

## **Experimental characterization of active facades**

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# Experimental characterization of active facades

This paper collects the experimental results of some active facades systems which have been tested in outdoor conditions and in building scale. The evaluated active facades solutions group is composed from conventional active systems such as Trombe wall to accumulation mechanism by PCMs (phase changing materials), through solutions such as photovoltaic facades. The test can reliably characterize the main involved heat transfer mechanisms in the energy performance of different facade compositions and it can also get mathematical models for building scale application. A perfect example of the previously exposed is the characterization of the convective behavior of ventilated chambers, the efficiency of collecting solar radiation and the thermal loads exchanged with the space to cool. This characterization not only permits to know the design efficiency but also provides the necessary information for its improvement.

The goal of the experimental study is that the results are completely reliable, so test methodology is the most important point to get it. For this reason, the test equipment used is a PASLINK test cell developed by DYNASTEE (**D**YNamic **A**nalysis, **S**imulation and **T**esting applied to the **E**nergy and **E**nvironmental performance of buildings) network. The objective of this cell is to achieve results traceability when the test is carried out. It is achieved by three premises: a standardized testing methodology, use of powerful tools for data analysis by parameter identification techniques and the last but not the least important point, taking part in round robin tests and getting correct uncertainties of the results calculation.

Whenever it's possible, data results are exposed with the test owner's permission.

Keywords: Outdoor thermal test, dynamical thermal characterization, PASLINK test cell, building energy efficiency.

## 1- Introduction

We know about the need of getting more benefit from the solar radiation in order to use in the buildings. It can be used for cooling or heating. We find that there are a great

number of active façade systems. We should optimize and improve their performance to be optimal depending on the different season, geography and climatology. Finally, to reach this objective, it is very important to know the behavior of the different parts of the solutions, and good test method is required.

To get a proper characterization of active facades by testing, 3 requirements are needed: reliable equipment, fully representative sample and finally an accurate and confident process of calculation and analysis of the obtained data. All these points are reached working with PASLINK cells and its test methodology. To make it more understandable, a practical example of an active façade is shown in the next chapter, focusing not only on the test cell but in the construction of the sample.

Some carried out tests of different active facades samples will be shown, beginning with light and heavy ventilated facades, where it will be seen the variation in the efficiency of the facade because of some parameters, such as the thermal inertia of the external layer and the thickness of the ventilated air. After that, examples of active facades will be displayed, with forced air movement, with phase change materials which store heat, Trombe wall with different configurations and ventilated photovoltaic façade analyzing not only its electrical behavior but also its heat gain in the ventilated chamber.

The behavior of the ventilated chamber will be studied in all cases, comparing the solar radiation and the heat absorbed by the chamber. That efficiency and the average energy gain per day expressed in kWh/m<sup>2</sup> will be determined for each solution.

## 2- Test & Sample

### 2.1 Test

#### 2.1.1 The birth of the project

The European project PASSYS (Passive Solar Systems and Component Testing) whose main objective was to perform tests under real weather conditions, but, nevertheless, in a highly standardised environment with a whole package of quality assurance control procedures, regarding the measurements and the operation of the test site [10] was developed from the mid-1980s to the mid-1990s. The principal result of these measurements was to obtain information for the test component regarding: its transmission losses (U-value); the use of solar gains under real weather conditions; and its dynamic behaviour: thermal inertia.

To enhance the existing quality procedures for testing and to contribute to European standardization in the field in long term, in 1994 a European Economic Interest Group was created: the PASLINK EEIG. The activities of this Group were the development of various European Research Projects, competitions in System Identification skills, regular inspections of the member test sites and its work systems, participation on European Standard Committees and the organization of periodic encounters for the divulgation of member works through workshop. Currently all the expertise of the PASLINK group has been integrated in the DYNASTEE (**DY**Namic **A**nalysis, **S**imulation and **T**esting applied to the **E**nergy and **E**nvironmental performance of buildings) informal group.

The test cell could function by a steady state methodology in order to determine the main (steady state) performance characteristics: the thermal transmission coefficient ( $UA$  – value) and the solar heat gain factor or solar transmittance ( $gA$ -value) of a

component. This was achieved by an indirect measurement, of the net heat flux through the building. The original concept of this test cell was proposed by Baker [1-2]

Basically, the PASSYS test cell [8] (figure 2.1) consisted of a well-insulated structure of 8 x 2.7 x 2.7 m with two spaces. One of 5.0 x 2.7 x 2.7 m called the “test room” to the south, and an adjoining space to the north called the “service room” containing acquisition and air conditioning equipment. The south facade (and cover if applies) of the test room is interchangeable so it is possible to test different building components (walls or roofs).

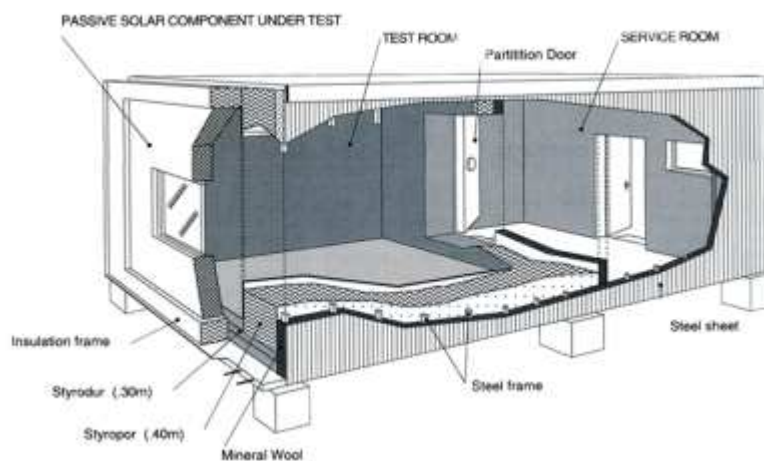


Fig. 1 General structure of the PASSYS test cell [10, p.18].

### 2.1.2. LCCE Test cells

The benefit of the PASLINK cells is that the heat transfer through the enclosure to the test room is measured or controlled with high accuracy. This way all the heat that passes through the element (to be tested) can be properly evaluated without the need of long stabilization periods. Two methods were developed to keep the heat through the envelope under control [5-6]: Pseudo-Adiabatic Shell (PAS) and the Heat Flux Sensitive Tiles (HFS Tiles) [9].

The PAS technique consists of an electric heating foil embedded between the original inner cell envelopes and one series of polystyrene and aluminum layers, used to compensate for the heat loss through the test room envelope, maintaining a null thermal difference between the heating foil layer and the hotter inner surface of the test room. On the other hand, the HFS technique consists of measuring the heat flux through the test room envelopes by a number of heat flux sensors in the form of tiles.

After more than 10 years of operation in the PASLINK group with the PAS and HFS technical solutions, it looks like the method of HFS Tiles simplifies operation, calibration and maintenance of the cell. Therefore, the HFS Tiles concept has been chosen as a solution to be implemented in the existing two PASLINK test cells in the LCCE (Laboratory for the Quality Control In buildings of the Basque Government) (see figure 2).



Fig. 2 Installation of HFS Tiles.

Nowadays there are two PASLINK test cells in the LCCE premises (see figure 3). One of them named EGUZKI which tests vertical elements of 2.7 x 2.7 m while the second test cell named ILARGI which tests both: vertical elements of 2.7 x 2.7 m and horizontal ones of 3.7 x 2.1 m.

