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# Dynamic insulation systems: experimental analysis on a parietodynamic wall

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**Abstract**

This paper shows the results of an extensive experimental campaign on a ventilated opaque double skin façade based on hollow clay bricks. The winter thermal performances of the dynamic insulated systems were investigated on two different full scale façade configurations through an experimental campaign in double climatic chamber and guarded heat flow meter apparatus.
The laboratory tests on dynamic insulated façade (DIF) in both exhaust and supply configurations show respectively an effective reduction of heat losses and the capability of pre-heat the supply air passing across the ventilated external channel. The results confirm the extra insulation offered by the ventilated gap, which allows for a reduction of the wall insulation thickness, providing heat loss reduction and high level of indoor air quality in thin wall construction.


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*Keywords:* Experimental assesment, dynamic insulation, advanced façade, double climatic chamber;

## 1. Introduction

The new frontier of building envelope technologies, aimed at minimising energy demand for heating, ventilation and air conditioning, is represented by responsive building elements (RBE), i.e. building components and systems able to adapt their behaviour to different boundary condition, balancing heat and mass flows crossing the buildings. RBEs are based on the integrated building design approach where a strong interaction between building services and envelope components is required.

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One of the most promising existing technology among responsive opaque wall components is represented by the dynamic insulation systems, such as breathing wall (permeodynamic) or void space dynamic insulation (parietodynamic). These systems, reducing building envelope heat losses, allow, on one hand an effective pre-heating of the ventilation air or a heat recovery of the exhaust indoor air and, on the other hand, allow to achieve better indoor air quality.

Nevertheless the lack of experimental results and the limited number of case studies where these systems are adopted represent one of the main barrier to an extensive market penetration of these solutions.

In this paper the authors present the results of an experimental campaign based on the thermal characterisation of a clay brick parietodynamic wall, aimed at demonstrating the effectiveness of this technology on reducing the heating energy consumption.

### *1.1. The opaque ventilated façade (OVF)*

Advanced integrated façades (AIF), are commonly classified considering the ventilation strategy, the air path and the system configuration as the most significant items [1].

For both natural ventilated (NV) and mechanically ventilated (MV) façades the possible façade arrangements are:

- (EAF) exhaust air façade configuration, which use the façade as an air heat recovery system;
- (SAF) supply air façade configuration, which use the façade like a supply air pre-heater;
- (OAC) outdoor air curtain façade configuration (common ventilated/rainscreen façade);
- (IAC) indoor air curtain configuration (Trombe wall).

SAF and EAF configurations were commonly considered as a dynamic insulation systems [1] and differ from OAC and IAC for the air flow path, respectively outside to outside for OAC and inside to inside for IAC.

The double skin façade are a consolidate technology in transparent ventilated façades (TVF) and many authors have described the great potential of these type of façade compared to the traditional single skin components [2], [3], while, for what concern opaque ventilated façade (OVF), so far a quite limited number of examples have been reported.

The lack of case studies and experimental results about OVF, in addition to the lack of knowledge about their actual thermal performance, represent the main reason of why these solutions are still not widely adopted. Nevertheless, in recent years the attention on dynamic insulation applied to OVF has been increased and some researchers focus their attention on the performance evaluation of this kind of technologies. The most studied dynamic insulated façade (DIF) configurations, as emerging from a literature review, were principally divided in permeodynamic breathing wall [4] and [5] and parietodynamic walls, [6].

## 2. The analysed wall configurations

The walls configurations was developed in order to combine different ventilation strategies, generating an adaptive ventilated double skin façade for both new buildings and energy retrofitting of existing buildings.
An experimental campaign in a double climatic chamber was carried out on two different DIF configurations integrated with a mechanical ventilation system. The different façade configurations used for experimental tests were summarized in table 1 and graphically illustrated in Fig. 1.

Table 1: Overview of the tested façade configurations.

| Test Sample | Ventilation Type | Air Flow Path | Experimental Condition | Performance Investigated | Air Flow Origin | Air Flow Destination |
|---|---|---|---|---|---|---|
| a | MV | EA (exhaust air) | steady state | winter | interior | exterior |
| b | MV | SA (supply air) | steady state | winter | exterior | interior |

Test specimens (a) and (b), as shown inFig. 1, consist into two OVF walls of 230 cm height and 76 cm width , differing for the direction of the air flow and also for the air flow origin and destination.

The walls assembly is summarized in table 2. Both the samples (a) and (b) are divided into two parts:

- the ventilated façade (layers 1,2,3,4,5);
- the brick wall (layer 6).

