ITC

TECHNICAL REPORT

N° 2012.09.20.382

Energy performance assessment of a dynamic window called VetroVentilato

AUTHORS

Ludovico Danza

Italo Meroni

DIRECTOR

Roberto Vinci

ITC ∩

CONSIGLIO NAZIONALE DELLE RICERCHE
ITC
Istituto per le Tecnologie della Costruzione

RAPPORTO TECNICO

N° 2012.09.20.382

Valutazione delle prestazioni energetiche di un serramento dinamico denominato VetroVentilato

AUTORI

Ludovico Danza

Italo Meroni

DIRETTORE

Roberto Vinci

Index

1   Introduction

This report relates to the results of the experimentation carried out on a dynamic window in agreement with the VetroVentilato srl.

The experimental campaign, conducted at the headquarters of ITC-CNR located in San Giuliano Milanese (MI), began in March 2011 and ended in August 2012.

The objective is to characterize the energy performance of the ventilated window. This study compares the thermal performance with that of a traditional window in terms of energy consumption, hygrothermal comfort and thermal transmittance variation.

The experimentations have identified the weather conditions in which the best results are obtained specifying the extent to which one window is better than the other, by analyzing its behaviour in external test cells, in both operating conditions of the heating and cooling plant (winter and summer) in order to compare consumption and, in the absence of the plant, to verify the hygrothermal comfort.

Such considerations are fundamental to designing a building, not only in compliance with the minimum requirements imposed by law, but also in order to size and properly manage energy flows and the control logic of a dynamic system.

As a second step attention has been paid to the thermal transmittance behaviour of the window in place. As it is well known, the thermal transmittance is not a constant characteristic of an element of building envelope.

Such a parameter is affected by the variability and the dynamism of the heat flow which passes through, for example, a window and it also depends on the operating temperatures of the environments which the element separates.

The focus is primarily on the real variation of the thermal transmittance, even in the presence of radiation, as a function of the air flow passing through the ventilated gap of the window in real operating conditions.

Although usually used for energy diagnosis and monitoring, the procedure for calculating the Energy Signature has been introduced for the analysis, thanks to which it was possible to verify and validate the thermal transmittance performance compared to a calculation conducted with the WIS software in accordance with ISO 15099.

2 EXPERIMENTAL ASSET

2.1 Experimentation management

An experimental campaign relies principally on measures carried out in working conditions in temperature-controlled environments. It is often accompanied by laboratory analysis and theoretical calculations.

Conducting an experimentation on dynamic windows must consider and measure several "independent" variables.

Such parameters, reported in Table 1, intrinsically affect the performance of the system and only a careful design allows them to be exploited to one's own advantage.

The results that emerge from an experimentation allow these variables to be controlled better and to determine, through the intersection of them, operating system algorithms that optimize the performance of the dynamic window.

Table 1. Variables of the system

	Independent variables	Value	Unit
1	Blind	Colour and distance from glass	cm
2	Air flow rate	0.9	h^{-1}
3	Extraction gap	Function of the experimental asset	--
4	fan	Function of the experimental asset	--
5	Ventilation period	Working day	h

In general it is possible to define the dependent variables that are the result of the analysis from three points of view: those carried out in the laboratory, those in operating conditions and theoretical ones.

Table 2. Dependent variables

Experimental analysis	Dependent variables
1	Energy consumption
2	Hygrothermal comfort

2.2 Test cell description

The test cells have dimensions 2.80 x 2.80 x 5 m. Their characteristics simulate the conditions of useful thermal mass, retrievable in national construction typologies (Figure 1).

Their degree of thermal insulation is high enough so that the external air temperature does not influence their behaviour during the test of a system.

The cells are equipped with internal temperature control devices and the temperature is obtained, in the winter season, by means of an electric heating system and, in the summer season, by means of a cooling system.

The cells are also equipped with a ceiling fan to ensure the homogenization of the indoor air temperature and to prevent stratification.

The cells are fully monitored with temperature and relative humidity sensors and are equipped with an electric energy meter; for each the air exchange per hour was measured.
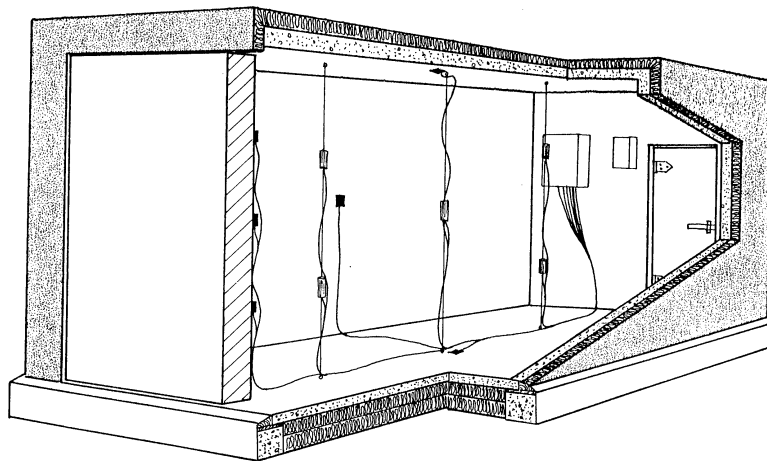
Figure 1. Outdoor test cell

2.3   Monitoring system

The test cells are equipped with an environmental monitoring and data acquisition system aimed at:

- determining the conditions of the internal environment;
- analyzing the behaviour of the internal surface temperatures of the walls;
- assessing the achievement of the conditions of internal comfort;
- measuring the energy consumption of the heating and cooling systems.

The system consists of two dataloggers TMF500 which represent the central unit of the remote control, monitoring and data acquisition system.

They are positioned in each of the two cells and have been configured for data collection and the sending of data via FTP to a dedicated server. Each device allows the connection of 24 sensors of different types.

Figure 2. Datalogger TMF500

The following parameters are measured:

- external monitoring:
    - o wind velocity and direction along the cartesian components u, v, w;
    - o temperature;
    - o relative humidity;
    - o solar radiation;
- internal monitoring:
    - o air temperature;
    - o radiative temperature;
    - o relative humidity;
    - o energy consumption;
- monitoring of the window:
    - o surface temperature of the external glass;
    - o surface temperature of the internal glass;
    - o surface temperature of the blind;
    - o air temperature at the outlet of the gap.

The internal temperature has been detected using Pt100 platinum resistance thermometers. Pt100 probes have a resistance of 100 ohms at a temperature of 0° C.

The relationship between the temperature and the resistance is approximately linear for a small range of temperature: from -40° to +60° C. The thermometers used have been certified by the producer as Class A probes, ensuring a precision of ± 0.15° C to 0 ° C.

Figure 3. Pt100 resistance thermometers

The air temperature is measured at 5 different points. The relative humidity is measured using a capacitive transducer made of a thin-film element whose capacity varies linearly with the relative humidity of the air, measuring a voltage between 0 and 1 V.

The range of relative humidity is 0 - 100%, with an accuracy of ± 2%. All data are certified by the producer.

Figure 4. Relative humidity and air temperature sensor for internal

Figure 5. Shielded temperature sensor

For measuring radiant temperature globe thermometers with Pt100 transducers are used. The sensor is secured within a copper sphere painted dull black (diameter 15 cm) and the shield is made in such a way as to ensure in any case the heating of the sensitive element.

Figure 6. Globo - thermometer

Consumption is monitored through a digital pulse converter that accounts for the energy consumption of the test cell.

The output of the converter is connected to the datalogger that, through channels dedicated to the reading of digital signals, is able to count the transmitted pulses and indicate the overall consumption.

Figure 7. Electrical panel with digital counter

A weather control unit measures the weather conditions. It is a system similar to that which is present in the test cells, constituted by a datalogger TMF500 and the following sensors:

- outdoor temperature and relative humidity sensor;
- solar radiation sensor;
- triaxial sonic anemometer.

The combined sensor for measuring relative humidity and temperature has the same characteristics as those used in the indoor environment: the outer coating protects against solar radiation and atmospheric events.

Figure 8. Relative humidity and air temperature sensor for external

The global solar radiation is measured through a Class 1 pyranometer. The sensor is constituted by a thermopile transducer, protected by a glass dome able to ensure high sensitivity in the range of 0.3 to 3 microns. The output signal of the sensor is 0 to 2 V corresponding to $0 \div 1300$ W/m2.

Figure 9. Global solar radiation sensor

An ultrasonic anemometer with three axes measures the wind conditions outside of the test cells. It is a device that gives information about the speed and direction of the wind, as well as the speed of sound and the sonic temperature in operational conditions. In this way it is possible to reconstruct the Cartesian components of the wind.

The direction and elevation of the wind with respect to the horizontal direction are measured with an accuracy of ± 1°. The wind speed is measured with an accuracy of ± 1% corresponding to a range of 0 - 60 m/s and 300 - 380 m/s. The temperature is measured in the range of -40° - +60° C with an accuracy of ± 1° C.

Figure 10. Ultrasonic anemometer

The datalogger acquires the data every 10 seconds. However, in order to avoid generating a huge amount of data difficult to manage, a measure is recorded every 5 minutes. The maximum, minimum and mean data are calculated in the range of acquisition. The mean datum, on which the analysis is carried out, is the most significant.

The data recorded by the datalogger is sent to the FTP server every 6 hours in order to reduce the number of files generated during a day and the procedures for their sending to 4. The data, once copied to the FTP server, are transferred into a relational database for quick reference, made by using Microsoft SQL.

2.4   Positioning of the sensors

The sensors were positioned to create a mesh of measurement from which average values representative of the test environment cold be extrapolated. As illustrated in Figure 11 and Figure 12 the sensors are positioned: along a diagonal in a central position, near the floor and near the ceiling.
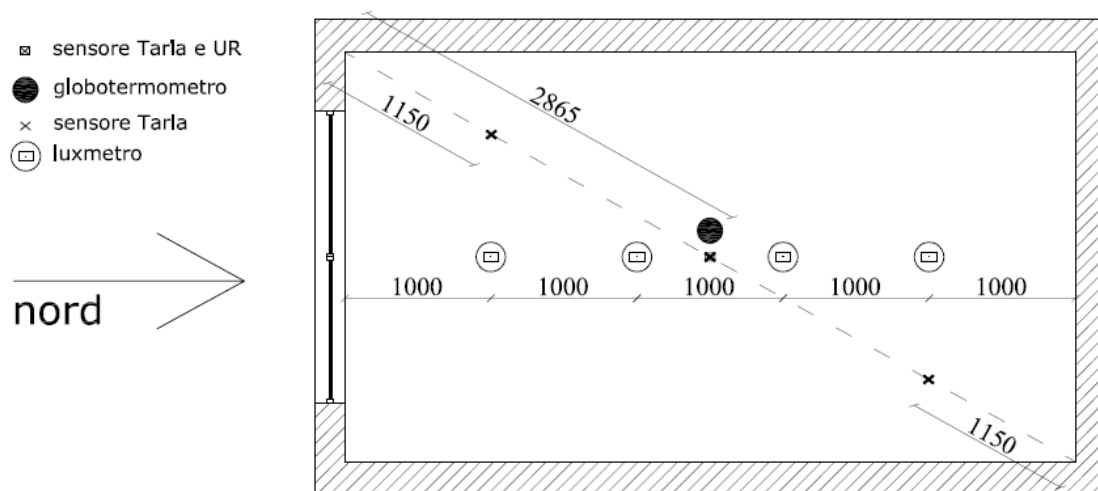

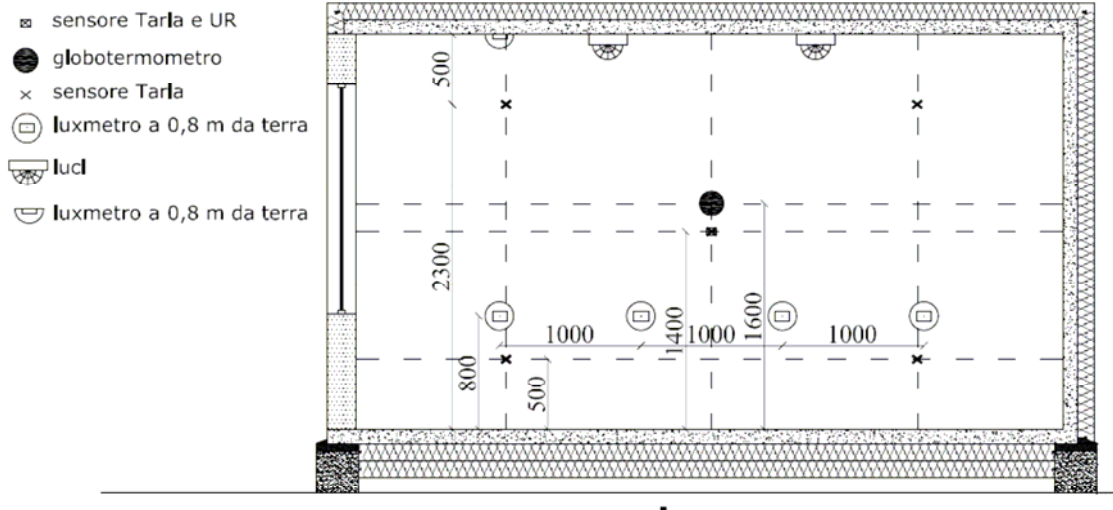Figure 11. Test cell plan. Positioning of sensors

Figure 12. Section of the test cell. Positioning of sensors.

2.5 The heating and cooling plant

The heating of the test cells was assured by 2 kW electric heaters with an efficiency approximately equal to 1.