Both test cells were bought from the Porto test site and before being used they were upgraded following the indications provided by Dr. J.J. Bloem of the European Institute DG Joint Research Centre, Institute for Environment and Sustainability in Ispra-Italy.



Fig. 3 PASLINK test site in the LCCE. From left to right: ILARGI cell with a vegetable facade sample, EGUZKI cell with a ventilated photovoltaic sample.

### *2.1.3. PASLINK Test procedures*

The test strategy is based on a routine of heating power input in the test room known as ROLBS. Before the test starts, it is necessary to ensure a steady state in both the test cell and the test sample. After this, the heating routine can begin. The heating input intervals of this routine last days, hours or thirty minutes. This variability allows us to obtain the necessary information in order to disconnect the thermal inertial behavior of the test cell envelope from the test sample. The heating power input must be adequate enough to reach the greatest possible difference in temperature between the test room and the exterior conditions. In the tests, we are looking to reach differences among environments around  $\Delta T \geq 20^{\circ}\text{C}$ . (see figure 4). This condition and the high insulation of the cell envelope permits to measure heat fluxes and temperatures through the samples

accurately.

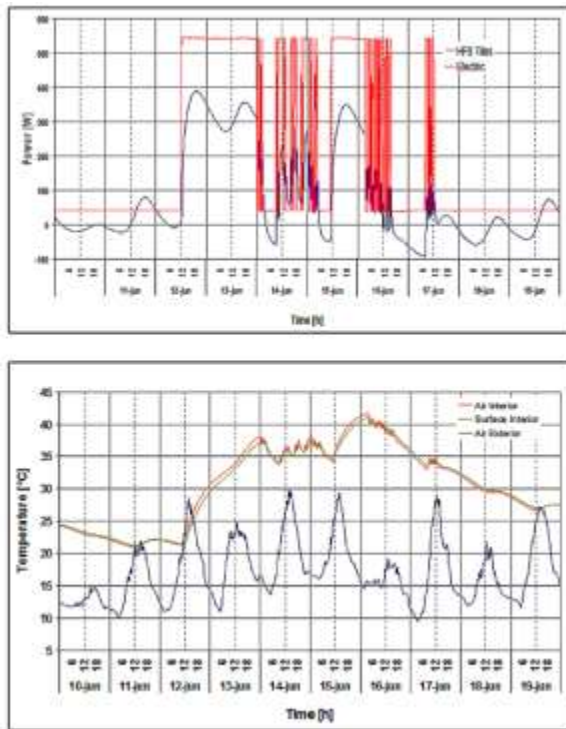


Fig. 4 (Upper graph) Routine of heating power input according to ROLBS [6-7] pattern throughout 10 days and (lower graph) the test room air and surface interior and the exterior air temperatures during the same period.

The basis for a test procedure, and the posterior modelling and study result validations are to ensure a previous steady state period in the whole cell, a representative temperature difference between indoor and outdoor environments, and to get the maximum decoupling of the main study variables.

The last part of the test process is the determination of the main parameters and thermal properties of the sample in study. In general, the values of interest for opaque components are the thermal resistances,  $R$  ( $m^2K/W$ ) and the thermal capacities,  $C$  ( $J/Km^2$ ), and for the semitransparent components in addition to the solar gain  $g$ . The tools used to determine these sample properties are the LORD (LOGical R-Determination), and the CTSM (Continuous Time Stochastic Modelling). Both methods use the grey box models where the parameters are determined through ordinary

differential equations of the heat transmission phenomenon applied to a lumped parameter model.

Two methods are applied [4-7] in order to determine the values of the study parameters in the objective functions: the minimization of the squared sum and the maximum likelihood estimates method.

The minimization of the squared sum method applied between the calculated function and the objective function is the most direct. In the simplest case with only one output fitting function, the function to minimize is,

$$N_t(\theta) = \sum_i [Y_{meas}(i) - Y_{calc}(i)]^2 \quad (1)$$

The likelihood function allows the determination of probability densities in function of the parameter variations, being possible to solve it sequentially by applying the probability rule given by,

$$P(A \cap B) = P(A|B)P(B) \quad (2)$$

## **2.2. Sample**

In this section, the sample holder system, manufacturing process of the samples, and a final section with the technical characteristics of the additional instrumentation of the sample, are defined.

### **2.2.1 . Sample Holder**

The PASLINK cell has a removable sample holder system on the south face, allowing the execution of the heavier specimens within an industrial hall ensuring quality of the construction and the installation of the instruments without damaging the sensor system of the cell.

The sample holder system consists of an structural metal frame, which provides mechanical properties. Within the metal frame is placed an insulating frame , and inside it the specimen is manufactured. The insulating frame is formed by a ring filled of expanded polystyrene with a thickness of 0.4 m , except in the base, in which the foam glass is used because of its larger bearing capacity. In Figure 5 it can be observed a cross section of the sample holder installed in the structure of the PASLINK cell [3], where it is seen the section of insulation frame , and also the manufacture of the frame.

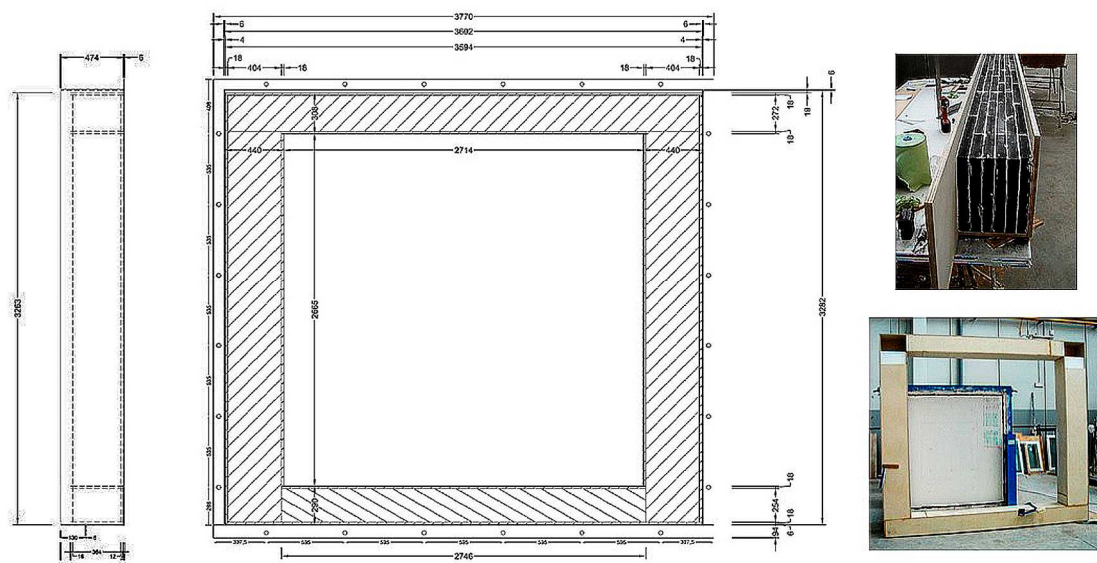


Figure 5 - Insulating frame configuration

Anchoring the sample holder to the structure of the PASLINK cell is accomplished by bolts disposed along the perimeter metal frame.

### 2.2.2 . Construction of the samples

The first step is the geometric definition of the sample and the design of the anchoring system in the sample holder . As an example, it is shown the implementation of a forced ventilated facade specimen. In the images of Figure 6 it is shown the proposed design for this example. Once the prototype is defined, the next task is to develop the construction plans of the sample, with the attachment details to the cell , see Figure 7.

