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Improved Performance of a PV Integrated Ventilated Façade at an Existing nZEB

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Abstract: Ventilated façades are among the existing measures to reduce the energy demand in buildings. The combination of this passive heating and cooling strategy with photovoltaics (PV) can drive new buildings towards the current European targets for near or even net zero-energy buildings (nZEB). The present work aims at studying the PV integrated ventilated façade of the nZEB known as "LUCIA" at the University of Valladolid, Spain. First, the transmissivity of the PV façade is measured. Then, the monitoring of the available solar radiation is presented together with the air-dry bulb temperatures indoors, outdoors and inside the ventilated façade. The experimental results permit the validation of a mathematical model that describes the behaviour of the ventilated façade in its current operating modes. The results show that dampers should be closed during winter to let the façade act as a further insulation for outdoor temperatures below 18.4 °C to improve energy efficiency. Indoor air recirculation would be helpful during 10% of the winter period.

Keywords: ventilated façade; photovoltaics; monitoring; model validation; energy conservation measure

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1. Introduction

Although the moment when the first building-integrated photovoltaics (BIPV) system was installed in Germany [1] passed more than a quarter of a century ago, investors and researchers are interested in different types of PV façades that could be put to use in modern low-energy or even net zero-energy buildings. Shahrestani et al. [2] found that ventilation in the air cavity of the PV façade system could significantly improve the energy performance of the system, even in a southeast facing façade. The results of research on Building Integrated Photovoltaics (BIPV) systems were shown in [3,4]. Li et al. [5] conducted a simulation study that showed that the surface temperature of the naturally-ventilated PV façade is obviously lower than in the case of the conventional PV façade; however, they noted the need for experimental studies in this area, as well as analysis in an economic range.

2. Materials and Methods

The present work focuses on the east–south oriented ventilated façade of a near zero-energy Building (nZEB), called "LUCIA", of the University of Valladolid, Spain (Figure 1). It is equipped with 56 photovoltaic modules composed of "6" polycrystalline cells. Each module has a power of 180 W and dimensions of 1730 × 1015 × 35 mm. The dimensions of the ventilated façade are a width of 12.8 m and height of 10.5 m, and it is orientated 35° south. It projects 1.1 m out from the main wall, which corresponds with the façade depth.


(**a**) (**b**)

Figure 1. View of the ventilated façade with photovoltaic (PV) modules (**a**) from indoors and (**b**) from outdoors.

A comparison of the measurements of the surface temperature through surface sensors and a thermal camera permits the determination of the façade's radiative properties. To characterize its behavior, measurements of the air dry-bulb temperature (DBT) and relative humidity (RH) inside the ventilated façade, indoors and outdoors, as well as solar irradiation, were taken every 5 minutes (Table 1).

Table 1. Measurements performed, with sensors and specifications. DBT: dry-bulb temperature; RH: relative humidity.

Parameter	No. (Position)	Sensor	Range	Accuracy
DBT/RH	9 (inside façade) 2 (indoor air)	Testo datalogger 175 H1	−20 °C to +55 °C 0 to 100%	±0.4 °C ±2 %RH
DBT/RH	1 (outdoor air)	Geonica STH-S331[1]	−40 °C to +60 °C	±0.1 °C
Surface temp.	(Various positions)	Testo Thermocouple K 0602 0393	−60 °C to +300 °C	±2.5 °C
Surface temp.	(Various positions)	FLIR InfraCAM	−10 °C to +350 °C	<0.1 °C
Solar radiation	(Various positions)	Ahlborn ALMEMO FLA628 S Piranometer	0 to 1500 W/m^2	±7%
Solar radiation	1 (roof)	HUKSEFLUX SR20-T2-10 Piranometer [1]	0 to 4000 W/m^2	±3%

[1] Sensors available at the meteorological station of the LUCIA building.

There are nine sensors for DBT measurement inside the façade, at three different points along the width of the three floors of the building. The indoor air DBT is measured on the first two floors of the building, as there is no occupied space in the third floor.

3. Results

3.1. Radiative Properties of the Façade

Firstly, the radiative properties of both surfaces of the ventilated façade are determined (Table 2). Transmissivity is calculated from the difference between the solar irradiation measured indoors and the value measured outdoors. Measurements are performed around noon for homogeneity and calculated for both the glass and the PV cells.

Table 2. Radiative properties measured in the façade.

Surface	Transmissivity	Absorptivity
PV cells	0.094	0.91
Outdoor glass	0.42	0
Outdoor glass with PV cells	0.37	-
Indoor glass	0.25	-

Absorptivity is determined by comparing the measured values with the thermal camera and the surface temperature. When both values correspond with each other, the emissivity selected in the thermal camera should coincide with the actual emissivity of the surface.

3.2. Operating Behavior of the Façade

Figure 2 shows the evolution of the different temperatures measured inside the façade, indoors and outdoors during the target period. The nomenclature used for the temperature sensors corresponds to a number and a letter; namely, the floor and the position (left–middle–right inside the façade, or "i" indoors).