To cool each of the test cells, a residential split type air conditioning unit constituted by internal and external units with a nominal COP equal to 3.6 was used
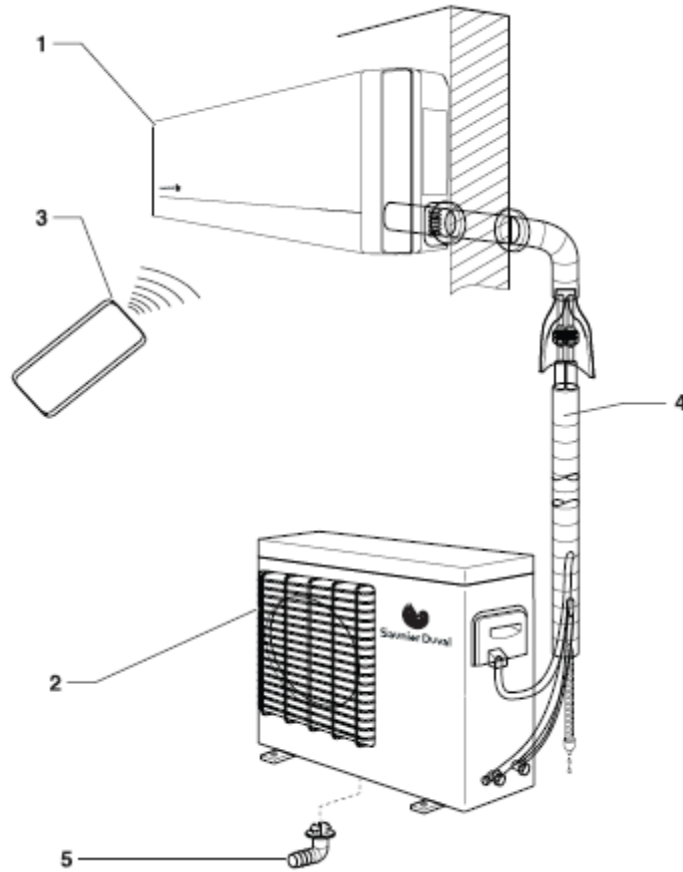
Figure 13. Heat pump: 1_Internal Unit; 2_External Unit; 3_Remote control; 4_Links and pipes; 5_Condensate drain pipe

The system can operate in "Cooling" mode or in "Heat Pump" one. In this experimental campaign the system works only for cooling. The external unit, through the condensation of the refrigerant, releases the heat removed from the internal environment using the split evaporator into the external environment.

2.6   The air change system

The cells are equipped with an air change system that is able to assure 40m3 / h, equal to the replacement of a volume in an hour.

The axial centrifugal aspirator, fitted to the reference cell, has a nominal diameter of 10 cm and is equipped with a minimum and maximum speed.

Figure 14. Centrifugal fan

From the technical sheets the technical information reported in Figure 14 emerges.

Table 3. Technical data of the centrifugal fan

Velocity	Absorbed current (A)	Absorbed power (W)	Air flow rate (m^3/h)	Rpm	Sound emission (Lp dB(A) 3m)	Pressure (Pa)
minimum	0.32	65	150	1660	51	274
massimum	0.38	85	235	2540	56	392

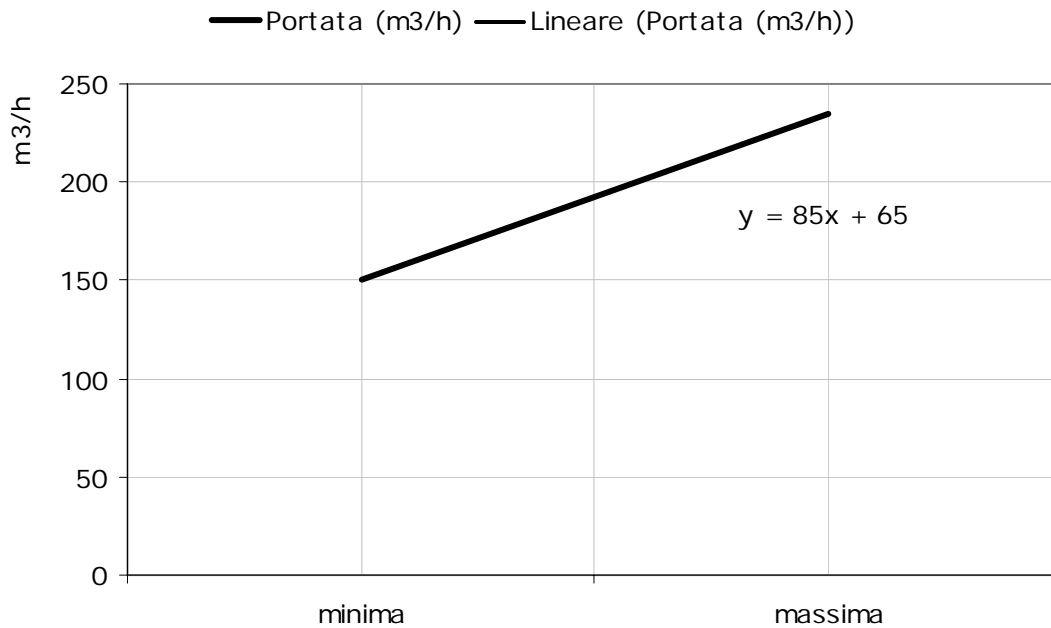Thanks to a control system it is possible to obtain 10 different speeds according to a linear trend.

Figure 15. Air flow rate in function of velocity

The operation of the extractor is adjusted to ensure the air change of 1 vol / h in the reference cell, while the same flow rate is guaranteed by the "VetroVentilato" in the other test cell.

2.7 Calibration of test cells

To proceed properly with an experimentation it is necessary to provide a preliminary calibration step of the thermal losses for ventilation and transmission by comparing two cells built with

completely opaque vertical and horizontal envelopes. Once the analogy of the energy behaviour of the two cells was checked, test windows were then fitted to them. Figure 16 shows energy behaviour with respect to accumulated degree-hours.
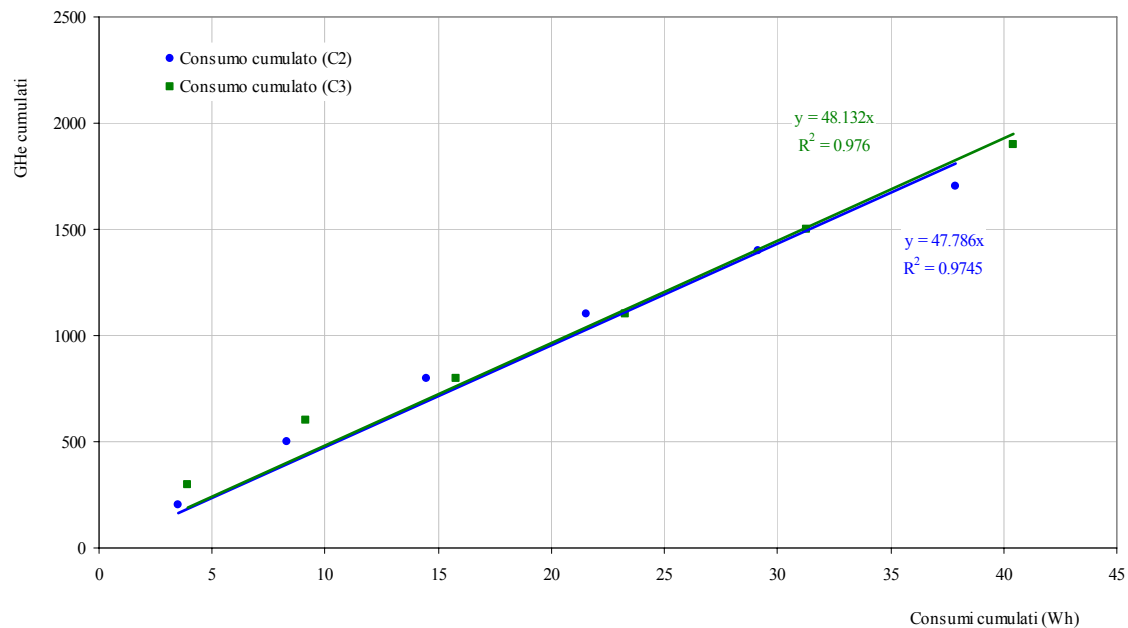

Figure 16. Cumulated consumption

The consumption trend indicates an identical energy behaviour of the cells.

Figure 17 shows the air change trend of the two cells. The blue line shows a cyclic pattern of activation of the extraction system (8 minutes per hour), alternated with a natural ventilation. The red line shows an almost constant trend of the air change per hour assured by the fan that is always operative in the window.

The average air change per hour for the two systems is the same. In fact, comparing the slope of the two straight lines you get the same values that represent precisely the air change rate.
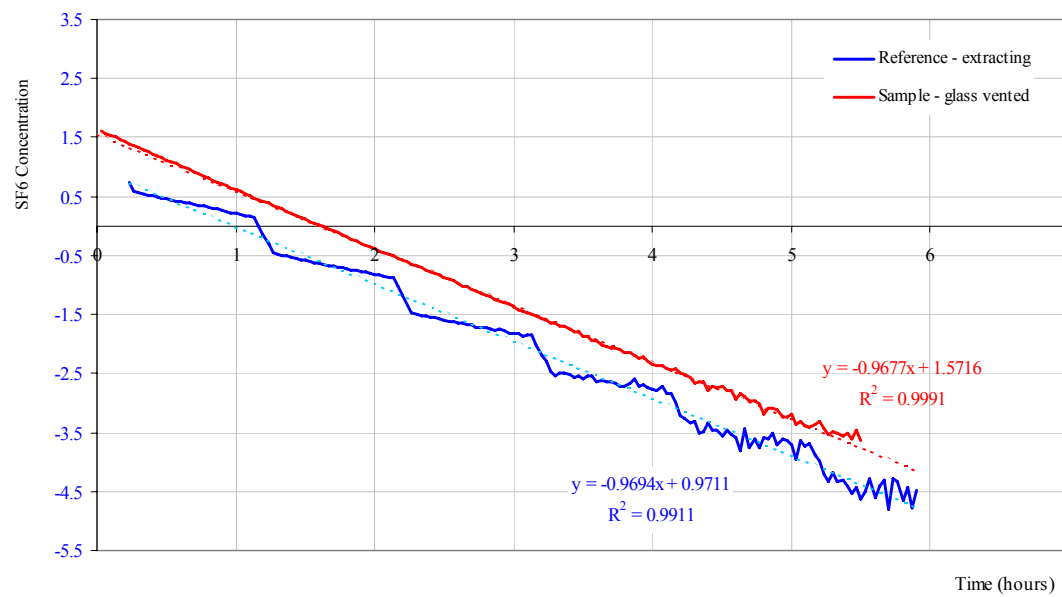
Figure 17. Air change per hour

The calibration phase thus demonstrated the effective equality of the experimental set-ups from an energy point of view.

2.8 Experimental program

From an energy point of view, consumption is measured in operative conditions (cooling in summer and heating in winter) to quantify the energy saving that is achievable with the application of a transparent ventilated system compared to that of a traditional reference window, in the same period of time, on equal internal microclimatic conditions ($\Delta\%$ PPD ≈ 0).

The experimentation is carried out on two test cells built with the same physical and geometrical characteristics relatively to the opaque vertical and horizontal envelope, and appropriately monitored and calibrated.

The calibration phase that preceded the experimental activity allowed different energy behaviours of the opaque envelopes and plants to be excluded. Two windows are fitted into both cells which are identical in terms of type of glass (low-emission double glazing), window (aluminum thermal break), size and darkening system (white microperforated blind).

To the first cell, called reference cell, a non-ventilated traditional window is fitted. The same window is fitted to the second cell (called sample) in which, however, there is a device for the mechanical ventilation.

The only difference between the cells is the ventilation system and the physical principle adopted for air change.

In the reference cell there is a centrifugal extractor located on the north wall, while in the sample cell the air change is guaranteed by a fan located in the upper frame of the window which extracts air from the inside toward the outside south.

In the first case the air at 20 ° C is directly ejected from the environment, while in the second case the indoor air enters the ventilation chamber of the window, between the blind and the glass surface, touches the transparent surfaces slightly and is extracted by the fan.

