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PV & Peltier façade: preliminary experimental results

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Abstract

The paper reports the preliminary experimental results of an hybridization between a classic ventilated facade and photo-voltaic panels powering a Peltier cells system to improve the inner summer comfort with an environmental friendly approach. The outer layer of the facade is made of photovoltaic panels while a pair of light alloy heat exchanger, coupled on the opposite sides of the Peltier cells, are fitted between the internal space and the air chimney of the facade. The Peltier cells are electrically wired directly with the solar cells: the more the sun affects the front, the more the solar cells produce power to feed the Peltier cells that work as a static heat pump, cooled by the air flowing through the interspace of the ventilated facade.

This will result in an inside cooling effect and this effect shall be summed with the well-known passive good performance of the ventilated facade in summer sunny days. During the winter, a simple switch of the power polarity would result in a free inner heating effect, partially using the solar energy incident on the front: the risk of icing on the cold exchanger in the chimney would be reduced because of the heat transmitted by the rear side of the photo-voltaic cells.

A small scale prototype has been tested during summer, showing an improvement of the inner air temperature of about 3-4 K during the sunniest hours, in comparison with the unequipped case.

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Keywords: photovoltaic; ventilated façade; Peltier cells; solar heating; solar cooling;

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1. Introduction

Over the last decades there has been an increasing attention towards the efficiency of building envelopes: from one side the passive performances of the building skin (e. g. thermal insulation) are increasing, from the other side the envelope is more and more intelligent, changing its behavior and its shape in order to mate at its best the actual climate. In the research field on the building envelope carried on by the former Department of Engineering of Building and Territorial Systems (DISET) at Politecnico di Torino (now Department of Structural, Building and Geotechnical Engineering, DISEG) an innovative façade system was developed and tested as a small scale prototype.

Referring to the classification of building envelopes [1] this kind of façade is belonging to the category of Ambient Dynamic Behavior Building Technologies (TECAD) because of its capability to partly modify the façade thermal balance according to the daily sun radiation and the heating/cooling necessity.

Often the solar energy use is directed to winter heating or summer inner ventilation, the Trombe Wall being improved several times, for instance adding electric fans and even photovoltaic panels [3]; in some more recent cases the use of solar energy is proposed to improve the summer comfort through a solar-assisted desiccant cooling [3] or to enhance the energy general efficiency of the building connecting the PV panels to the electric grid and cooling them via the air blade chimney effect [4] in case equipping the PV panels with heat absorbers [5].

The innovation of the proposed system is the off-grid direct use of solar energy to generate a cooling effect without any in/out air exchange. The façade system was designed to:

- self-regulate its thermal flow;
- contain the over-heating of its inner layers in summer;
- reduce room temperature during summer sunny hours;
- increase room temperature during winter sunny days.

2. The hybrid façade system

The system is made of a ventilated façade with its external skin formed by photovoltaic panels. These panels are back cooled by the chimney effect of the air blade flowing in the interspace; they are also very serviceable due to their dry assembly into the system with all the wiring concealed in the air gap. The PV panels are supported by the customary metallic substructure of any ventilated façade, so no unusual elements are introduced in the dimension modularity of the envelope.

Electrically, the system consists of a series of the photovoltaic panels that are directly coupled to the Peltier cells. The photovoltaic cells are coupled without any interposition of regulators or other electronic circuits to static heat pumps, consisting of a row Peltier cells with their heat exchangers. They are mounted so that they separate the indoor from the cavity of the ventilated facade. We chose to use the Peltier cells because the static heat pump made up of these semiconductors works with direct current and with the power supply provided by the photovoltaic panels without needing additional complex DC/DC conversions. The direct matching of PV panels and Peltier cells is possible only if they are selected to have the PV maximum voltage output similar to the Peltier max input [9].

The Peltier cells are thermally coupled by means of a conductive silicone paste with two series of heat exchangers made of aluminium, one on the hot side of the cells and one on the cold side.

In summer, PV panels have the task to cut off the solar radiation on the envelope and to give power to the Peltier cells. In this way we can invert the sun effect: the more the façade is catching the sun, the more the Peltiers will cool the inside. The heat exchangers on the cold side remove the heat from the ambient air: their optimal position is therefore on the upper part of the room. The heat exchangers on the hot side dissipate the heat removed from the room and the power needed for operating the Peltier cells.

During the winter the effect is the opposite, simply commuting the polarity of the Peltiers' connections. So the solar energy is converted into inside heating, partially recovering the missed envelope warming that otherwise would have been cut off by the ventilated interspace.

The heat exchange with the airspace of the façade is favored by the chimney effect increased through the heat radiating from the panels' backs. In summer, the internal heat exchange is mainly due to natural convection, via the aluminium coolers placed at the top of the inner wall; in winter the heat exchanger will warm up the upper layer of the room air and so the whole ceiling (radiant heating).