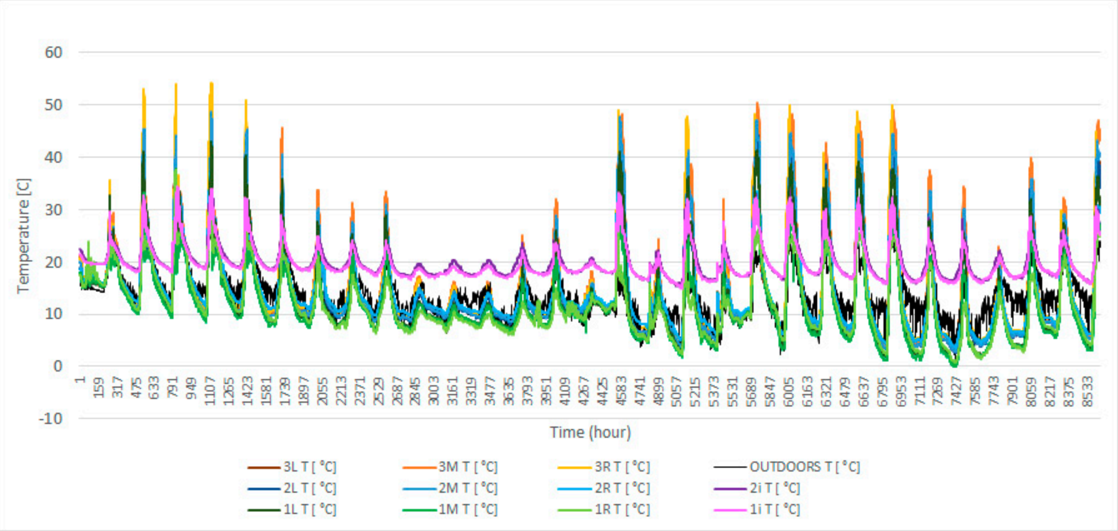

Figure 2. Outdoor, indoor and façade temperatures registered from 5 November to 5 December.

During nighttime, there is a drop in the air DBT within the façade, but these temperatures increase above the values registered inside the building during daytime. The highest differences in temperature arise during periods of high irradiance. The indoor temperatures measured on the first and second floor are similar.

Figure 3 shows the difference between the predicted values obtained by the model and the average measurements for a short period from 19 November.

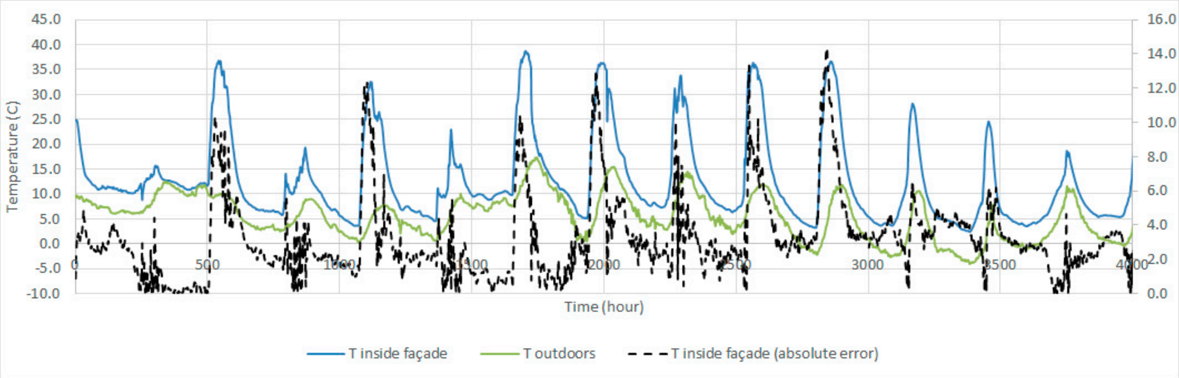

Figure 3. Absolute error of the predicted temperature inside the façade in comparison to the measured value.

4. Discussion

No relevant patterns of temperature gradients exist along the façade's width, with the differences observed being due to the effect of uncontrolled factors in their particular position. Indoor temperatures measured on the first and second floor are similar. This shows that the temperature gradients inside the building are not significant. However, peaks registered evidence that these sensors can be affected by solar radiation and hence are not properly shielded.

Regarding Figure 3, the model can be used to predict the temperature inside the façade only beyond periods of high irradiance. A comparison between the DBT inside the façade and inside the building shows that different operating modes are recommendable during winter periods. Although it seems helpful to recirculate indoor air within the façade for most of the daytime, there is a need to identify a control condition to determine when it is preferable to keep the air enclosed within the façade. In this way, it is proposed that when the outdoor air temperature is below 18.4 °C, the dampers should remain closed, and then the façade will act as a further insulation. When outdoor air exceeds that value, air recirculates, passing through the ventilated façade. This last measure would incur additional fan power. The ventilated façade could operate under a recirculating mode during 10% of the winter time in Valladolid [6].

5. Conclusions

The PV ventilated façade installed in the LUCIA nZEB is an interesting measure taken to improve the efficiency in the building in terms both of its thermal behavior and its PV electricity generation. The actual behavior must be monitored to determine the best operating modes under the different possible outdoor conditions. This work presents the operating conditions for one month during the winter period to propose the optimal control to enhance the achievable thermal energy savings. The results show that dampers should remain closed and the façade should act as further insulation when the outdoor temperature is below 18.4 °C. The recirculation of indoor air would be helpful during 10% of the winter period. Improvements in PV performance under air recirculation should be dealt with in future work.

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