The evaluation of the effect on the thermal performance due to the presence of ventilation for both EAF (a) and SAF (b) configurations (layers 1,2,3,4,5) was carried out through the comparison of the results obtained for the ventilated façades with the ones obtained for the simple brick wall (layer 6), used as reference.

Sample (a), consisting in an exhaust air façade (EA) was analysed under 2 different configurations:

- in configuration 1, the external EPS (layer 1) is 2cm thick as represented in table 2, corresponding in an equivalent layer with thermal resistance *R* of 0.571 ($m^2K/W$);
- in configuration 2, the external EPS (layer 1) is 1cm thick corresponding in an equivalent layer with thermal resistance *R* of 0.286 ($m^2K/W$).

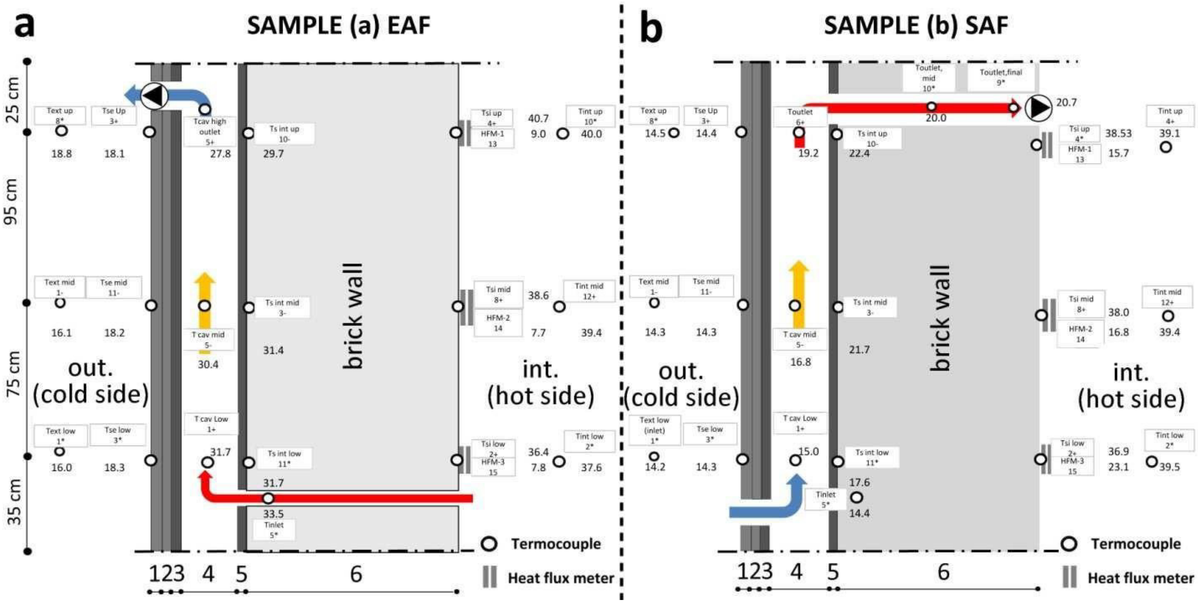


Fig. 1. (a) Exhaust air façade EAF; (b) Supply air façade SAF.

Table 2: Sample stratigraphy from inside to outside

| number | name | Thickness [mm] | Thermal Conductivity [W/mK] | Thermal Resistance [$m^2K/W$] |
|---|---|---|---|---|
| 1 | EPS | 20 | 0.035 | 0.571 |
| 2 | MDF | 12 | 0.103 | 0.117 |
| 3 | External brick layer | 10 | 0.401 | 0.025 |
| 4 | Ventilated air cavity | 50 | - | - |
| 5 | Internal brick layer | 10 | 0.401 | 0.025 |
| 6 | Structural brick | 250 | - | 1.05 |

## 3. Laboratory measurement methodology

The experimental characterization of samples a and b was carried out through a double climatic chamber apparatus (Building Envelope Test Cell "BET cell"), as shown in Fig.2. Moreover the thermal conductivity of each layer that constitutes the two samples was performed by means of a guarded heat flux meter apparatus

LASERCOMP FOX600, the measurement uncertainty was less than 3%according to the international standard EN ISO 12667:2002 [7].