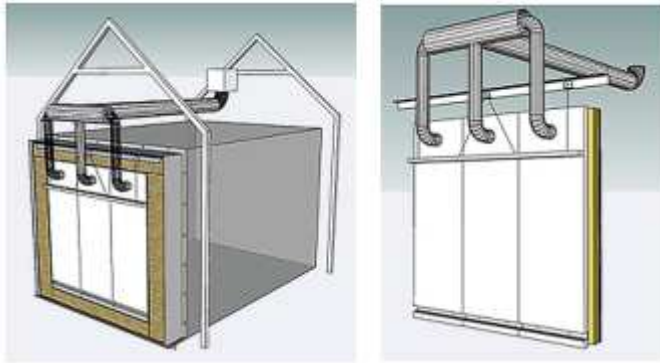


Figure 2.6 - Prototype design

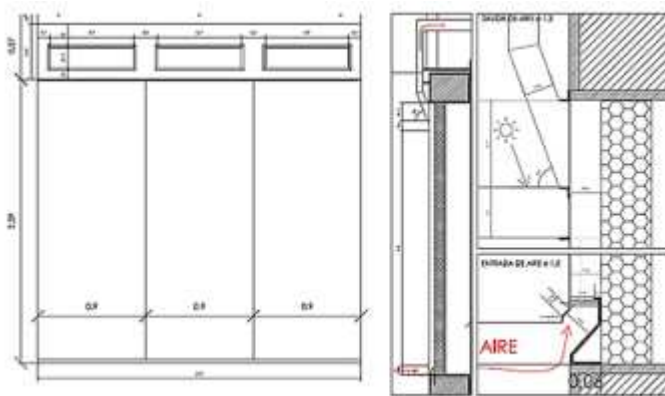


Figure 2.7 - Construction plans and anchoring details

Once the sample definition is made, the construction of the sample is the next step. It is carried out inside the industrial hall. The work is performed with the sample holder placed in a bed with precision and control, and total security for technicians, see Figure 8.



## Figure 2.8 - Construction of the sample

After the sample construction is completed inside the industrial hall, the sample holder is installed in the test cell. In this process a crane is used, see Figure 9. With the sample holder adequately secured, final work on the specimen and sealing of all perimeter joints to reduce infiltrations are performed. The suitable sealing of the joints is verified by the pressure test, achieving the requirement of less than 0,5 ren/h with 50Pa of pressure difference.



Figure 9 - Movement and installation of the sample in the test cell

### 2.2.3 . *Specific instrumentation of the sample*

The sample is equipped with the necessary instrumentation in order to achieve the characterization of:

- Thermal properties of the sheets that form the façade;
- Behaviour of air within the chamber ventilated.

For the measurement of these two properties , the following variables are recorded :

- Surface temperature

- surface heat flux
- air temperature
- air temperature difference
- air velocity
- Pressure drop and airflow

In Table 2.1 it is shown the technical characteristics of the measuring instruments used in the tests.

<b>Parameter</b>	<b>Units</b>	<b>Type of sensor</b>	<b>Uncertainty</b>
Temperature	°C	PT100, A class, connect 4-wire	± 0,2 °C
Temperature	°C	T type thermocouple	± 0,4 °C
Thermo pile	°C	K type thermocouple	± 0,01 °C
Heat flux	W/m <sup>2</sup>	Ahlborn FQA-0801-H	± 5 %
Thermo anemometer	m/s	Ahlborn FVA-605-TA-1	± 0,01 m/s
Differential pressure	bar	Ahlborn FD8612DPS/APS	± 0,5 mbar
Airflow	m <sup>3</sup> /h	Kimo CP300-ALETAS DEBIMO	± 3 %

Table 2.1 - Technical characteristics of measuring instruments

For the measurement of the thermal properties, surface temperature is recorded using Pt100 surface RTD. Along with temperature, the one dimensional flow in the central point of the surface is recorded, by heat flux meters.. For the measurement of the thermal properties, surface temperature is recorded using Pt100 surface RTD.

The measure of the air ventilated chamber conditions includes to record temperature and air velocity at different points. To measure the total heat gain that occurs in the air ventilated chamber it is used a thermopile of ten measurement points which can directly record the temperature difference between inlet and outlet of air , with high accuracy.

The last parameter is the pressure drops and are recorded by differential pressure sensors.

### 3- Ventilated facades

#### 3.1 - Light ventilated facade

The first point of the study is to define the constructive solution of the ventilated façade. It is chosen a base wall model widely used since the 1970s to mid-90s. It is a double brick leaf solution with an air chamber. After that, the light ventilated façade system is installed on the base wall. it is shown the constructive scheme of the sample In Figure 10.

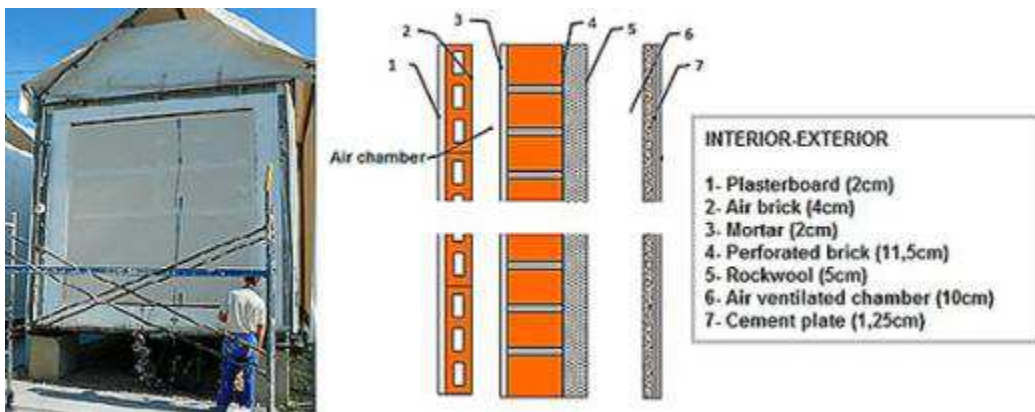


Figure 10 – Sample in the PASLINK cell (left) and constructive solution of light ventilated façade sample (right)

The experimental tests of the ventilated facades, which are much more complicated than the base wall, are divided into two different periods. In the first period, data are used to develop the mathematical model of the behavior of the ventilated chamber. The second period is used for validation or contrast.

Below, the most important parameters collected during the test period (about 15 days) are described, and the evolution of the main sample parameters during a representative day is shown.

Solar radiation and wind speed at the height of the sample is collected in the figure 11. These two variables are fundamental to the study of the behavior of the ventilated facade as they are responsible for the movement of the air within the

ventilated chamber. On one hand, the incident of the solar radiation on the outer leaf of the sample is the cause of the air movement by natural convection, and the main component to analyze in the test. On the other hand, when there are high wind speeds, the exterior air velocity pushing effect should be added to the flotation component in the air movement.