Appropriate tests for measuring the concentration of the SF6 tracer gas in confined environments allowed the air change per hour of the different mechanical ventilation systems to be adjusted.to a value close to 0.9 h-1.
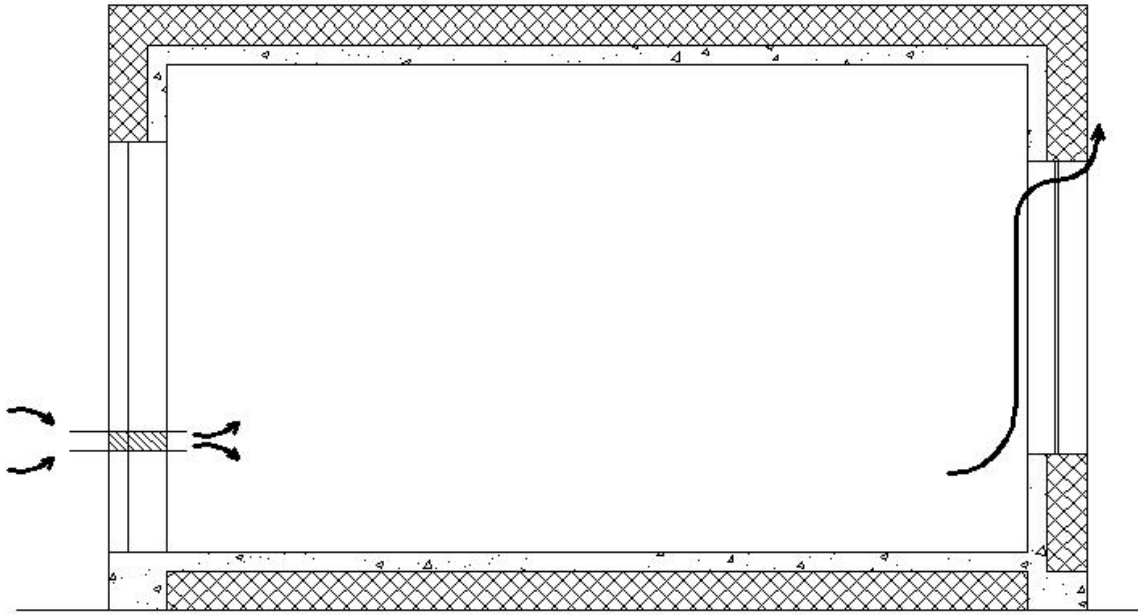

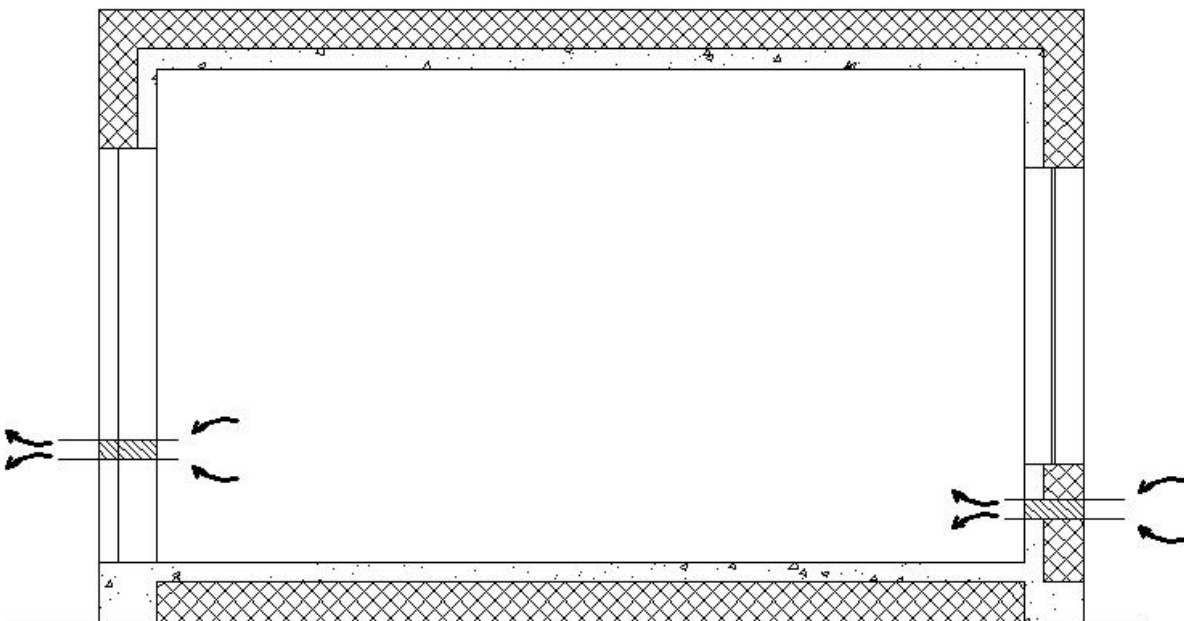Figure 18. Test cell section - Scheme of ventilation in the sample cell (VetroVentilato)

Figure 19. Test cell section - Scheme of ventilation in the reference cell

The choice of a selective experimental configuration allows a clear objective to be pursued: to study and verify the transmission behaviour of the sample window in real dynamic conditions by comparing the results with those obtained with the WIS software under standardized boundary conditions.

Secondly, we evaluate the energy saving achievable with such a window.

The identification of the test cells was carried out according to the following nomenclature:

- Cell 2: the cell to which was fitted the traditional window;
- Cell 3: cell to which was fitted the ventilated window.

The presentation and interpretation of results will be done using the above mentioned nomenclature.

2.9 Theoretical analysis
This section describes the theoretical approaches followed for analysis.

2.9.1 *Energy Signature*

The Energy Signature is a graphical representation of a real consumption (gas, electricity), as a function of an external factor (for example the external temperature).

The Energy Signature of buildings, according to the UNI EN 15603, is an evaluation method in which the energy consumption is correlated with climatic variables.

Unlike the energy classification that requires an aggregation of several variables and an expression of qualitative data with a single index with respect to a reference scale, the Energy Signature describes the energy real behaviour of building.

The Energy Signature is a graphical representation of a power or energy consumption (heating, cooling, hot domestic water, etc.) as a function of an external parameter (usually the outside temperature). The ES is used to compare the actual consumption of a building with other buildings, and to compare the calculated and real values or to verify the quality of an energy refurbishment.

The Energy Signature doesn't give an indication of the optimal use of a building. It is a qualitative tool. The comparison between the curves provides useful information for understanding the functioning of the plants and the building behaviour. Through the energy consumption trend ES method allows the heat loss variation of the envelope to be assessed. The test cells have the same characteristics as the opaque envelope. Only the windows are different. In this way the ES method allows the performance of the thermal transmittance of its windows to be calculated.

According to EN 15603 the Energy Signature depends on the thermal loss coefficient H, determined as a function of transmission and ventilation losses of the building; this coefficient represents the slope of the straight line, known as Energy Signature, interpolating energy consumption.

As is known, the angular coefficient of the straight line is represented by the ratio between the thermal powers (given by the difference between the power at the external temperature and that at 0 ° C) and external temperatures:

$$H = (\Phi - \Phi_0)/(\theta_e - \theta_0) \qquad (4)$$

The unit of measurement is the same as the coefficient of heat loss: W / K.

The "H" coefficient, in accordance with EN 13790, represents the reactivity of the building to the changes of external temperature and it can be calculated according to the formula:

$$H = H_{tr} + H_{ve} \qquad (5)$$

where:

H_{tr} is the thermal loss coefficient for transmission;

H_{ve} is the thermal loss coefficient for ventilation.

Comparing the angular coefficients of the two cells differences may arise depending on the weather conditions.

2.9.2 Hygrothermal Comfort

The thermo-hygrometric comfort environment has been studied, refering to the method described in the UNI EN ISO 7730, and then by calculating the PMV index PPD ("Percentuage of Predicted Dissatisfied") that provides information on thermal discomfort, discomfort or heat, providing the percentage of people who perceive a sense of discomfort in the environment.

3 DESCRIPTION OF SAMPLES

This chapter describes in detail the technical characteristics of the analyzed sample.

3.1 Description of frame

The frame supporting the glass is the PR75TT model produced by Presal Extrusion Italy Srl.

For the purposes of the experimentation it was decided to use a thermal break aluminum frame of high average performance, standard and easy to find on the market.

The sample in question is equipped with a frame L series called PR75TT, produced by Presal Extrusion Srl Italy.

The PR75TT range is constituted by a system of L and Z profiles that allow the construction of hinged doors and windows.

The fixed frame windows have a 67 mm section and a 75 mm shutter section. In this way the outer surface of the window is coplanar and has an 8 mm thick overlap inside, between the surface of the opening parts and those of the fixed parts.

The extrusions for window and door are made of EN AW 6060 aluminum alloy, the thermal cut is achieved by the insertion of PA6.6 polyamide bars reinforced with 25% glass fiber, assembled with the aluminum semi-extrusions by means of mechanical rolling . The insertion of thermal bars will ensure a thermal transmittance value of the window Uw <2 W/m^{2}K.

The fixing of the glass is obtained by glazing beads with locking mechanism or fitting them by bayonet method with useful height of 22 mm. All seals are in EPDM / DUTRAL.

For the experimentation a window with two fixed glasses and devoid of opening shutters was made. For the realization of the frame a 67 mm fixed extrusion was used. In Figure 20 the section of the side fixed extrusion of the installed window is shown.
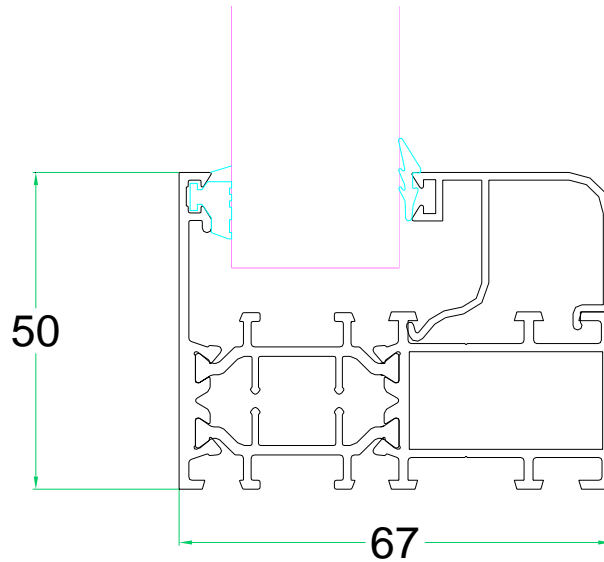
Figure 20. Section of the frame

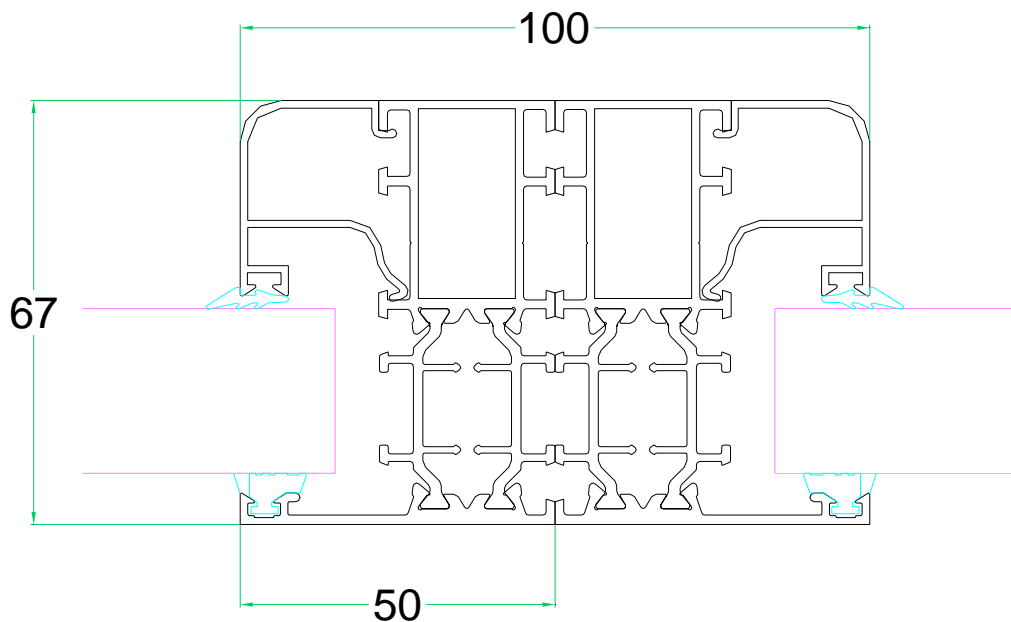The central fixed window-post is obtained by uniting two side extrusions as shown in Figure 21.

Figure 21. Section of the central frame

The frame was tested according to UNI EN ISO 14351-1. To verify its performance, calculations of the thermal transmittance were made using flixo 5.0, a software of finite element simulation. It calculates thermal bridges and is validated according to UNI EN ISO 10211:2007 and UNI EN ISO 10077-2:2006.

To obtain the thermal transmittance value relative to a node, using Flixo, we start from the dwg drawing provided by the applicants. The thermal conductivity values of various materials, supplied by the software as table values, are assigned to it .

The choice of materials from the library of Flixo 5.0 was conducted on the basis of : the documentation provided by the applicant , the UNI EN ISO 10077-2 or literature data.