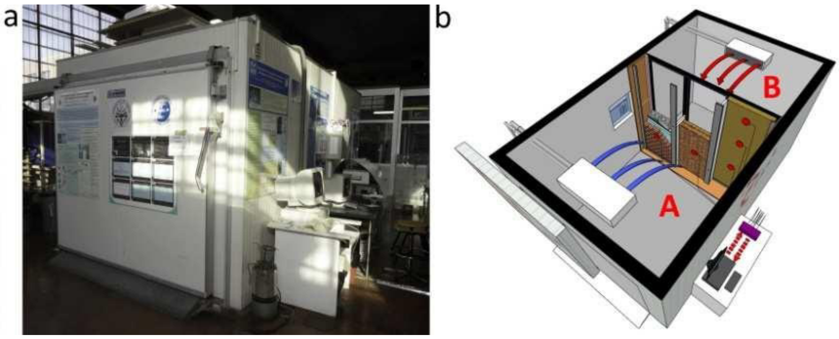


Fig. 2. Climatic chamber: (a) external view; (b) sketch of the internal view.

The double climatic chamber has been specifically implemented to test advanced building envelope components and consists in a double room with a separation frame that host the sample walls, with maximum sample dimensions 240 cm height and 275 cm width.

The sub-module "A" (cold room) is equipped with an HVAC system that allows to simulate both steady state and transient dynamic boundary conditions. During the measurement the sub module A was continuously maintained at the desired set point temperature of 14°C, with an accuracy of ±0.5 °C, by means of an all air system.

The sub-module "B" (hot room) is equipped whit a radiant heating system and was continuously maintained at the desired set point temperature of 39°C, with an accuracy of ±0.3 °C.

The monitoring apparatus for the measurement of thermal resistance and thermal transmittance, according to [8], consisted into 4 heat flux meter plates (HFP01) with an expected accuracy within ±5% and 36 (TT) thermocouples with an expected accuracy of ±0.3 °C, connected to a datataker (DT85).

For the measurement of the ventilation air flow rate in the SAF and EAF the tracer gas method was used and the measurements were carried out by means of the Bruel and Kjaer gas monitor 1302 equipment.

## 4. Experimental results and discussion

### *4.1. Steady state thermal performance of supply air façade configuration (SAF)*

The steady state thermal performance of the SAF configuration was investigated by means of a double climatic chamber facility, as described in section 3. The measurements on SAF were performed using 3 electrical fan devices (with different diameters) and measuring the air flow rate for the entire wall width was measured through the tracer gas method, the results shows respectively for the 3 fans an air flow rate *Q* of: 9, 16 and 27 m$^3$/h. for 76 cm of façade width.

The thermal performance of the SAF configuration as shown in figure 9 was evaluated through the parameter $\eta_{pre-heat}$ (pre-heating efficiency), according to the equation (1) which represent the potentiality of the façade in terms of its capability to pre-heat the air in the gap [2].

$$\eta_{pre-heat} = \frac{(T_{inlet} - T_{out})}{(T_{in} - T_{out})} \tag{1}$$

Where:

$T_{inlet}$ is the supply air temperature measured in the top of the façade air cavity;

$T_{out}$ is the outside air temperature maintained at 14°C (cold side A);
$T_{in}$ is the inside air temperature maintained at 39°C (hot side B).

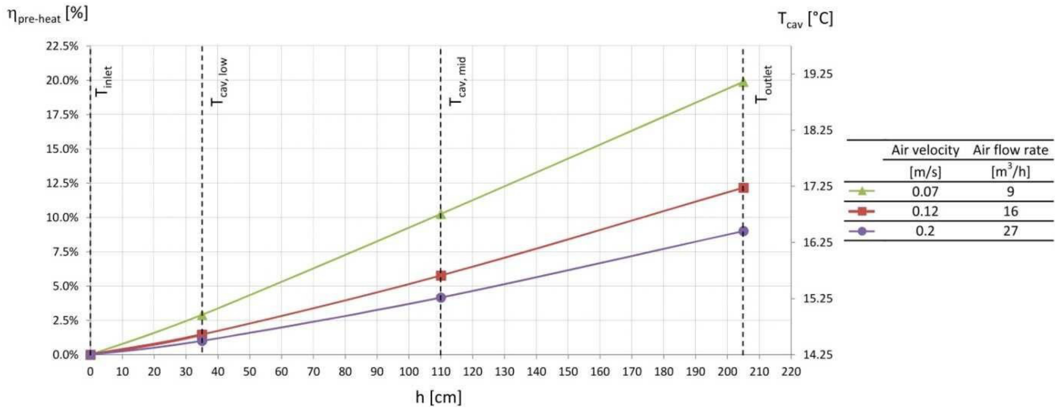


Fig. 3. Air cavity temperature $T_{cav}$ and $\eta_{pre\text{-}heat}$ at different façade height.