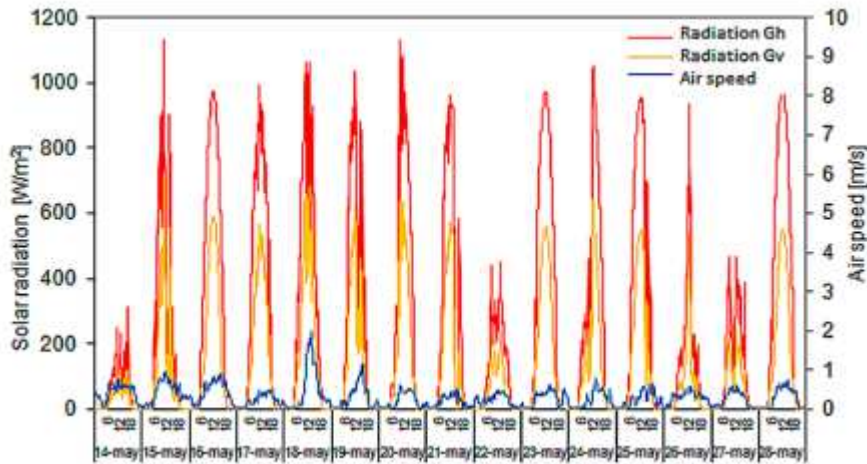


Figure 11 – Solar radiation and wind speed during light ventilated façade test period

In Figure 12 it is able to appreciate the evolution of the temperatures of the test room and of the outside environment. The average gap between these two temperatures is  $18^\circ\text{C}$ , maintaining homogeneity of air temperatures in the test room under  $0.5^\circ\text{C}$ . The test cell can be considered as a very stable workspace.

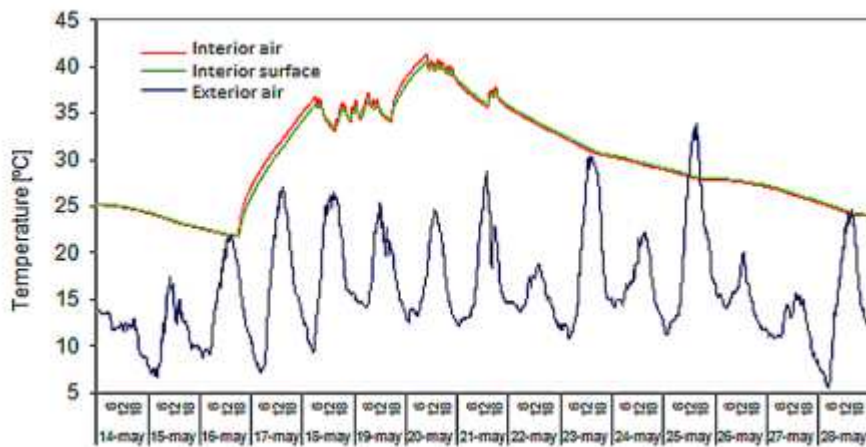


Figure 12 – Test room and exterior temperatures during light ventilated facade test period

### 3.2 - Heavy ventilated facade

After studying the thermal behavior of a light ventilated facade solution, the next objective is to characterize a sample that includes the effect of inertia on the outer layer. For this, the light sheet of cement is replaced by a heavy concrete sheet (8,5cm). Another parameter that is changed is the width of the air chamber (from 10cm to 3,5cm). Basically, all of these changes let us know the effect of the thickness on speeds and air flow rates in the ventilated chamber. Figure 13 shows the constructive solution of the heavy ventilated façade sample.

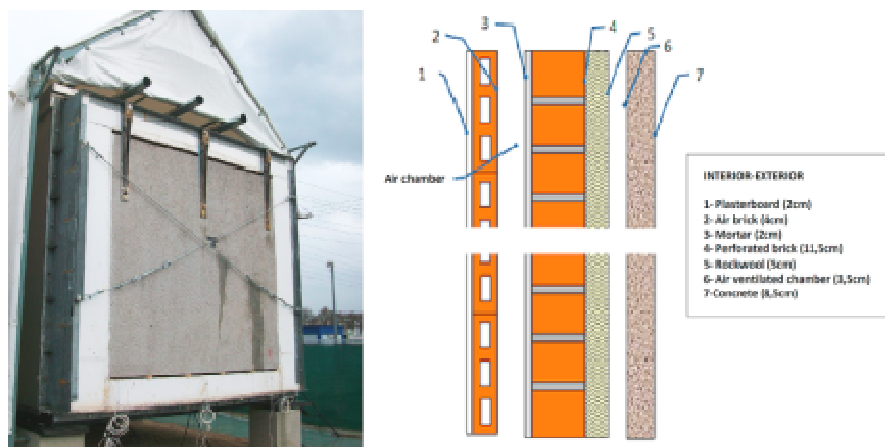


Figure 13 – Heavy concrete sheet and the sample in the test cell (left) and constructive solution of heavy ventilated façade sample (right)

### 3.3 - Comparison between light and heavy ventilated facade

To further analyze the behavior of the ventilated façade, the data of a representative day is taken. It is studied the development of the main variables, and the behavior of air is evaluated within the chamber depending on the environmental conditions of temperature and solar radiation. Finally both kind of facades, light ventilated façade and the heavy one, are compared.

The first parameter to be studied is the temperature. Figure 14 shows the variation of the temperature along the different layers of the two samples (light and heavy) at 1,35 meters of height.

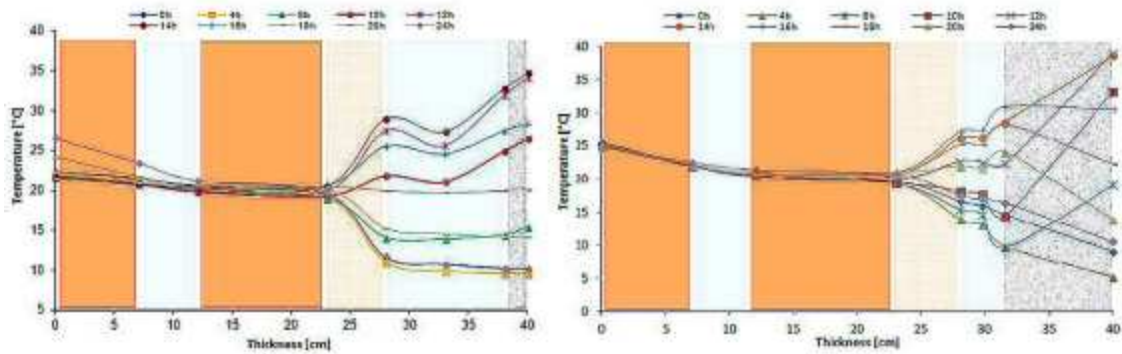


Figure 14 – Temperature profiles of the light ventilated facade sample (left) and temperature profiles of the heavy ventilated facade sample (right) at 1,35m.

The first worth mentioning point is that it can be appreciated that the temperatures of both samples before the insulating layer do not suffer large variations from the indoor environment. Temperatures remain very stable throughout all the day. On one hand, in the light facade solution, the temperatures of the ventilated chamber are not linked to the adjacent layers, and its temperature is usually less than the temperature of the insulating layer and the cement layer. The variation of the temperature has a parabolic profile. On the other hand, in heavy façade solution, temperature variation in the ventilated chamber is related to both layers, having a linear profile. The nearest zone of the ventilated chamber to the insulating layer has temperatures close to that layer, repeating the same phenomenon for the areas close to the concrete layer.

For a better understanding, in the next figure 15, the variation of the temperature of the ventilated chamber depending on the time and the thickness for both types of façade can be seen.