Through simulation a thermal transmittance value of the node equal to $U_f = 2.26$ W/m^{2}K was obtained.
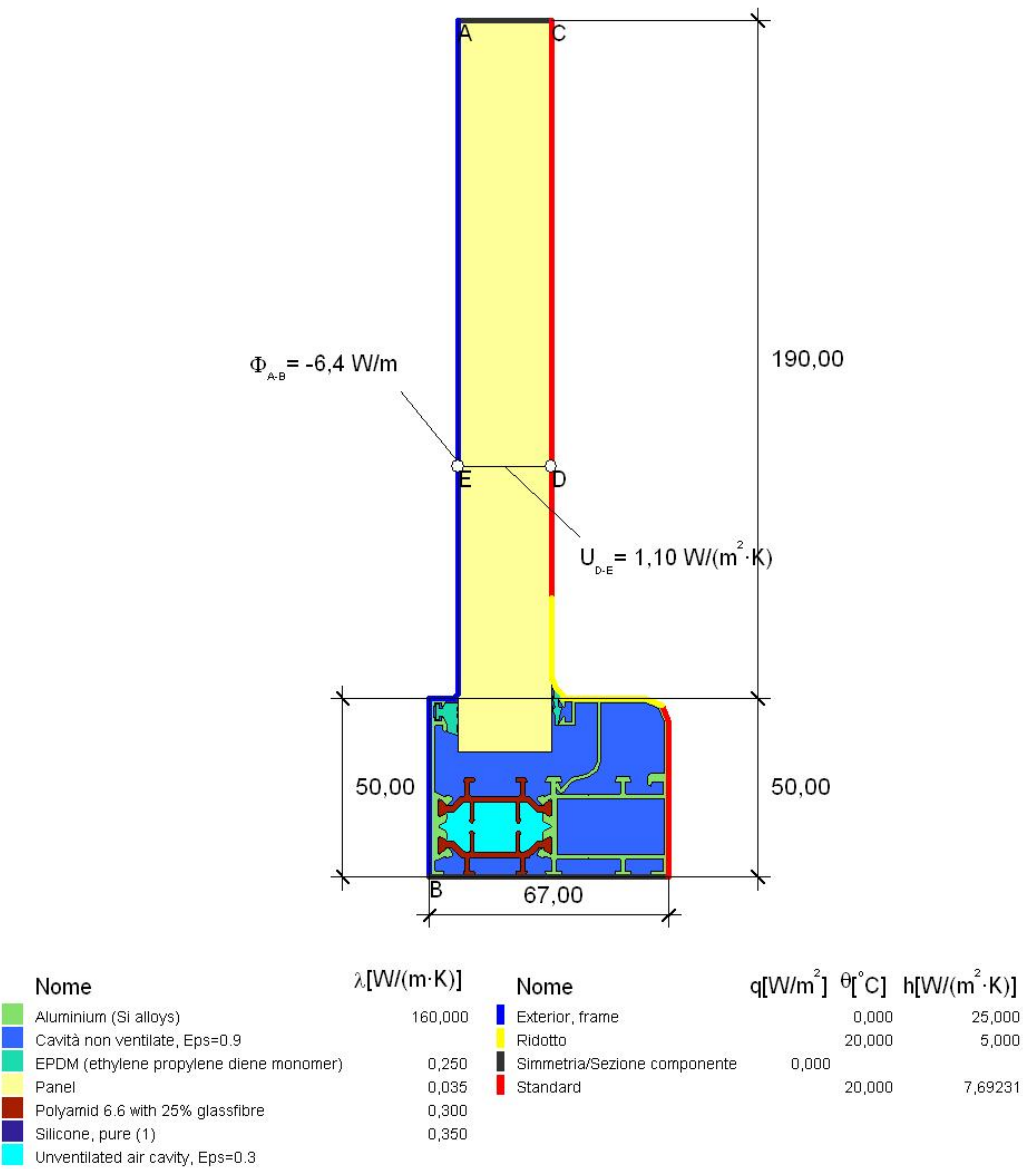
Figure 22. Results of the simulations with Flixo 5.0

The analyzed frame was used to make a window with two fixed panes of glass and devoid of opening shutters.

The absence of opening shutters allowed nodes of small dimensions to be used, so as to maximize the area of the transparent part and to minimize the area of the metal nodes that are the most thermally weak part of the window.

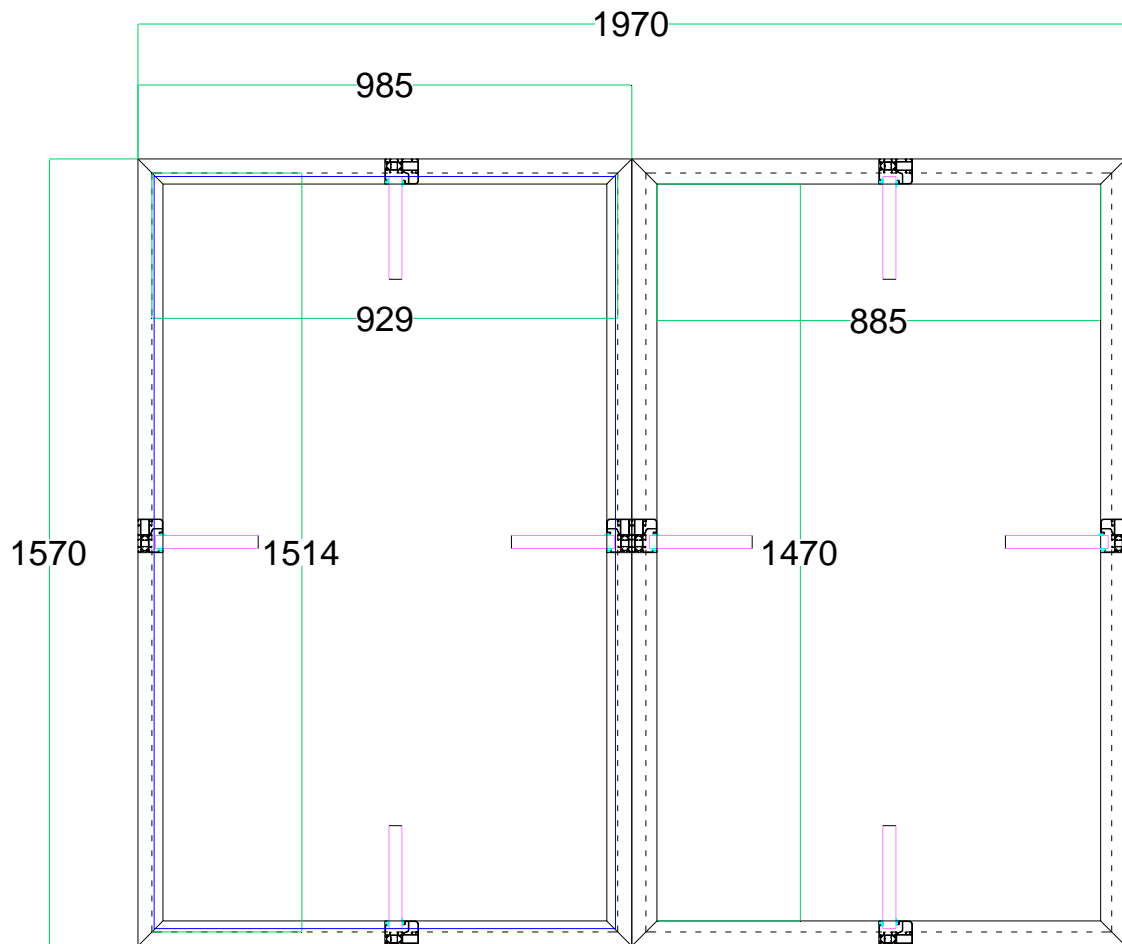The window shown in Figure 23 was thus obtained.

Figure 23. Prospectus of the window

3.2 Description of prototype

The VetroVentilato system is constituted by a double-glazing coupled to an internal blind and a control system of ventilation.

At the top of the sample there is a fan which is able to extract air from the space between the blind and the most internal glass.

By extracting air, the fan creates a vacuum inside the gap, thus creating air circulation inside the room.

The extracted air is ejected outside, both in summer and in winter.

The goal is to remove the accumulated heat on the glass by reducing the solar heat during the summer and the thermal trasmittance during the winter.

Figure 24. Functional scheme of the window

3.2.1 *Stratigraphy of the window*

The innovative double-glazed window with a semi-transparent blind has the following stratigraphy (from the outside to the inside):

1. Clear laminated glass (3 +3 mm)

2. Air gap (16 mm)

3. Low-emission glass (3 mm)

4. Forced air gap (25 mm)

5. Semi-transparent blind roller VSL812

The traditional glass has no blind and has the first three characteristics listed above.

The technical characteristics of the glasses are shown in Table 4.

Table 4. Technical characteristics of the glass panel

glass	s (mm)	λ (W/mK)	TS	R_{se}	R_{si}	TL	R_{le}	R_{li}	T_{irr}	R_e	R_i
1-Stratified (3.3)	6	1	0.818	0.081	0.081	0.896	0.084	0.084	0.542	0.061	0.061
3-Low-emission	3	1	0.585	0.283	0.283	0.879	0.041	0.041	0.492	0	0

where:

s (mm): thickness

λ(W/mK): thermal conductivity;

TS: solar transmission;

R_{se}: external solar reflectance;

R_{si}: internal solar reflectance;

TL: light transmission;

R_{le}: external light reflection;

R_{li}: internal light reflection;

T_{irr}: infrared radiation transmission;

R_e: reflection of external infrared radiation;

R_i: reflection of internal infrared radiation.

3.2.2 *Microperforated blind*

Internally there is a microperforated blind with the following characteristics:

Table 5. Technical characteristics of the blind

	light transmission %	solar transmission %	external solar reflectance %	Absorption of solar energy %	g-value
Tecknoscreen	14	23	77	0	0.18

3.2.3 *Control System*

The operation of the fan is regulated by sensors capable of reading the temperature of the glass and of the environment. A device is able to remotely control the fan speed and to adjust the time of activation.

It is in fact provided a centralized management system, via the master board panel which adjusts the variables considered by the system, and a hardware component decentralized (slave board) positioned inside the frame (Figure 25).

Figure 25. Scheme of the VetroVentilato management system

The control panel is equipped with a sensor of the environmental temperature, as well as the slave board is equipped with a temperature sensor of the air outgoing from the window, connected by cable to the master board.

The functions associated with it are:

- calculation of the difference in temperature between that measured by the sensor placed inside it, and that measured by the sensor on the slave board;
- measurement of the current absorbed by the motor of the tangential fan;
- control of the supply voltage of the engine;
- control of the time of recirculation;
- storing the maximum and minimum temperatures reached.

The variables managed by the system and set manually are listed below:

- ΔT: is the temperature difference between the environmental indoor and the outgoing air and defines the limit beyond which the fan is started. The smaller the delta is , the more responsive the system is to climate change, on the contrary a large delta allows larger variations in temperature.
- Fan power: is provided for the selection of different power levels in order to control the flow of air extracted from the frame.
- Orientation of the venetian blind: orientation can be adjusted with a knob and defines the shielding effect from the sun,
- Time on and off: a timer sets up the functioning of the tangential fan, so it is possible establish a continuous and controlled air change.

3.3 Optimization of the prototype

Below there are the first measurements of air exchange in the test cell on which it is mounted the innovative glass. The expected air exchange rate was approximately equal to 1 h^{-1}.
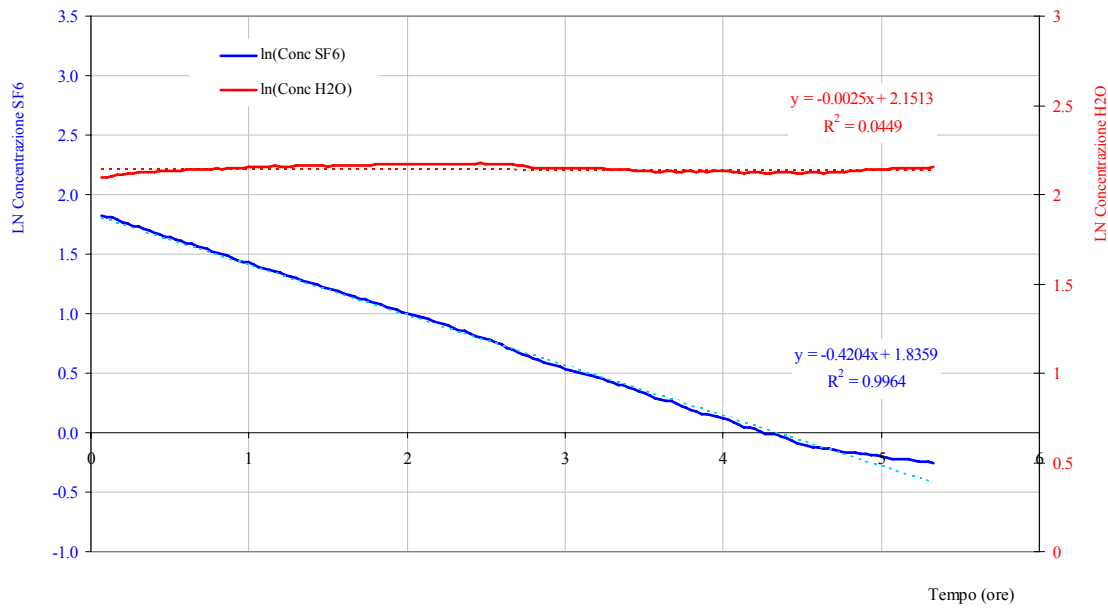
Figure 26. Air change of VetroVentilato with the first fan

The air change measurements (the slope equal to 0.4 h^{-1}), of the previous graph, show an inefficiency of the exchange system, mainly caused by a fan with low flow feature and localized losses too high.

