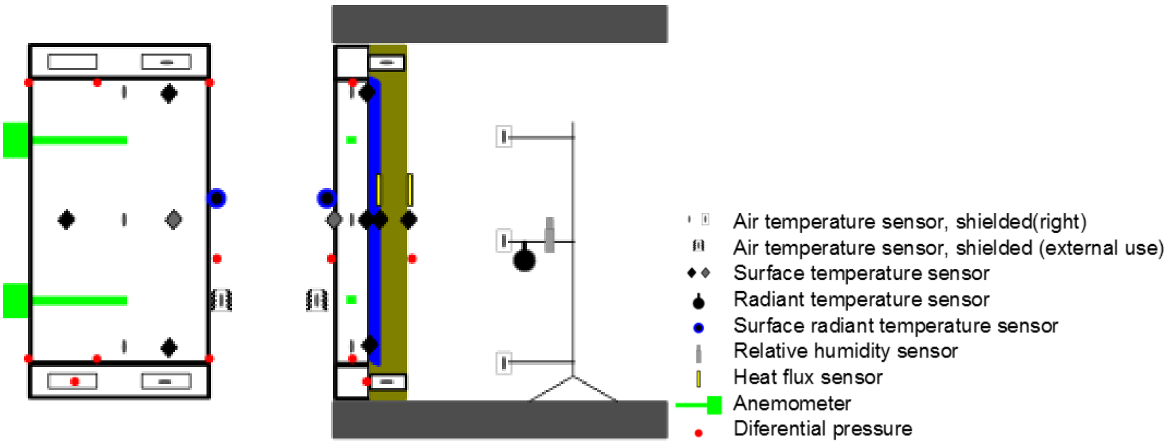

Fig. 6. Sensor scheme for the experimental campaign of the MeeFS prototype

Data was gathered with a minute frequency, and several analyses were performed. Due to different scopes in the research, different data was pursued. In MeeFS, a transfer-function-like expression was targeted, for its implementation in the control system of the product. In Retrokit, the overall possible temperature increase in the system was targeted, with different results for various moments in the day.

The mathematical expressions obtained from the MeeFS experiment is presented in (1 and 2). Two equations are required to correctly model the thermal performance of the air channel and the PCM thermal storage layer. Further detail of the research output of the MeeFS project is available in [6].

$$T_{Outlet,i} = 0.001021 * I_{Solar,i} - 0.014535 * T_{Outdoor,i} + 0.54845 * T_{Inlet,i} + 0.467655 * T_{PCM,i} \quad (1)$$

$$T_{PCM,i} = 0.003765 * I_{Solar,i} + 0.058234 * T_{Outdoor,i} - 0.242383 * T_{Indoor,i} + 0.467655 * T_{Inlet,i} + 0.718308 * T_{Inlet,i} \quad (2)$$

In Retrokit, regression techniques were used to find suitable expressions of the thermal performance of the solar collector for different ambient temperature and solar radiation cases. In figure 7, collector outlet temperature, and inlet-outlet temperature gains for various moments along the day are shown.

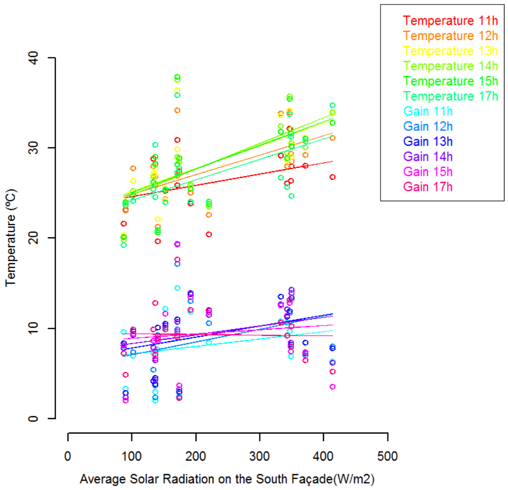

Fig 7. Service temperature levels and temperature gain in the air stream in the RETROKIT Solar air collectorFull scale integration in occupied building

6. Full scale implementation in a building retrofitting project

The overall goal of project MeeFS is a development of an industrialized concept for building envelope retrofitting with multifunctional envelope panels. The system, based on a modular grid is then equipped with various technologies such as insulation, green façade, ventilation and solar technologies. The air solar collector presented in this work was designed to fit into the MeeFS grid. A demonstration setup of this system will be constructed in Spain in 2016, where 2 air solar collectors will be installed.

These collectors were constructed in an industrial setting near Bilbao, and transported by Road for final installation. The systems were delivered with all automatic parts and control system already installed.

Fig 7. Original configuration and façade project for the energy retrofitting of the MeeFS demonstration building in Mérida, Extremadura, Spain.

7. Conclusions

In this paper, a technological platform for the development and particularization of air-solar collectors is presented. Two particular developments are presented where a dynamic solar façade with automatic control, and a ventilation module with an integrated solar heater.

Experimental performance of these collectors was tested, and mathematical models and heat gain metrics were obtained. In project MeeFS, the performance of the solar collector is defined by two equations. In project Retrokit, the solar gain capacity of the device is set at 5ºC over inlet/ambient air.

At present state, the solar thermal platform has evolved, and industrially manufactured prototypes were delivered to a demonstration setup in a real building in Spain.

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