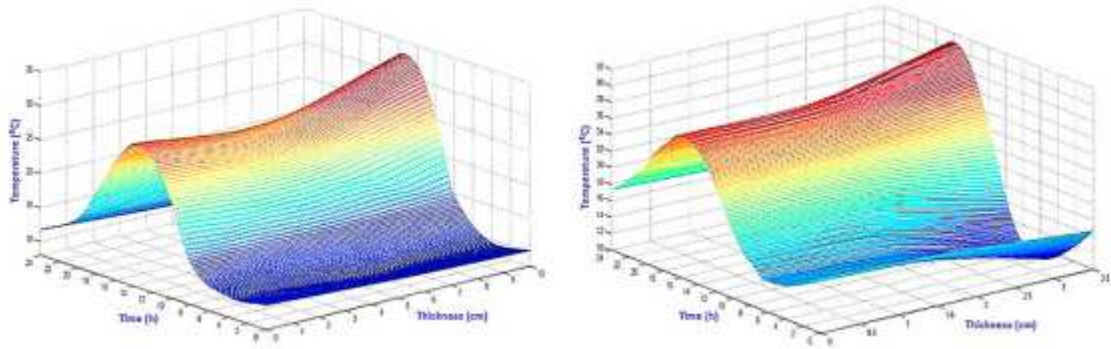


Figure 15 – Temperature variation in the ventilated chamber depending on the thickness and time of the light sample (left) and heavy sample (right)

Once the temperatures have been evaluated, the next important parameter to analyze is the behavior of the velocity of air in the ventilated chamber [11-13]. It directly participates in the dissipation of the heat by the air flow. Figure 16 shows the air velocity in the ventilated chamber of both solutions at different heights.

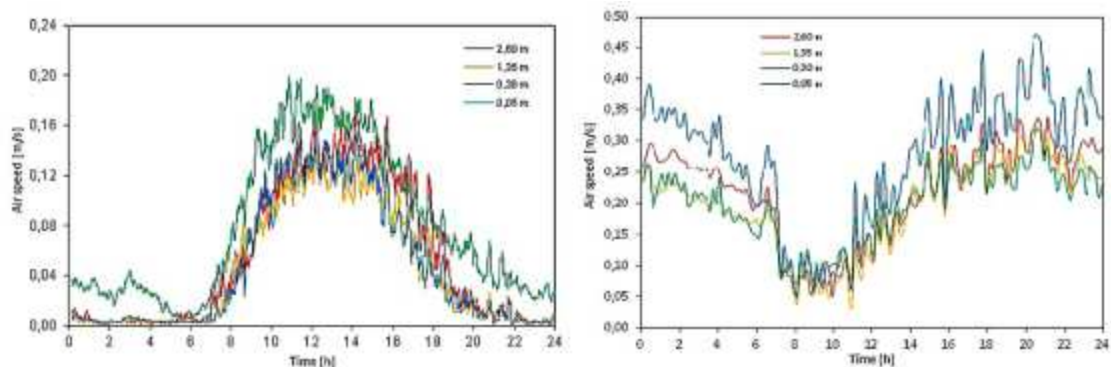


Figure 16 – Air velocity in the ventilated chamber of the light sample (left) and of the heavy sample (right) at different heights

As can be seen in the light ventilated façade, the maximum speed achieved in the ventilated chamber does not exceed values of 0.2 [m / s ] . There is an entry effect, and it is translated into an increasing of the air velocity, and it is clearly seen in the sensor placed at 30 [cm ] . From 50 [cm ] to the top of the sample the speed values are stabilized. The air acceleration takes place during the middle of the day, reaching a maximum value. During the night, those values are stopped.

Unlike the light façade , the air movement inside the heavy facade is much more constant. From 0h to 7h there are mean velocities about 0.2 [m / s ], due to the heat accumulated in the concrete leaf . Between 7am and 11am there is a break, because air temperatures are equal within the ventilated chamber than the outside air . And finally, between 11h and 16h there is an air acceleration to reach values about 0.3 [m / s ], which are held until the end of the day .

It is essential to know the thermal behavior of the ventilated chamber in order to get proper designs of active systems such as the ones which will be shown in the following sections.

#### **4- Active facades**

We are showing some different examples of facades that we have test in PASLINK cell over the last years. We start with light and heavy ventilated facades with forced air movement, after those samples it is shown a trombe wall, and the last example is a photovoltaic ventilated façade.

##### ***4.1 - Light opaque ventilated facade***

Figure 4.1 shows a light opaque ventilated façade test. The objective of this test was to mainly determine the combined solar energetic capture plus air impulsion capability as reinforcement for the HVAC equipment in installations with high loads of air renovations. In winter the air passing through the façade goes into the building and in summer it returns to the exterior. For the study of these kinds of façades, the test cell has an impulsion fan capturing the air of the chamber façade through three chutes. This configuration allows adequate control and stable air flow along with an accurate measurement of the air flow at all times [12].

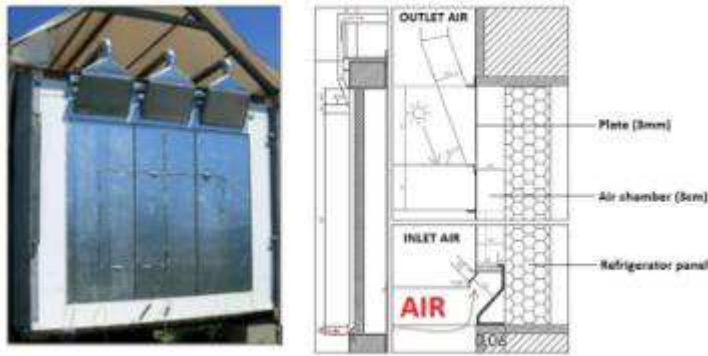


Fig 4.1 - Light opaque ventilated façade sample in Paslink test cell and the construction solution of the sample

It can be reached temperatures close to 60 °C in the external layer of the sample when maximum solar incidence happens, getting simultaneously an absorption of heat by the ventilated chamber. It is appreciated, that when solar radiation is reduced, the temperatures rapidly go down. Figure 4.2 shows for a single sample day what has been said in this paragraph.

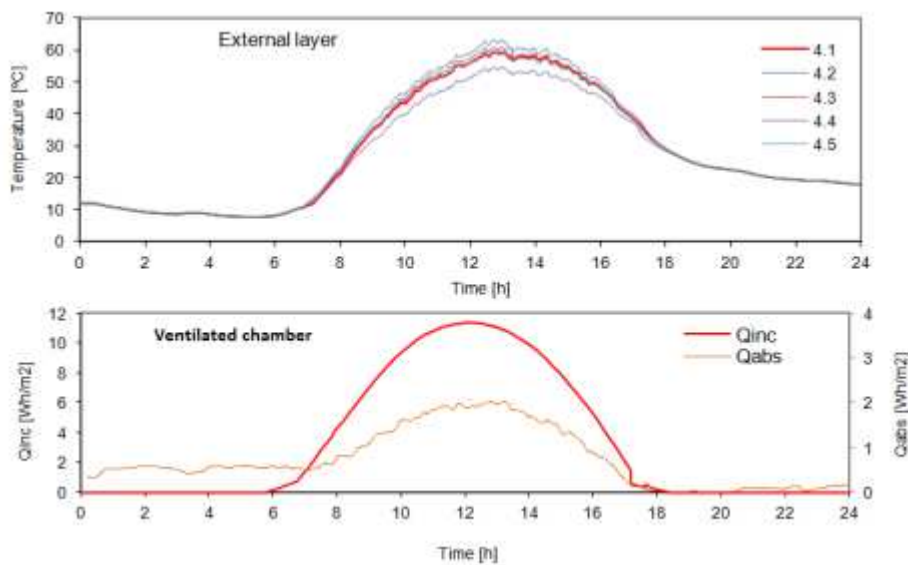


Figure 4.2 - Profile of temperatures (above) of the external layer and the solar radiation and absorbed heat (Below) in the ventilated chamber throughout a single day

Energy is absorbed only when there is solar radiation, because of the absence of thermal inertia of the external layer. This fact is a great disadvantage in the point that

energy production does not have to match with the moment of the energy demand.