The fans have been replaced with those at higher flow rate. The outgoing air from the VetroVentilato system has been directed into a grid for evacuating the air in correspondence to the fan. In this way the internal fluid dynamics are improved. (Figure 27 and Figure 28).
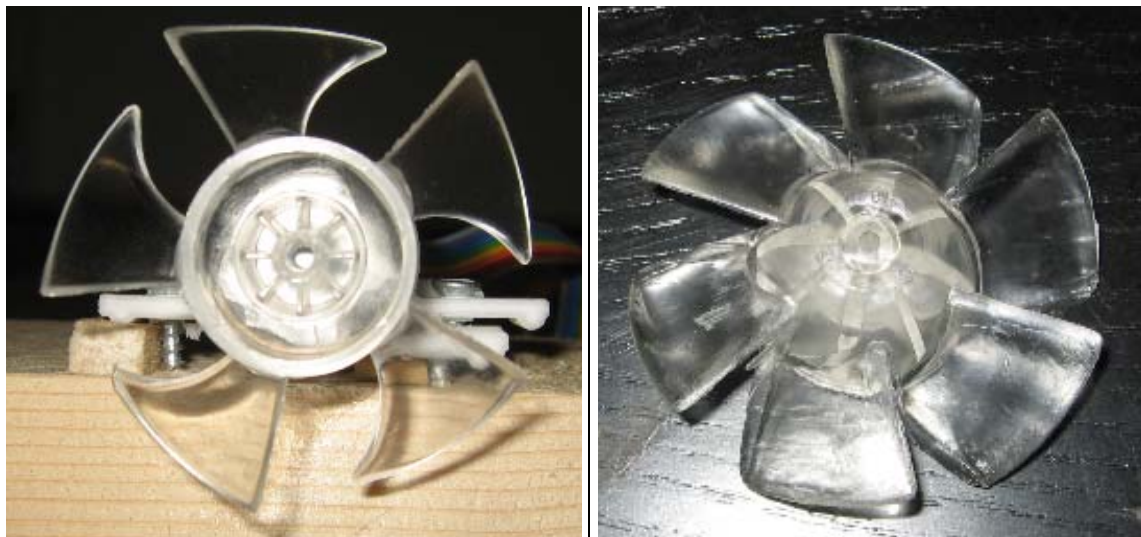
Figure 27. Typology of the adopted fan. Left: replaced fan. Right: fan more efficient

Figure 28. Comparison between the grids before (left) and after (right) the improvement

New measurements show in Figure 29 a trend of acceptable air exchange rate equal to 0.94 h^{-1}.
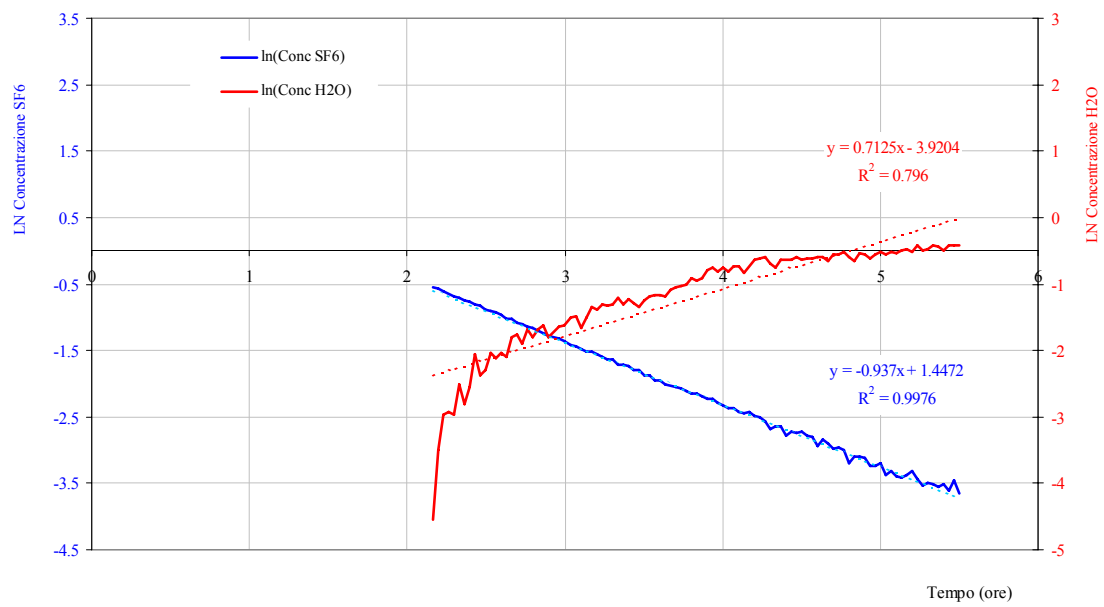
Figure 29. Air change of Vetroventilato with the improved fan

4 ANALYTICAL CALCULATIONS

The structure of the frame allows the air sucked by the fan to be channeled both inwards and outwards. Analytical calculations were performed using the simulation program WIS in order to understand the variation of the thermal transmittance and the solar factor as a function of the air flow passing through the window frame and the type of ventilation: internal-internal or internal-external.

4.1 Ventilation internal-internal

The difference of the thermal transmittance and solar factor of the ventilated glass (internal-internal and blind) respect to the standard glass (without ventilation) in the winter period (Figure 30) was compared.

The increase of the rate air flow of ventilation increments the thermal transmittance value of the ventilated window, which even exceeds the values of traditional window if there are 90 m3/h. The solar factor of the ventilated glass is more advantageous due to the presence of the blind.
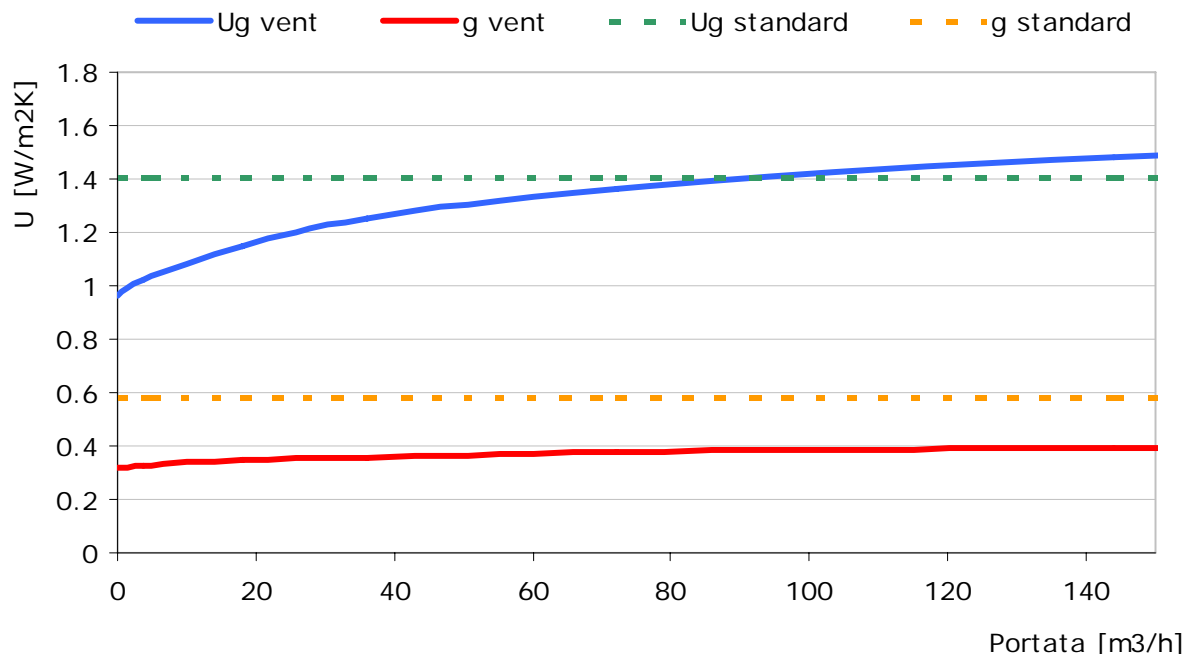

Figure 30. Winter, ventilation internal- internal, thermal transmittance and solar factor of the glass

In Figure 31 the window (frame + glass) has the same trend as the glass: both have the same trend and the window reaches thermal transmittance values higher, while the solar factor remains the same.
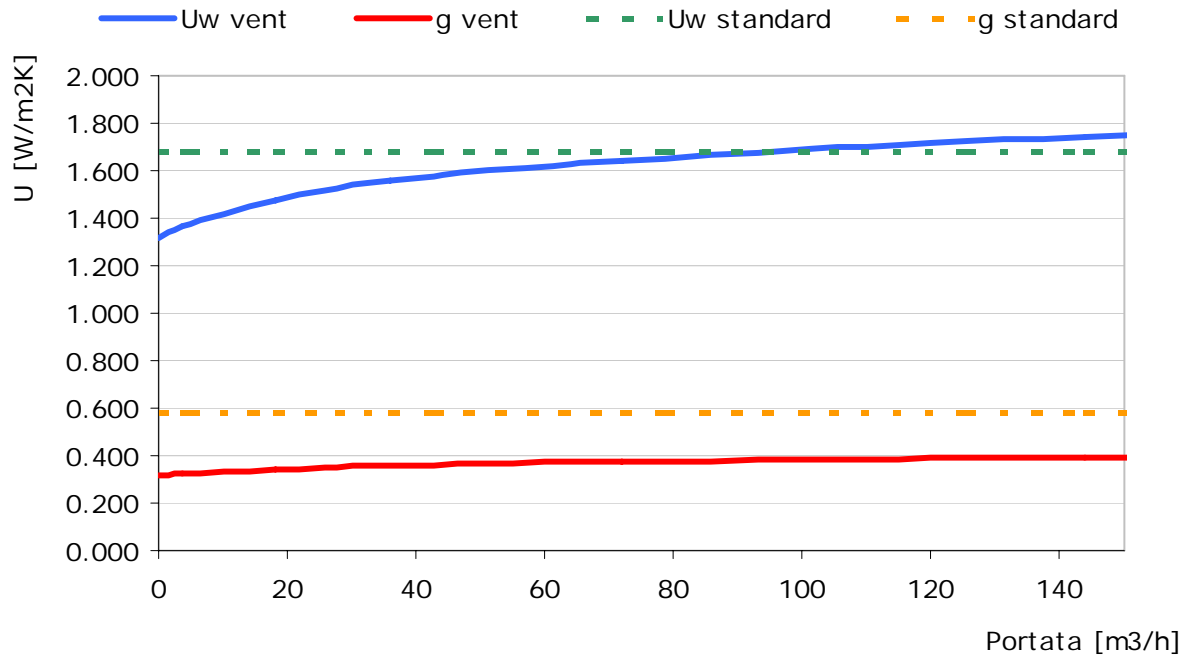
Figure 31. Winter, ventilation internal- internal, thermal transmittance and solar factor of the window

During the summer period (Figure 32, Figure 33) the two panes and the two windows have the same trend as seen in the winter case, even if the thermal transmittance of the ventilated system exceeds that of the traditional system at lower air flow rates (about 80m3 / h).
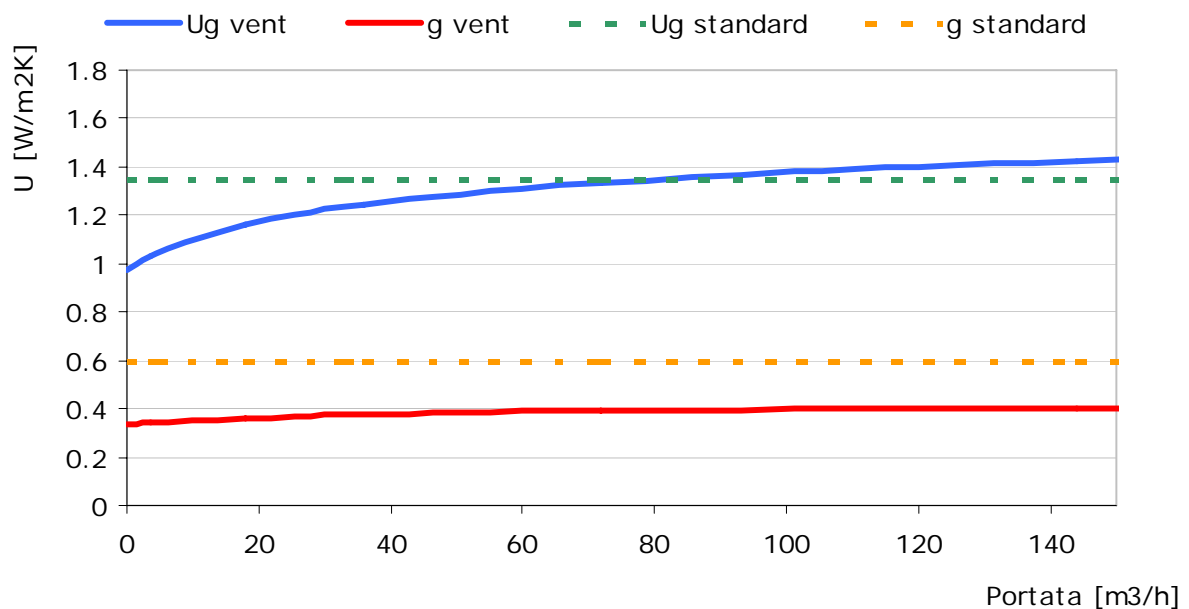

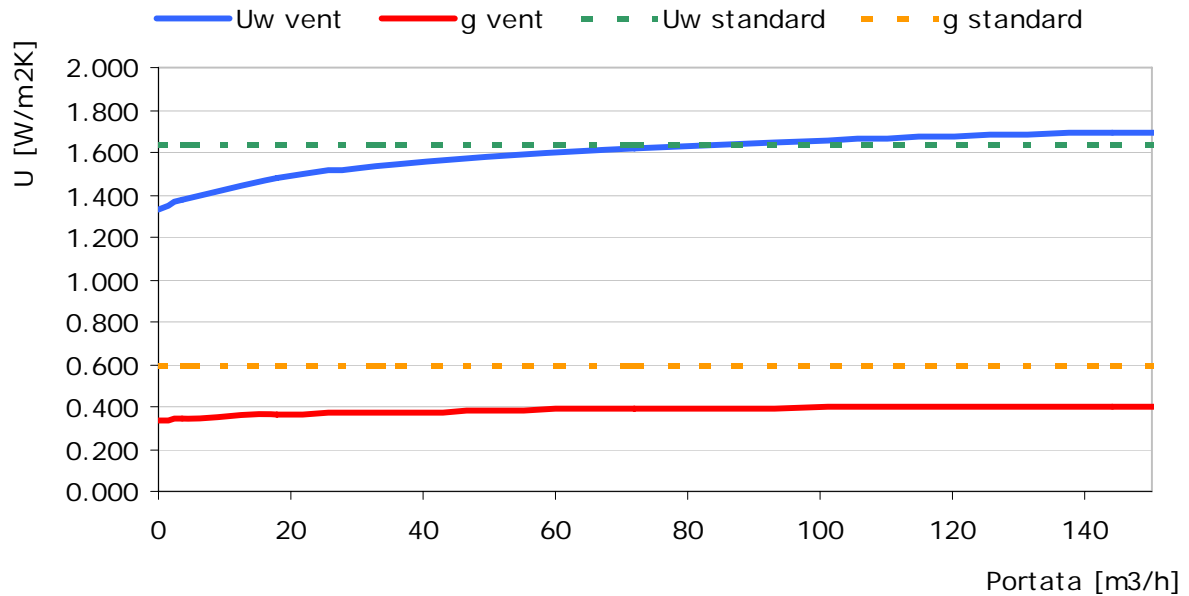Figure 32. Summer, ventilation internal- internal, thermal transmittance and solar factor of the glass

Figure 33. Summer, ventilation internal- internal, thermal transmittance and solar factor of the window

4.2   Ventilation internal-external

If the ventilation system aspires air from the inside and expels it to the outside environment, there is a variation of tendency.