For both of the series of exchangers it was preferred to obtain thermal exchange by natural convection as opposed to the more common forced convection [2, 6] because the former does not consume electricity for running fans. As a side effect, natural convection presents a less efficient thermal exchange and therefore needs larger heat exchangers which have the advantage, on the internal side, of lowering (summer) or increasing (winter) the average radiating temperature [8].

2.1. Layers of PV & Peltier ventilated façade

The elements and layers of the system are conceived as follow (see Fig. 1):

2.1.1. External skin (A)

Made of photovoltaic panels whose pattern should be integrated into the façade design. The proposed system can have a fully planar vertical skin or a skin similar to a sort of venetian blind. In this way each PV rows could be inclined e.g. of 60° to the horizontal to favor efficiency and winter operation: as a matter of facts, in Turin (45° 7' lat. N) during summer the PV cells inclination of 30° to the horizontal is considered optimal [7], while a greater inclination facilitates the winter efficiency, a real weak point considering the sun hours.

2.1.2. Air blade (B)

Being the distinctive element of any ventilated façade, in this case the interspace ventilation has a threefold purpose: preventing the temperature rise in the inner façade layers due to solar radiation; cooling the PV panels; cooling (summer) or heating (winter) the external heat exchangers.

2.1.3. External dissipators (C)

Aluminium alloy heat exchangers (H × L × W: 250 × 240 × 46 mm each) transferring Peltier heat by natural convection to the air blade (B) and increasing the chimney effect. Natural convective dissipation coefficient 3.125 W/K.

2.1.4. Bearing plate (D)

Multilayered support plate, integrating in the envelope vertical closure the thermal insulation and the Peltier cells (E) with their inner dissipators (F) and outer dissipators (C).

2.1.5. Static heat pump (E)

A row of 4 Peltier cells (see Tab. 1), semiconductors behaving as static heat pumps when DC powered with the electricity generated by photovoltaic panels. Depending on the polarity of power, the Peltier cell can cool or heat the room. In summer the heat extracted is about 1/2 of the power provided, while in winter the heating effect can theoretically reach the 3/2 of the electrical power.

Table 1. Peltier cell datasheet

Specifications	unit	Value
Nominal power	W	33.4
Max current	A	3.9
Max voltage	V	15.4
Max temp.	°C	85
Max ΔT among opposite sides	K	67

2.1.6. Internal dissipators (F)

The indoor end of the system. This aluminium alloy heat exchangers (H × L × W: 150 × 240 × 46 mm each) operates by natural convection, in order not to have any PV power loss to run fans: this results in simpler maintenance (no filters) and no noise. Natural convective dissipation coefficient is 2.5 W/K.

The location of these heat exchangers is very near the ceiling, to favor summer heat exchange and the stratification of the cooler air at the room bottom, where actually serves most. Instead, during the cold season, the exchangers heat the upper layer of air and thus the ceiling that will contribute to warm up all the room by its IR radiation.