Efficiency close to 22% were obtained, with an average of  $0.9\text{kWh/m}^2$  per day. Figure

4.3 shows the solar radiation and the absorbed heat by the ventilated chamber during the test period.

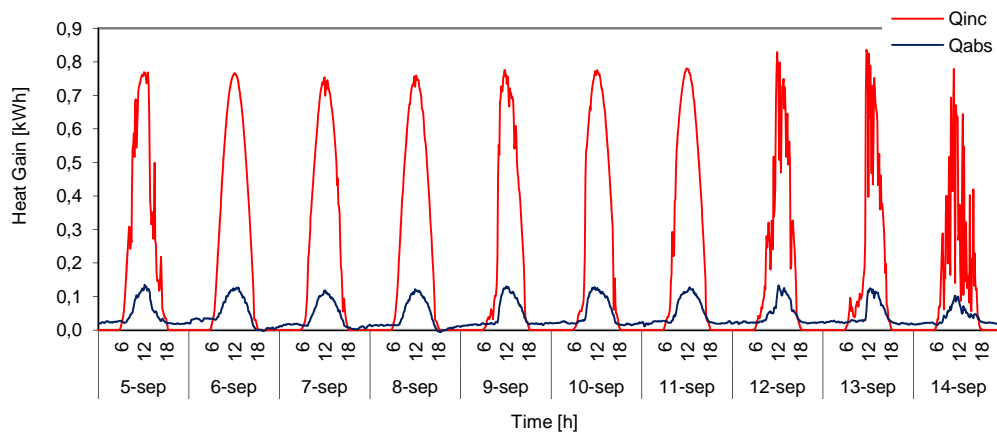


Figure 4.3 - Solar radiation profile and the absorbed heat in the ventilated chamber profile during 10 days

#### ***4.2 - Phase change material facade***

The second example is a test of a ventilated façade with forced air movement. The particularity of this façade is the use of phase change materials (PCM) [19] in the exterior layer instead of the light facade (previous example), increasing the solar capitation and employing the residual heat for winter heating, and to reduce solar gain in summer. The figure 4.4 shows the use of an air buffer in the entrance to the ventilated air chamber in order to eliminate the wind effect in the study.



Figure 4.4 - Forced ventilated facade with PCMs in the exterior layer

The advantage of this solution lies in the accumulation of heat by the PCM. When this process occurs, the increasing of the temperature is slowed down, getting lower maximum temperature values than in other solutions. When the cooling process occurs, PCM extend the temperatures profile along the time. The figure 4.5 shows the evolution of the temperatures in the PCM layer in a single day. To determine this temperatures profile, 15 temperature sensors were installed in the profiles at different heights. It can be appreciated that the process of absorbing the heat by the ventilated chamber remains in the time even though there is no solar radiation.

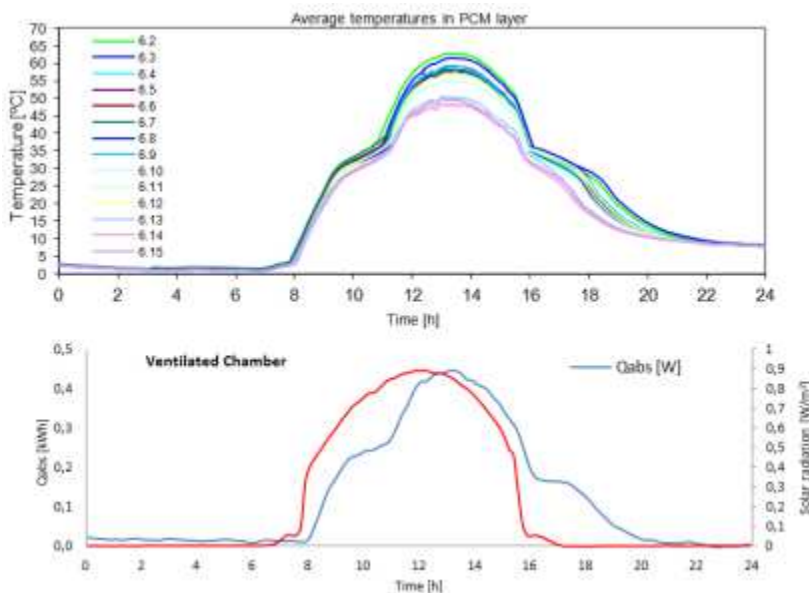


Figure 4.5 - Profile of temperatures (above) of the PCM layer and the solar radiation and absorbed heat (Below) by the ventilated chamber throughout a single day

The following figure 4.6 shows the absorbed heat in the ventilated chamber and incident solar radiation. It is seen that even after there is no radiation, the ventilated chamber is absorbing heat due to PCM. It is estimated that it is absorbed about 45% of solar radiation, with an average of 1,35 kWh/m<sup>2</sup> per day.

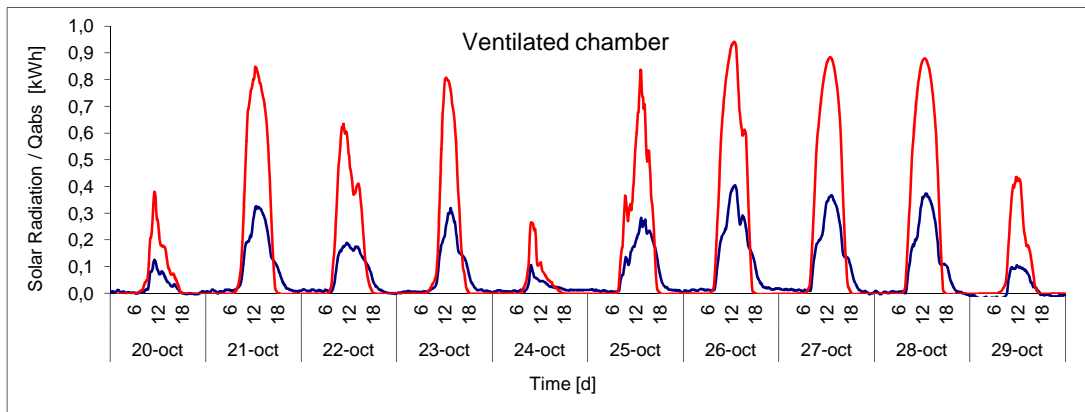


Figure 4.6 - Solar radiation profile and the absorbed heat in the ventilated chamber profile during 10 days

### 4.3 - Trombe wall

The next example is about Trombe wall [14-15-16-17]. The objective of this study was the analysis of the different ways for the solar radiation use through its capture and accumulation in the mass of the wall. The heat captured by the wall and accumulated by the greenhouse effect of the low-emissive glass used like an enclosure of the air chamber, could be managed by putting it into a conditioned indoor environment during winter through an interior-interior or exterior-interior air curtain. Likewise, the potential of a refrigeration condition can be analyzed through an exterior-exterior or interior-exterior air curtain. All of these possibilities are shown in the next paragraphs. This behaviour versatility can be added to a Bayesian network control system that allows to predict the climatic conditions evolution, and through a thermal behaviour model of the façade, to choose the adequate air curtain function for the maximum energy profit. The figure 4.7 shows the Trombe wall facade and the construction

definition of the sample.