In Figure 34, the thermal transmittance of the traditional glass is a constant value equal to 1.4 W/m2K while that of ventilated glass decreases progressively with the increasing flow of ventilation until reaching a value of 0.2 W/m2K. Thus, the solar factor is also reduced with the increasing flow converging towards a value equal to 0.2, compared with 0.6 of traditional glass.
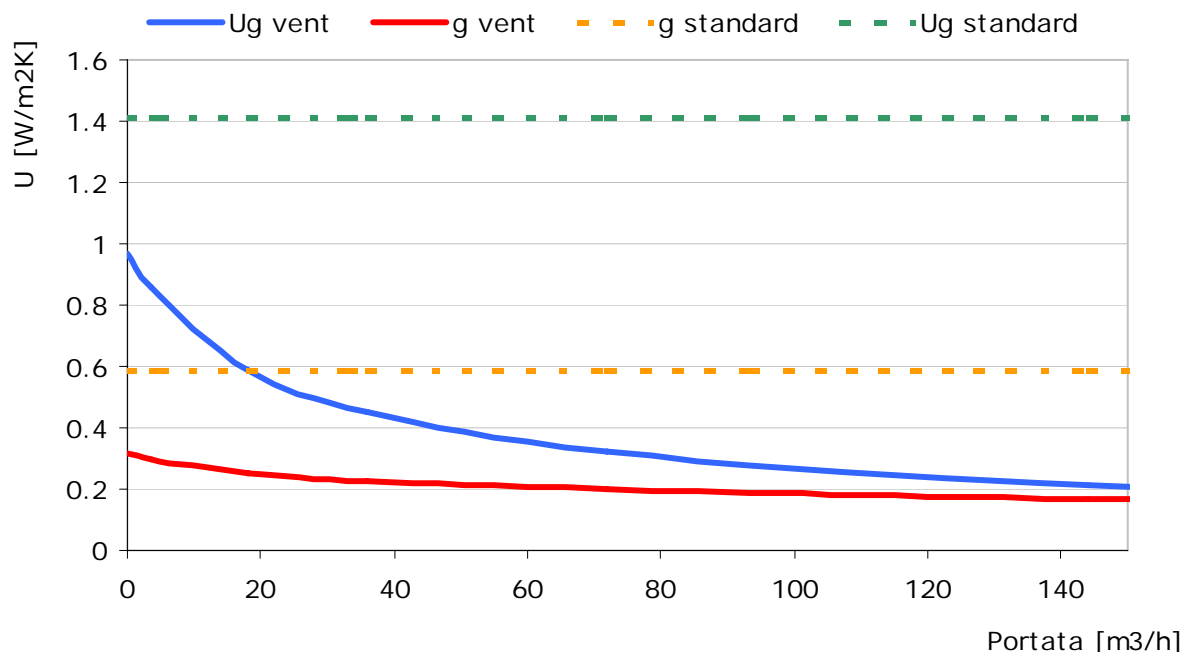
Figure 34. Winter, ventilation internal-external, thermal transmittance and solar factor of the glass

The same trend, seen for the glass, can be observed for the system glass + frame (Figure 35). The ventilated glass reaches a thermal transmittance value equal to $0.7W/m^2K$.
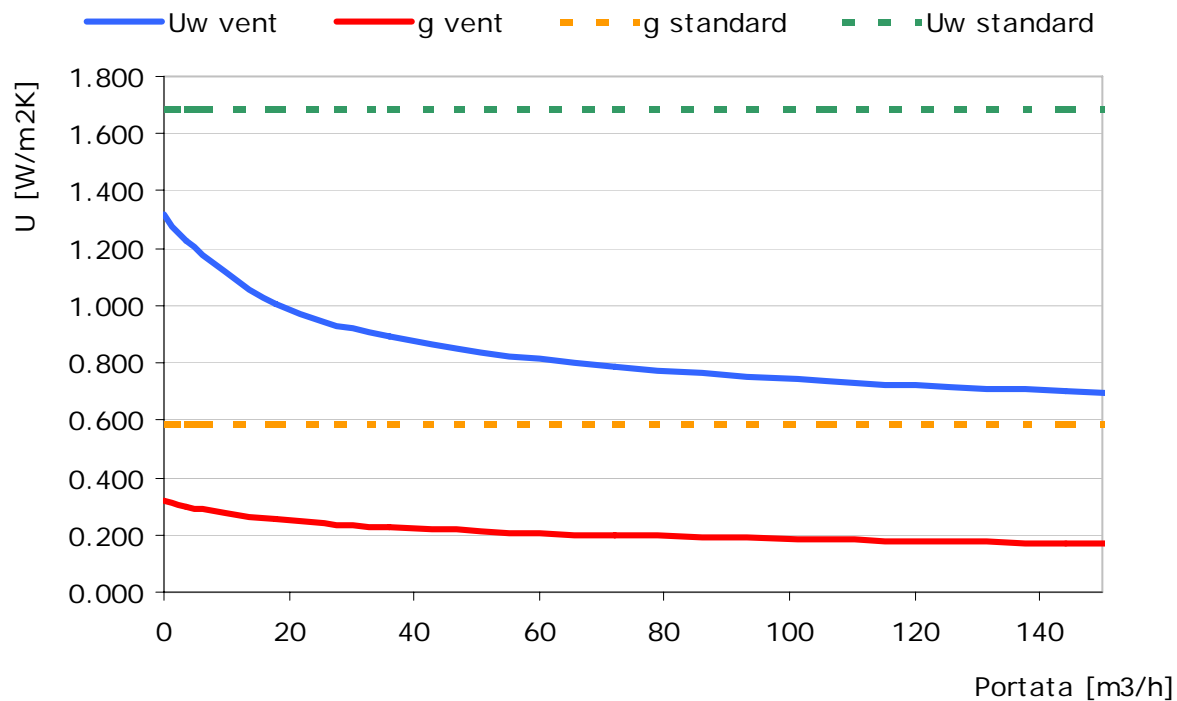

Figure 35. Winter, ventilation internal-external, thermal transmittance and solar factor of the window

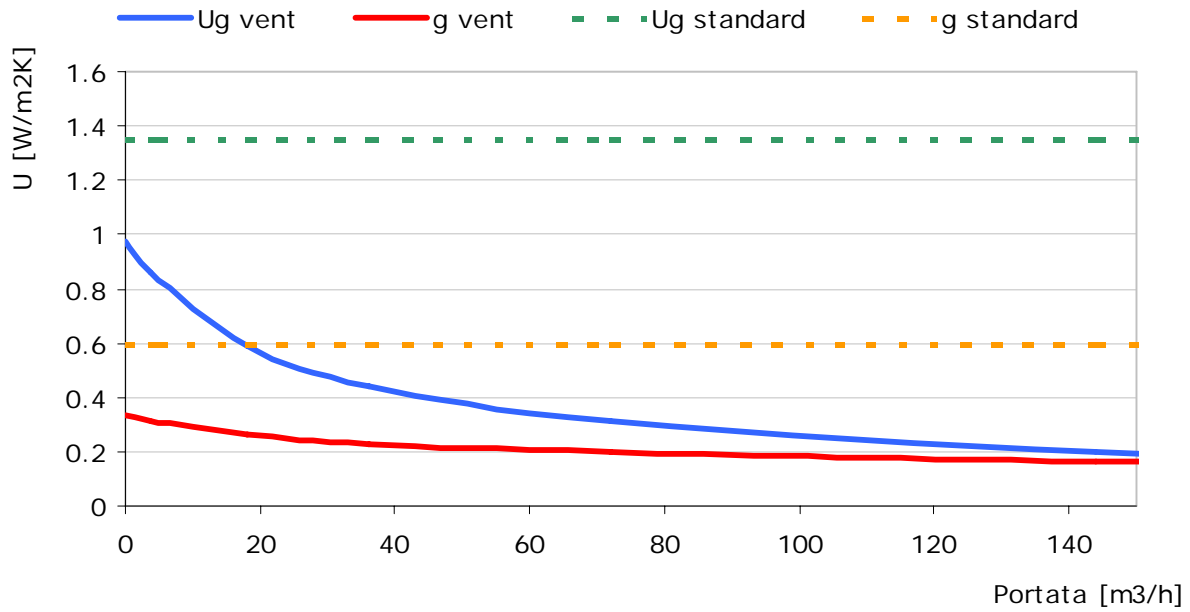The same trends are registered in the summer case (Figure 36, Figure 37).

Figure 36. Summer, ventilation internal-external, thermal transmittance and solar factor of the glass
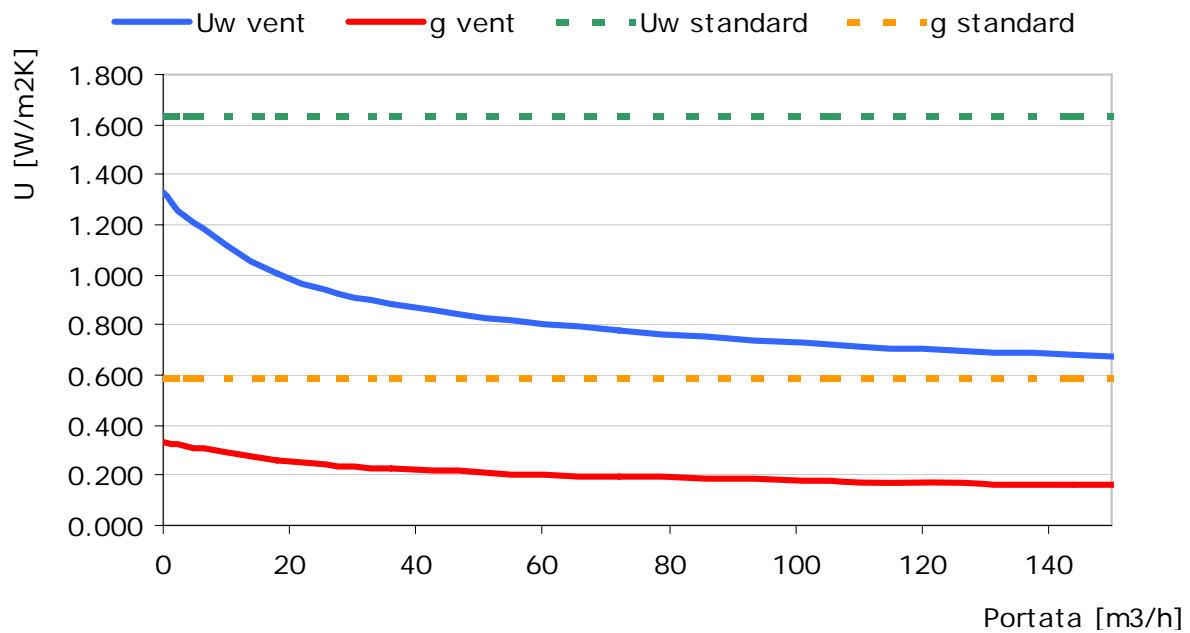

Figure 37. Summer, ventilation internal-external, thermal transmittance and solar factor of the window

The graphs show the best performance of the glass with ventilation inside-outside, in the summer and winter period. It is possible to hypothesize a study of the internal-internal system in conjunction with a heat recovery.

5   SUMMER EXPERIMENTATION

5.1 Energy consumption summer

5.1.1 *Active VetroVentilato*

In the summer period the following graphs show a greater energy consumption for the reference cell compared to the test cell with the dynamic glass.

The energy saving achieved varies depending on the state of the outside temperature and then also the solar radiation.

There is a variation that oscillates between 20% and 50% with average values around 35%. For cloudy days (for example 11 and 12 August 2011) it observes a decrease of VetroVentilato performance up to minimum values of 20%.