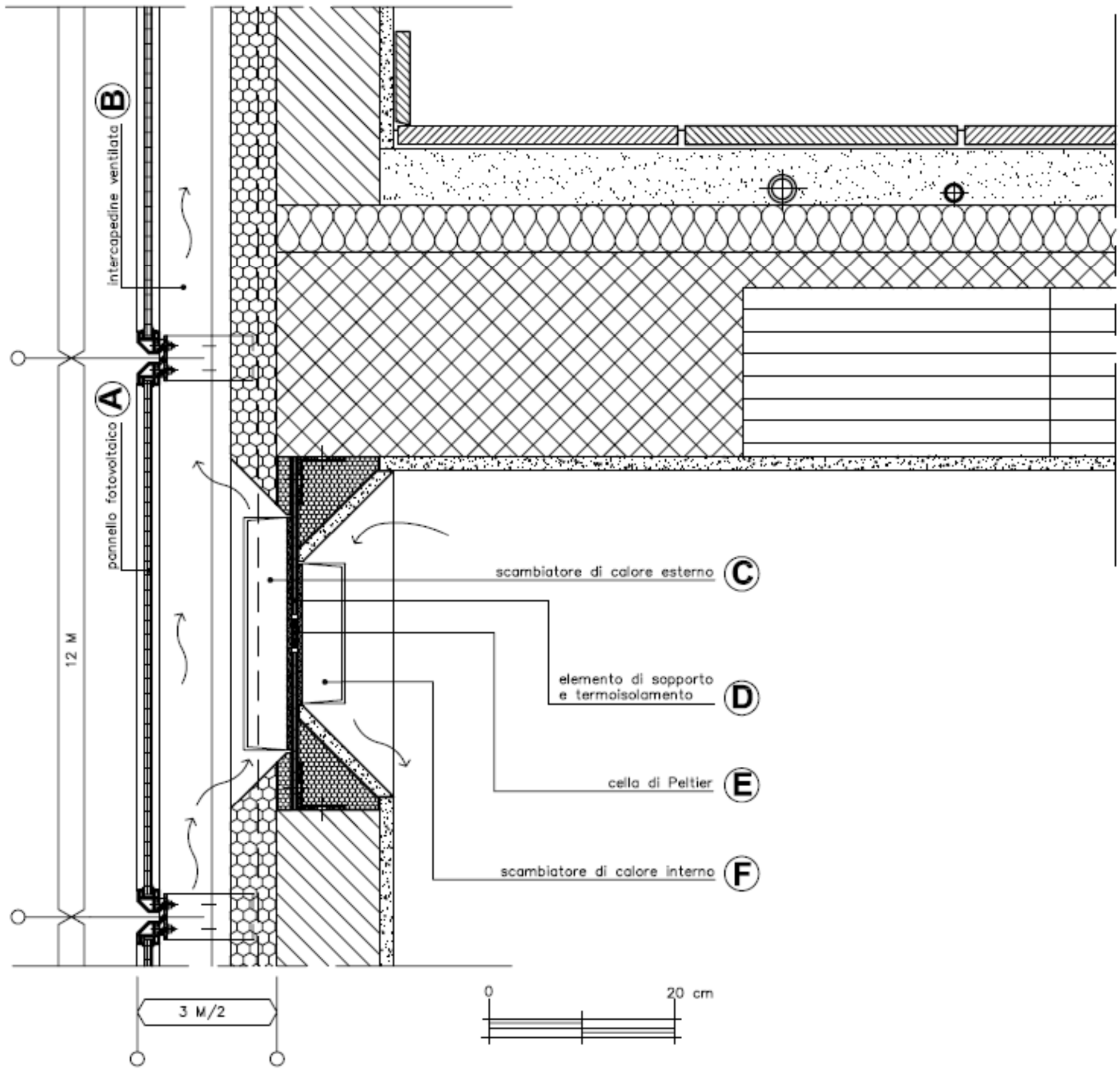

Fig. 1. Cross section of the system: PV panels (A); Air chimney (B); Outer dissipator (C); Bearing plate (D); Peltier cell (E); Inner dissipator (F)

3. Experimental results

A small scale system was tested during a summer. The test campaign was conducted through the comparison between the inner temperature in two small rooms (about 1 m³ each), one equipped with the hybrid façade system and the other with a conventional ventilated façade. Both the rooms were fully exposed to the summer climate (four external walls, external ceiling and floor), in order to simulate a real climate load situation in Turin. Thermal sensors (precision of 0.15 °C) were placed to measure the temperature of each room, the outer temperature and the airblade temperature in the hybrid system; they were connected with data loggers in order to monitor the test rooms continuously (12 readings per hour).

The typical situation of a summer sunny day is displayed in Fig. 2: the hybrid system contributes to lower the inner temperature between 2 and 3 °C in comparison with the room equipped with a conventional ventilated façade.