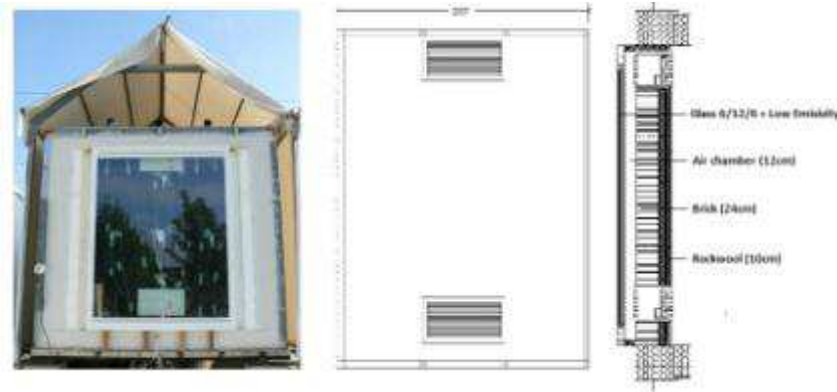


Figure 4.7 - Trombe wall facade and the construction solution of the sample

In summer conditions the air curtain configuration can be used to get refrigeration. In Figure 4.8 the evolution of the behavior of the ventilated chamber along the test period is shown, and it can be appreciated that the evacuated heat by the air curtain remains constant throughout the day, even when the solar irradiation was lower due to increased cloudiness. These days allow to reduce the contained energy in the brick leaf and improve the starting conditions for sunny days. It is estimated that it is absorbed about 57% of solar radiation, with an average of 1,8kWh/m<sup>2</sup> per day.

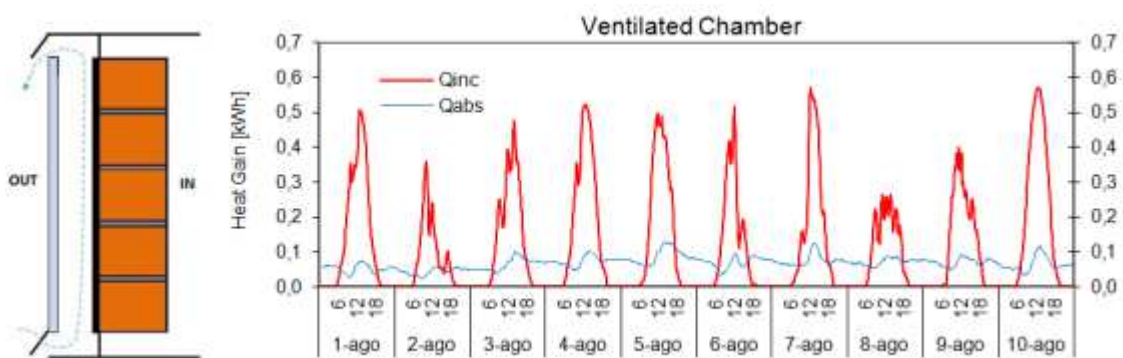


Figure 4.8 - Out-out air curtain configuration, incident radiation and absorbed heat during the test period

Using in-out air curtain solution, it can be observed how the cooling effect depends more on the solar component than in the case of outdoor air curtain

configuration. It generates higher percentages of absorbed heat than in the previous example. This described behavior is shown in figure 4.9. It is estimated that it is absorbed about 36% of solar radiation, with an average of 1,4 kWh/m<sup>2</sup> per day.

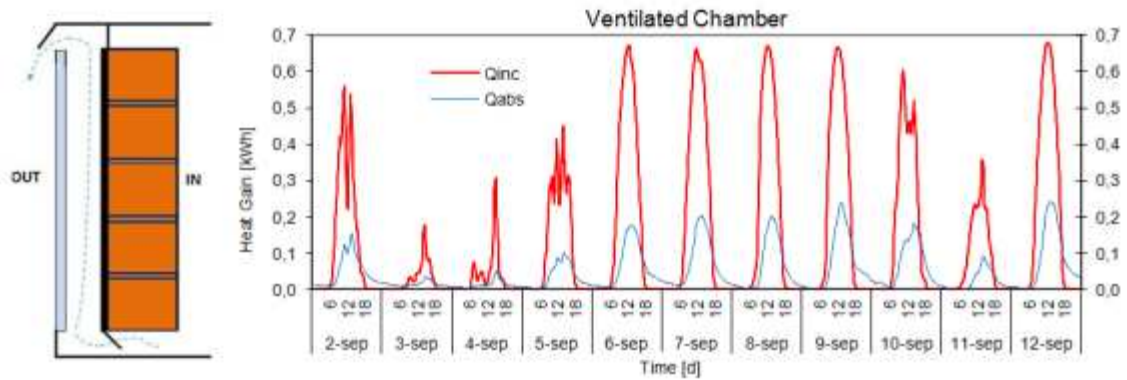


Figure 4.9 - In-out air curtain configuration, incident radiation and absorbed heat during the test period

In winter conditions the indoor air curtain solution has a clear objective: heating the building by passing the inside cold air of the house through the air ventilated chamber. The gained heat in the process is shown in figure 4.10. It is estimated that it is absorbed about 58% of solar radiation, with an average of 1 kWh/m<sup>2</sup> per day.

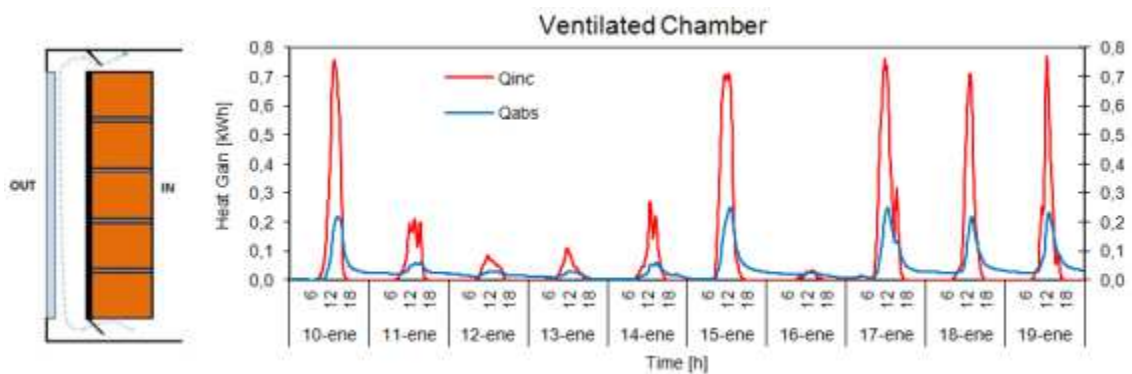


Figure 4.10 - In-in air curtain configuration, incident radiation and absorbed heat throughout a single day

Last air curtain solution can be used in spring, getting high percentages of absorbed heat due to the speed of the air in the ventilated chamber. Even in a day with little solar radiation because of the cloudiness, the absorbed heat maintains constant or

even higher than the solar radiation. Figure 4.11 shows the process. It is estimated that it is absorbed about 61% of solar radiation, with an average of 2,6 kWh/m<sup>2</sup> per day.