This means that the benefit of ventilated glass is reduced on cloudy days, while it is higher on sunny days.
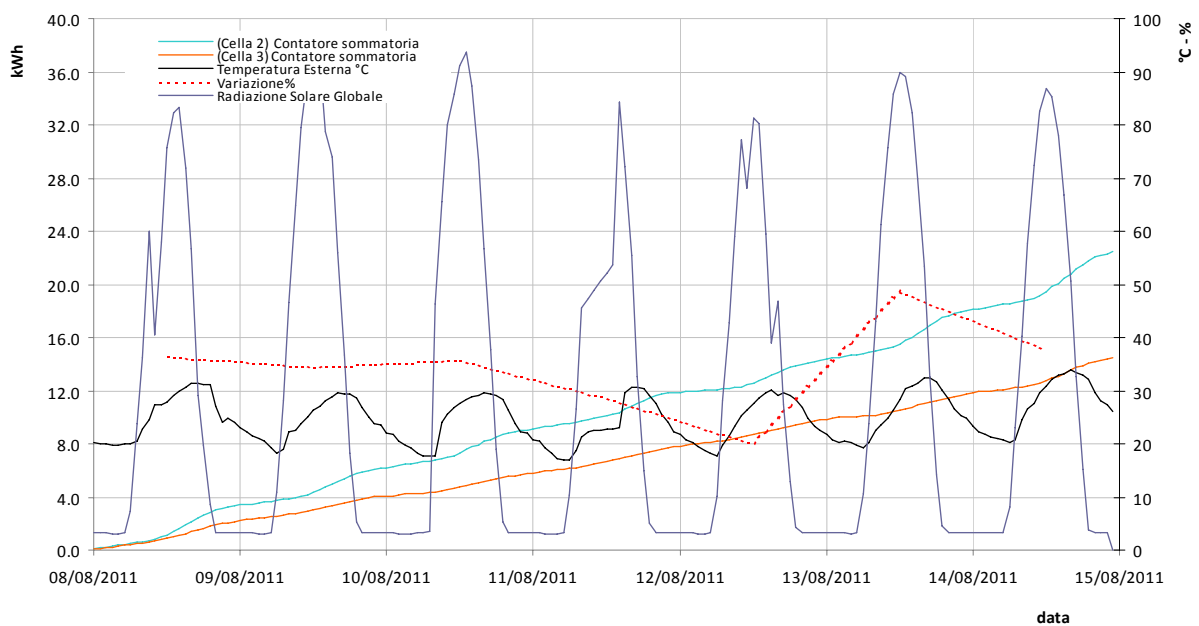

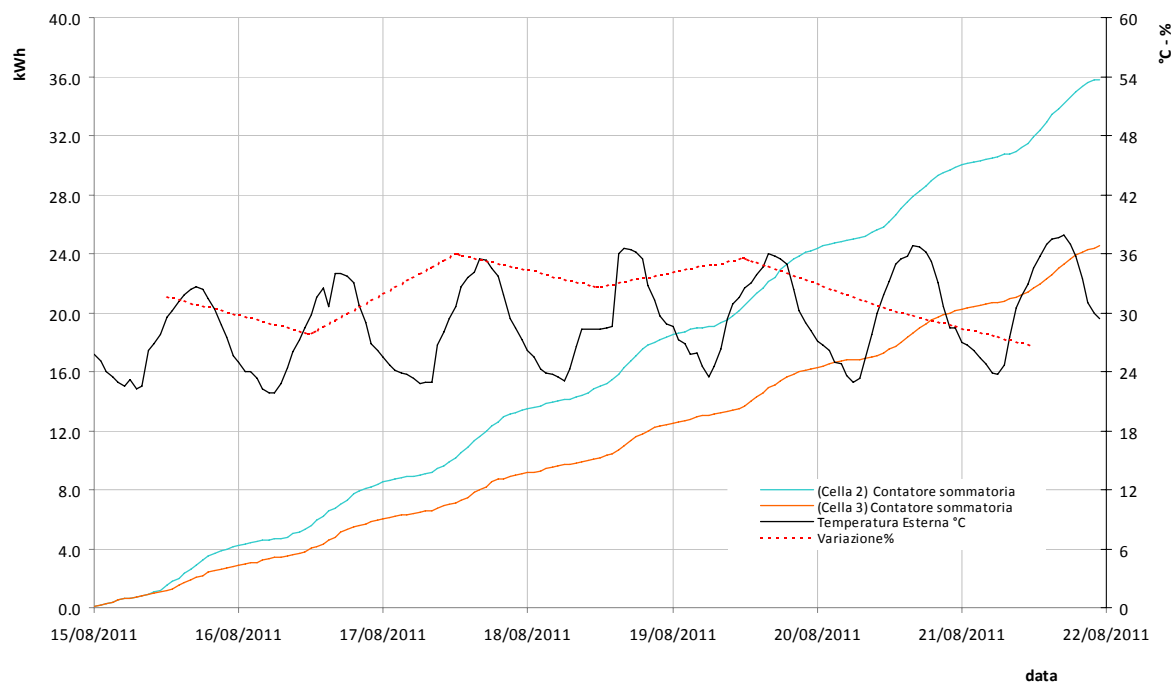Figure 38. Energy consumption from 08/08/2011 to 14/08/2011

Figure 39. Energy consumption from 15/08/2011 to 21/08/2011

The following graph confirms that for the same accumulated degrees-hour (which identify the sum of temperature differences between inside and outside) the consumption of the reference cell is significantly higher. The same measured degrees-hour indicates that the test cells have the same thermoregulation and therefore the different consumption is due to the different dispersions and thermal storage.
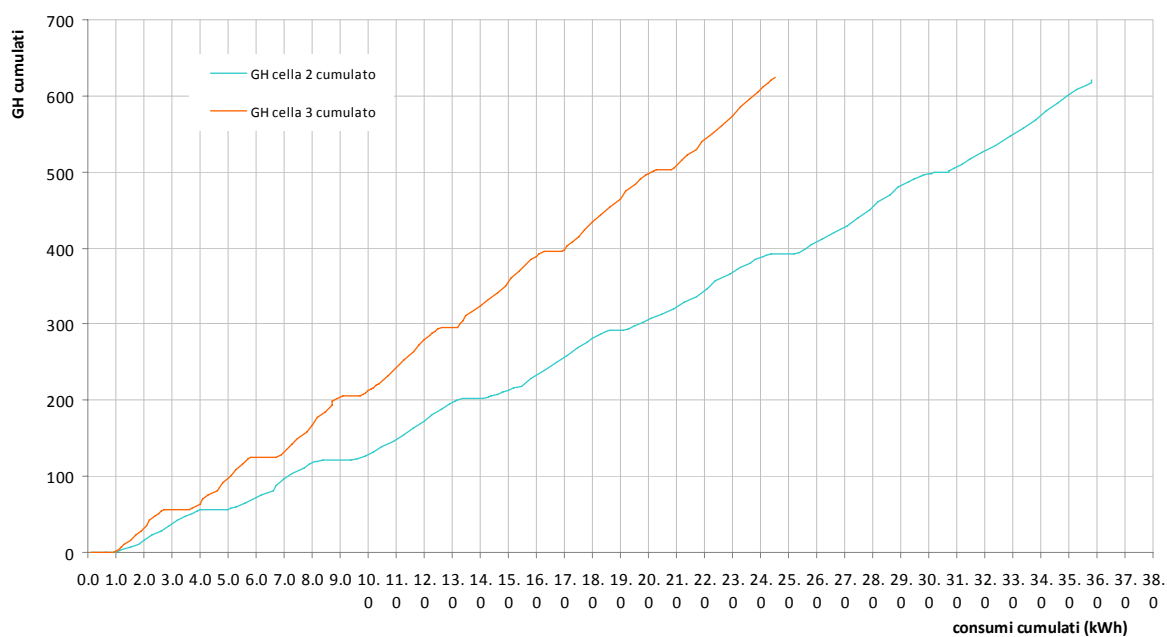

Figure 40. Cumulated consumption from 15/08/2011 to 21/08/2011

The average temperature of the test cells are the same. The relative humidity rather, for external average temperatures of 27 ° C, is similar. The RH of C3 is higher of around 5% for temperatures greater.
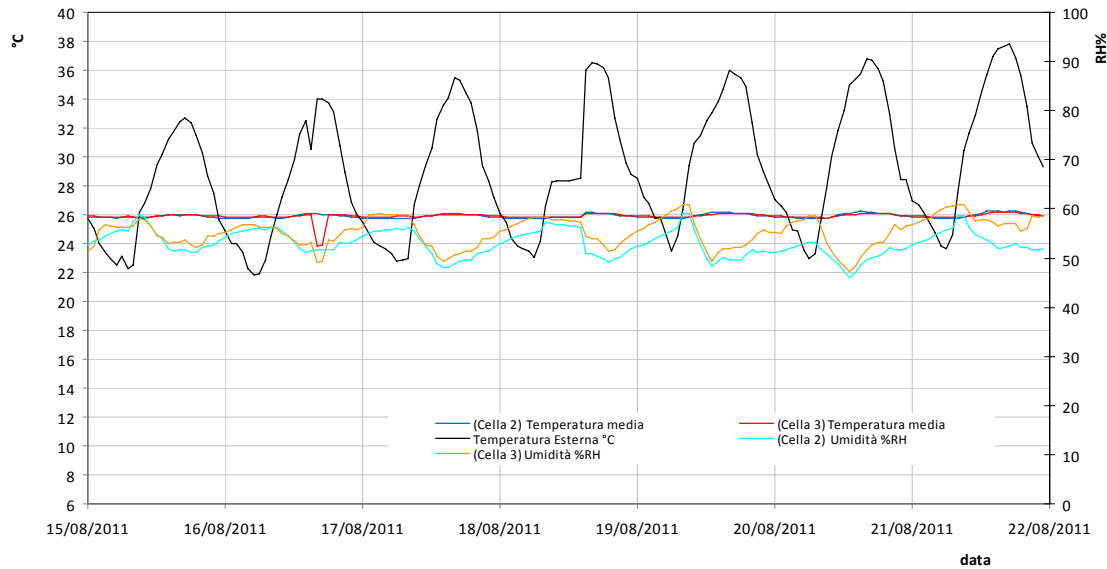

Figure 41. Average temperatures and relative humidity from 15/08/2011 to 21/08/2011

Looking at the graph below it shows a significant aspect: the temperatures of the C3 glass are slightly higher than the window of C2.
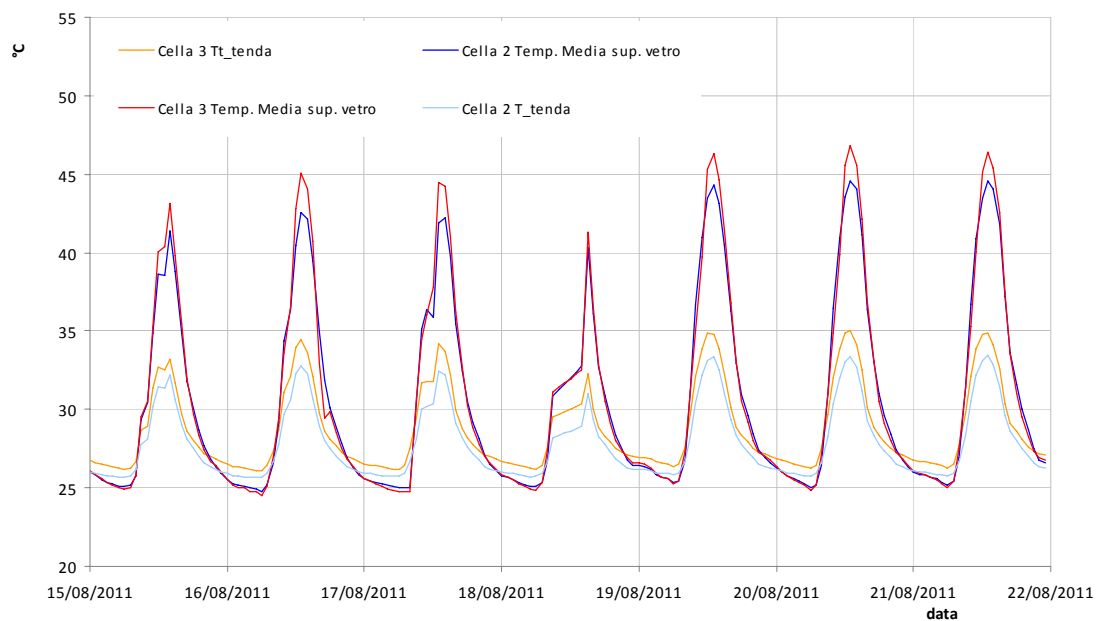

Figure 42. Surface temperatures of the windows from 15/08/2011 to 21/08/2011

5.1.2 Inactive VetroVentilato

This configuration assumes the VetroVentilato inactive. The VetroVentilato cell should theoretically provide the same performance of the reference cell. The graph below compares the energy consumption, the operating temperature and relative humidity.
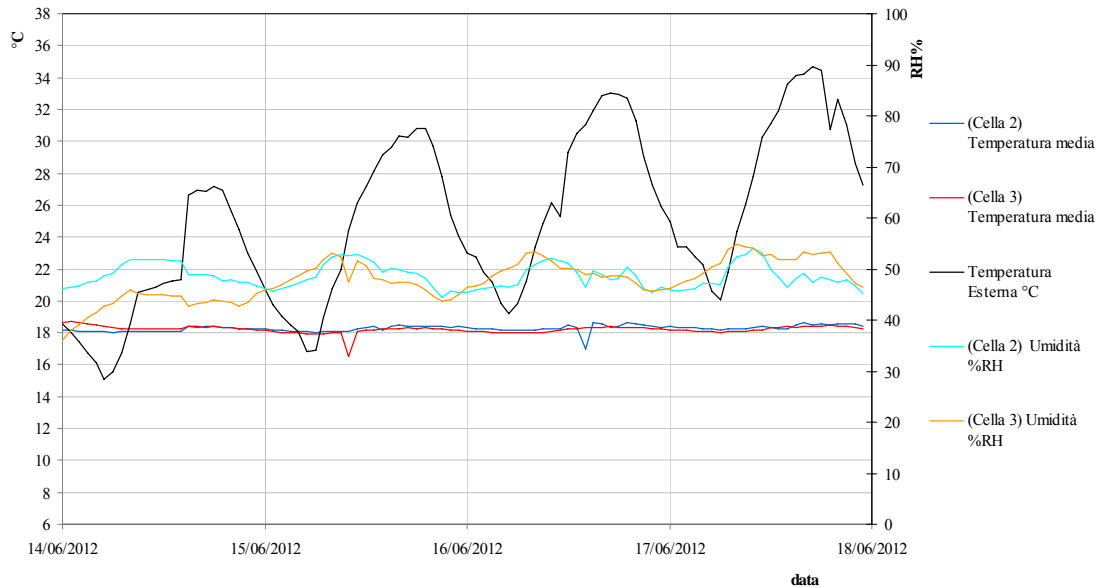