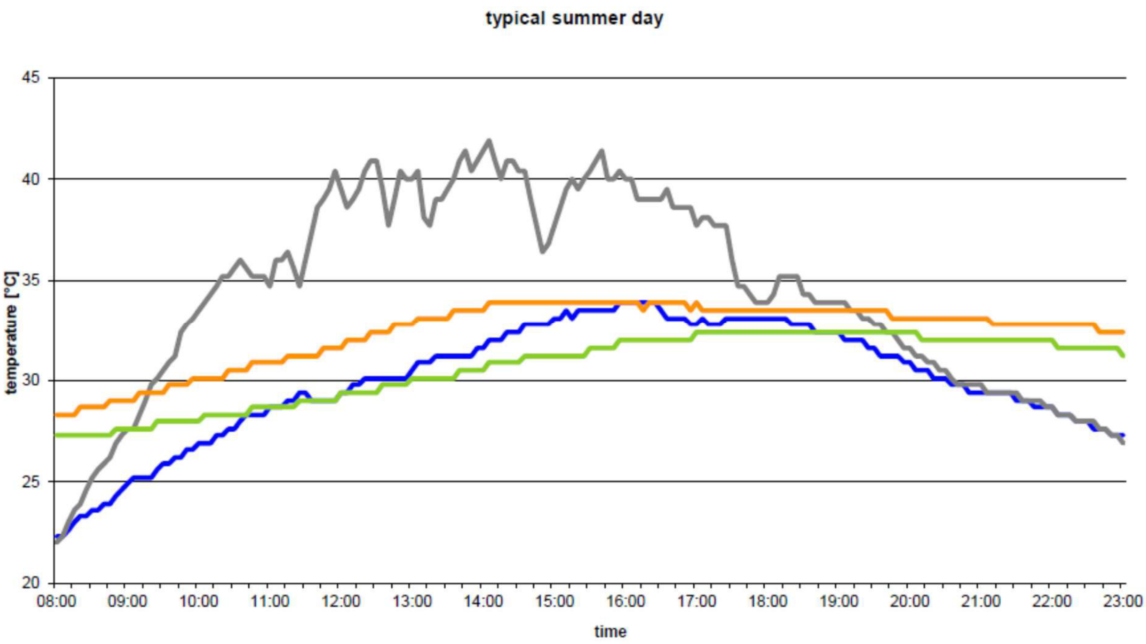

Fig. 2. Hot day measured temperatures: outer (blue), test rm. w/ hybrid façade (green), test rm. w/ conventional façade (orange), airblade (gray)

4. Conclusions

The proposed system offers the advantage of hybridising technical systems currently on the market (photovoltaic panels, Peltier cells, ventilated facades, etc.) to affect the energy flows through the building envelope in order to achieve better comfort and reduce the building's energy needs. The system lends itself well to various degrees of building integration, and can also be configured as a refurbishment envelope unit on existing buildings. It can even work in synergy with transparent envelopes equipped with partially photovoltaic glass, a case which is considered particularly interesting, especially considering the problems of summer comfort in semitransparent envelopes coped with a small thermal mass.

It is also important to focus the hybrid system's capability to reduce not only the general cooling power of the building, but mainly its energy peaks due to sun irradiation, with favorable facilities cost reduction and positive effect on the peak loads on the national electrical system.

In less hot days (e. g. September) the hybrid system itself can supply all the cooling needed to maintain the inner temperature conditions within comfort standards (Fig. 3).

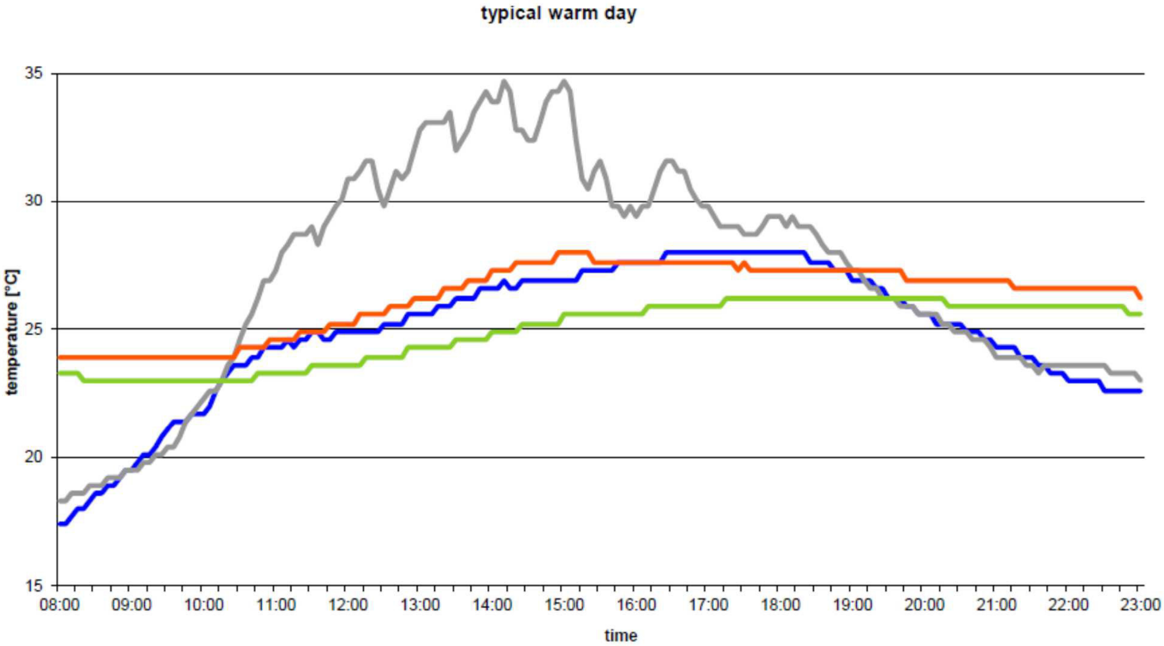

Fig. 3. Warm day measured temperatures: outer (blue), test rm. w/ hybrid façade (green), test rm. w/ conventional façade (orange), airblade (gray)

Further experimentation of the hybrid façade system should achieve in the future a natural-scale testing to collect all the necessary data (above all, the time evolution of cooling power vs. cooling needs) to optimize the design parameters. Also a full scale testing will be effective to compare the hybrid façade outputs to the performances of a PV grid connected system powering a vapor compression cooler, comparison impossible to make in small scale prototype, in which the air conditioner would necessarily be oversized, heavily affecting the consistency of the measures (inner temperature, electric demand, etc.).

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