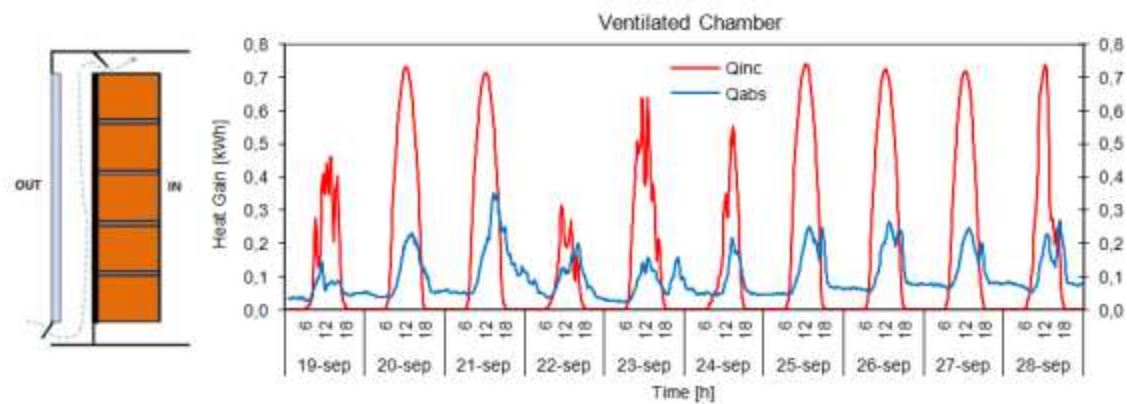


Figure 4.11 - Out-in air curtain configuration, incident radiation and absorbed heat throughout during test period

#### 4.4 - Ventilated Photovoltaic facade

The last example is a ventilated photovoltaic façade. This solution is the most common type of active systems in building envelopes, being the solar production the unique important part, forgetting that the exchanged heat within the ventilated chamber increases the energy building efficiency. In most of these facades, the air curtain is only used for cooling photovoltaic panels and improve the hygroscopic behavior of the facade. In this commercial solution test with outdoor air curtain, the behavior of the ventilated chamber is studied in order to get electrical behavior of the photovoltaic panels much more efficient and to use the absorbed heat within the chamber. This kind of active façade has great potential to introduce a forced extraction system [18], as it has been shown in previous examples which would greatly improve the overall energy efficiency of the envelope of the building. In the figure 4.12, the façade sample in the Paslink cell and the electrical behavior of the photovoltaic panels are shown.

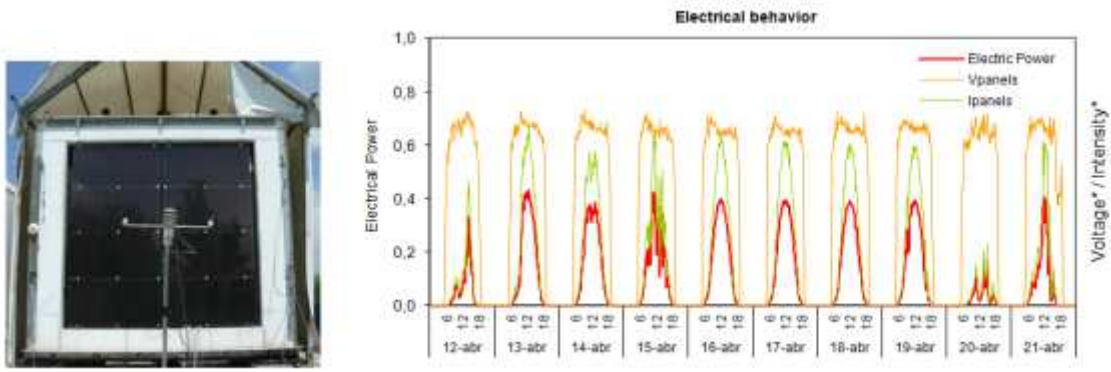


Figure 4.12 - Photovoltaic facade sample (left) and the electrical properties of the sample during the test period \*The shown values are nominal ones

As it has been mentioned above, an important aspect of the study was to quantify the absorbed heat by the air of the ventilated chamber in relation to the incident solar radiation. For a test period of 15 days, considered fully representative, the heat gain percentage was close to 30%, with an average of 1 kWh/m<sup>2</sup> per day. It could be used to supplement in building heating. Figure 4.13 shows the absorbed heat in the ventilated chamber.

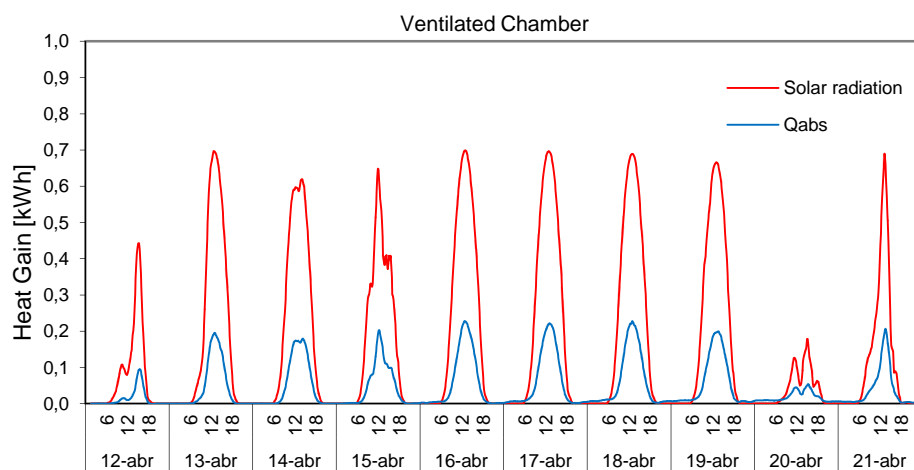


Figure 4.13 - Solar radiation and absorbed heat by the air curtain during 10 days of the test

## 5- Summary and conclusions

We have already noticed that PASLINK test cell allows us to characterize reliably and accurately any type of ventilated facade. Furthermore, we are able to know the behavior of ventilated chambers and it brings us new opportunities to use them in optimal conditions in a near future.

Analyzing the examples that are shown in the paper, and starting with ventilated facades, we can see how the thermal inertia of materials can affect in absorbing heat from solar radiation. An external layer with thermal inertia let the ventilated chamber to reach high air temperatures, high air velocities and extended periods of time absorbing heat (energy) even when there is no solar radiation. This energy can be used for cooling or heating depending on the weather conditions, the season of the year, the location...

For this reason, It appears to be very interesting the concept of using forced air movement to optimize the solar gain → Active facades

Within active facades, it has been observed that for the same base wall, and only changing external layer of the solution, the heat collection efficiency of the ventilated chamber is doubled in the case of thermal inertia materials (in this case, phase change materials with heat storage). Another example shows a Trombe wall, and changing only the air curtain configurations we can get great efficiencies in all seasons. Finally, ventilated photovoltaic facades would be more useful if we take advantage of the absorbed heat by the ventilated chamber.

If the main goal is to achieve a NZEB (Nearly Zero Energy Building), there is only one way to get it, and it is about working with experimental data and testing all the different solutions in order to have optimal active facades which generate energy and participate in the energy demand of the building.

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