Fig. 3 reported the results of the air cavity temperature $T_{cav}$ and the pre-heating efficiency $\eta_{pre\text{-}heat}$ for the 3 different air flow rates and air velocity inside the air channel.
The $\eta_{pre\text{-}heat}$ results, shows for any air flow rate, a linear behavior at the different façade heights (between 0 cm - $T_{inlet}$ and 205 cm - $T_{outlet}$). As expected the results show that the lower the air velocity inside the air cavity, the higher is the $\eta_{pre\text{-}heat}$.. In particular for low air velocity (green line triangle marked) the results show an increasing of the air cavity temperature around 2°C every one meter of height. As a result at 205 cm the air is quite warmer, passing from 14.2 °C to 19.2 °C), corresponding to a 20% of pre-heating efficiency. For air flow rate of 27 m$^3$/h, corresponding to an air velocity of 0.2 m/s (blue line dot marked), the pre-heating efficiency is noticeably lower with a value of about 9%.

### *4.2. Steady state thermal performance of exhaust air façade configuration (EAF)*

The experimental performance evaluation of the exhaust air façade configuration, was carried out through a comparison with the reference brick wall (without the layers 1,2,3,4 and 5).
First of all the thermal resistance of the simple brick wall (layer 6) without the adoption of any ventilation strategies was assessed through heat flux meter measurements, according to EN ISO 9869:2014 [8].
The experiment on ventilated EAF configurations were performed using 6 different electrical fan devices generating an air flow rate between 9 and 37 m$^3$/h for 76 cm of façade width.
The heat loss reduction $\Delta q$ of the exhaust air façade (sample a) compared to the reference wall (ref) was calculated using eq. (2)

$$\Delta q = 1 - \frac{q_{(a)}}{q_{(ref)}} \tag{2}$$

Where:
$q_{(a)}$ is the average heat flux measured at 3 different heights in the sample wall (a);
$q_{(ref)}$ is the heat flux measured in the reference wall (ref).

Fig. 4 shows that the heat flux reduction $\Delta$q goes with the increase of the air flow rate $Q$ between 46% and 68% for configuration 1 (black dashed line) and between 43% and 68% for configuration 2 (grey dashed line).

The graph shows an asymptotic behavior for air flow rates over 35 $m^3/h$ for 76 cm façade width, thus meaning that an additional increase of the air flow rate has a negligibleimpact on the façade thermal performance.
The difference between the configuration 1 with 2 cm of external EPS layer and configuration 2 with 2 cm of external EPS layer, is more evident for low air flow rates; moreover the results shows that the higher is the air flow rate, the lower is the influence of the external insulation.

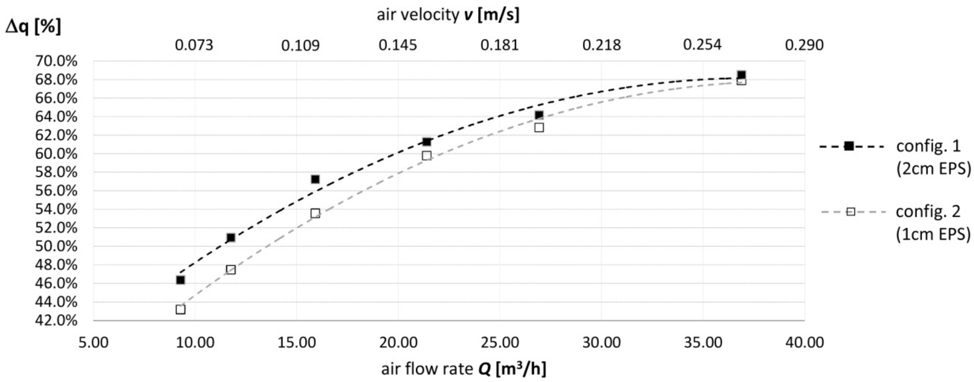


Fig. 4. Heat flux reduction for different air flow rate $Q$ and air velocity $v$.

## 5. Conclusion

In this work an experimental campaign aimed at assessing the actual thermal performance of two different dynamic insulated walls was carried out. The results on the different tested configurations (EAF and SAF) show that for the SAF configuration, a pre-heating efficiency between 9% and 20%, depending on the air flow rate, can be achieved, whilst for the EAF configuration, a heat loss reduction between 43% and 68% was measured.
The SAF seems not to lead noticeable thermal advantages, but it should be noticed that the steady state experimental campaign neglect the key-role effect of the solar radiation, that could improve the pre-heating efficiency if the façade is correctly exposed.
It is important to underline that the experimental results presented in this paper are related to the single performance of each façade configuration evaluated one by one. Nevertheless in order to effectively evaluate the real benefits of these technologies the two different façade configurations must be combined and integrated with the HVAC systems.
This work, representing a first step of a wider research activity on these kinds of façades, show encouraging results and underline the great potential of this technology. Additional experimental campaigns, on full-scale mock-up exposed to real external environment, are undergoing.

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