Figure 43. Average temperatures and relative humidity from 14/06/2011 to 17/06/2011
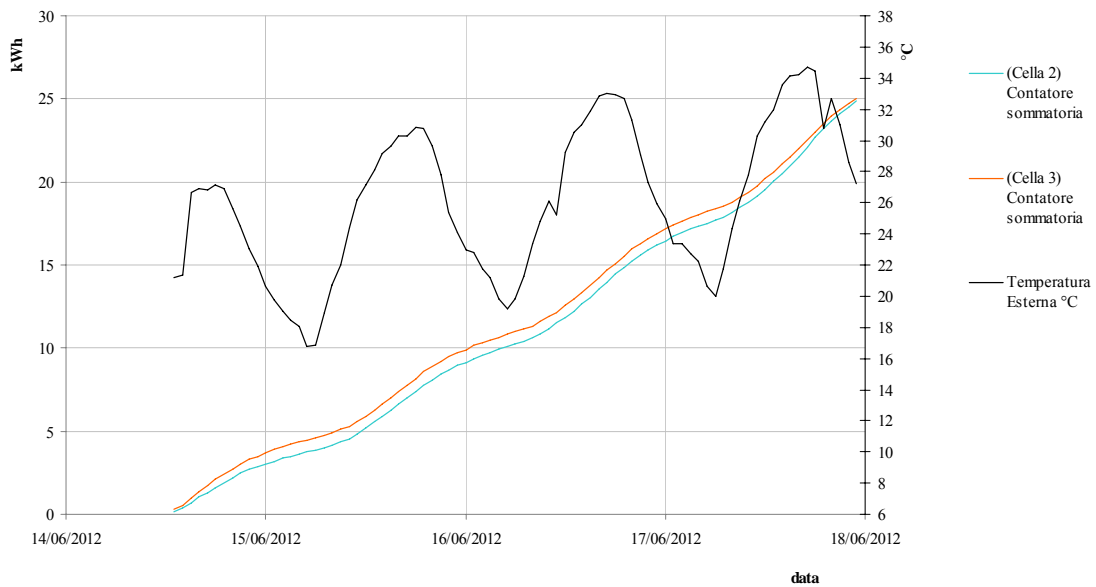
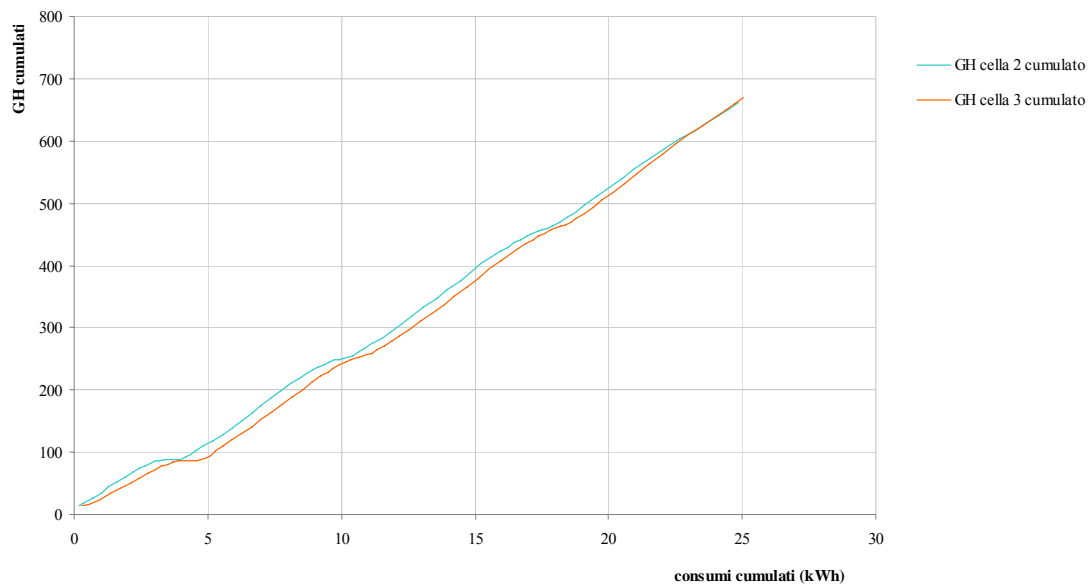

Figure 44. Energy consumption trend

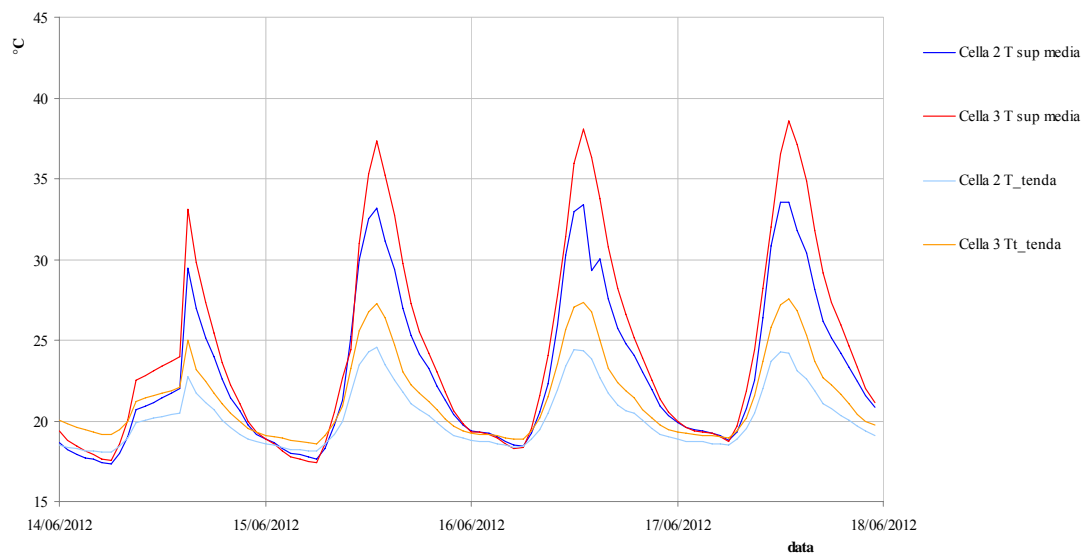Figure 45. Cumulated consumptions respect to degrees-hour

Figure 46. Surface temperatures of the windows in Summer

The trend of the glass surface temperatures in C2 and C3 are similar.

Figure 45 shows that the temperatures relating to C3 are always higher than those measured in the reference window in C2 of about 5 °C during the maximum insolation.

Similarly occurs for the surface temperatures of the respective internal blinds. This behaviour is justified by the position of the blinds.

In the reference window the blind is placed at 10 cm from the inner glass, while in the dynamic window the blind, integrated into the frame, is located only at 2.5 cm.

A reduced distance (C3) causes an increase of the temperature near the blind as visible in the graph.

Obviously higher temperature regimes reduce the heat flow passing through the dynamic window.

5.2   Surface temperatures: active VetroVentilato

The following analysis focuses on the surface temperatures patterns at three points of glazing systems:

-    internal blind;

-    internal surface of the glass;

-    external surface of the glass.

The internal blind of the dynamic window is positioned at 25 mm from the inner glass. Therefore the ventilated gap has a reduced thickness compared to that of the traditional double glazing. In this way the cavity maintains the heat inside it and it overheats preventing the inside heat losses. In fact, the chart below shows the surface temperatures of the blinds.

In accordance to the surface temperatures trend of the blinds, the inner surface temperatures of the traditional window are higher than the dynamic window, due to the greenhouse effect of the ventilated gap. Conversely, this trend appears to be a benefit in terms of efficiency of the system, as visible in the section on energy consumptions.

On the external surface however the temperature trend is reversed. The surface temperatures of the traditional window are higher. In this case, the thermal behaviour of the traditional window is more stable than the dynamic one (mainly due to the dynamic characteristics of the window).
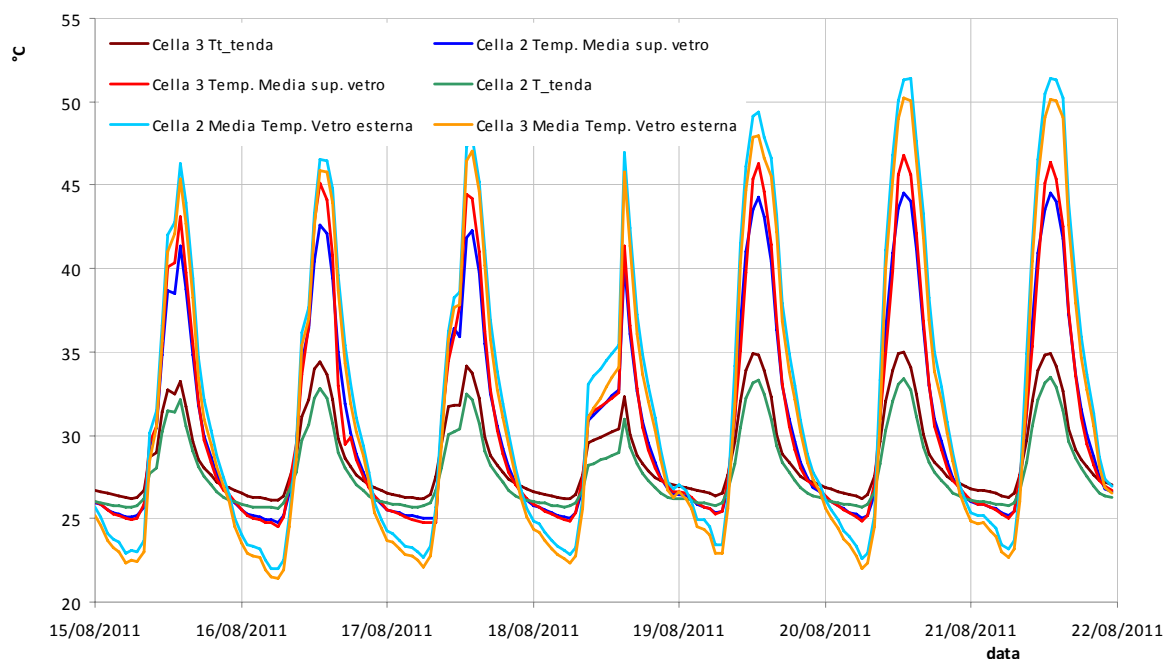

Figure 47. Surface temperature analysis of the windows

5.3   Hygrothermal comfort

5.3.1   Active VetroVentilato

The graphs do not represent all of the experimental campaign, but they are an exemplification, showing the measurements taken in the days most representative and significant that best describes the information necessary to assess the performance of the dynamic window.

As previously mentioned, the mechanical ventilation active in the gap leads an improved energy performance and significant energy saving. In the absence of conditioning it verifies now the test-cells behaviour in terms of equilibrium of internal air temperature and relative humidity.

In order to obtain the best conditions of comfort and discriminating between the occupants´ perception of hot or cold. May is considered as a period in which the solar gain is crucial. In this case the equilibrium temperature of the C3 is less than 1 °C compared to that recorded in the reference cell (C2). Similarly for the relative humidity are measured values lower by about 10% in C3.
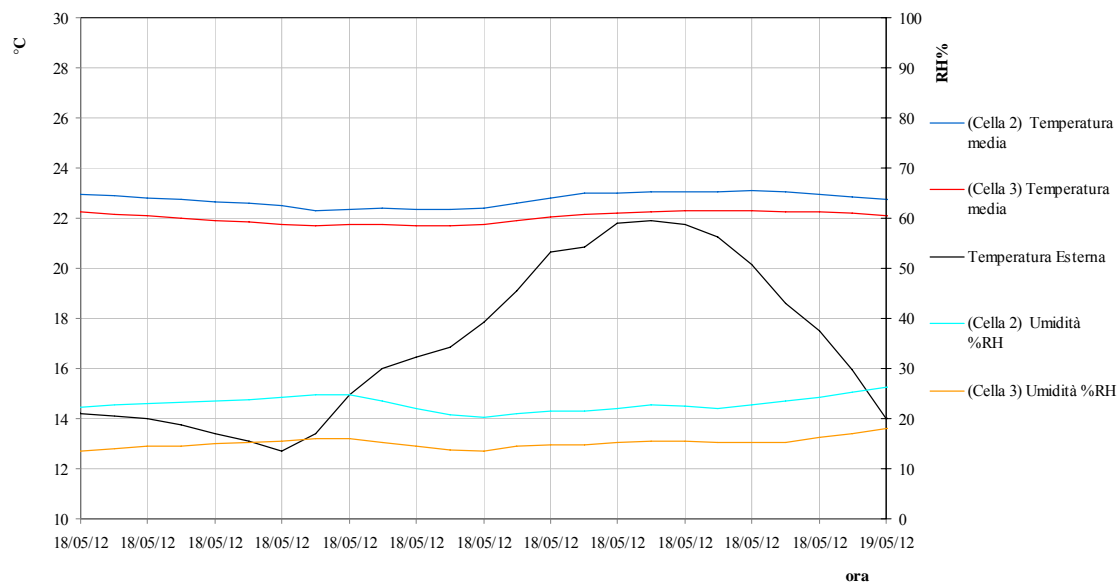

Figure 48. Average temperatures and relative humidity with VetroVentilato active – summer comfort

The following graph shows the hourly trends of the parameters:
- solar radiation;
- external temperature;
- percentage of people dissatisfied in C3 with VetroVentilato system (PPD);
- percentage of people dissatisfied in C2 (PPD);
- percentage variation of PPD between C2 and C3.

Considering a spring week, the PPD data (Figure 48) are better in the reference cell taking into account that in C2 the PMV (Figure 49) indicates a feeling of well-being "neutral". In this period the maximum temperature reaches about 22 °C. The C3 maintains lower temperatures reaching comfort values corresponding to "slightly cool" in terms of PMV. Taking into account this affirmation, in summer period, when outside temperatures are even higher, C3 would maintain lower temperatures of C2 and therefore more comfort.
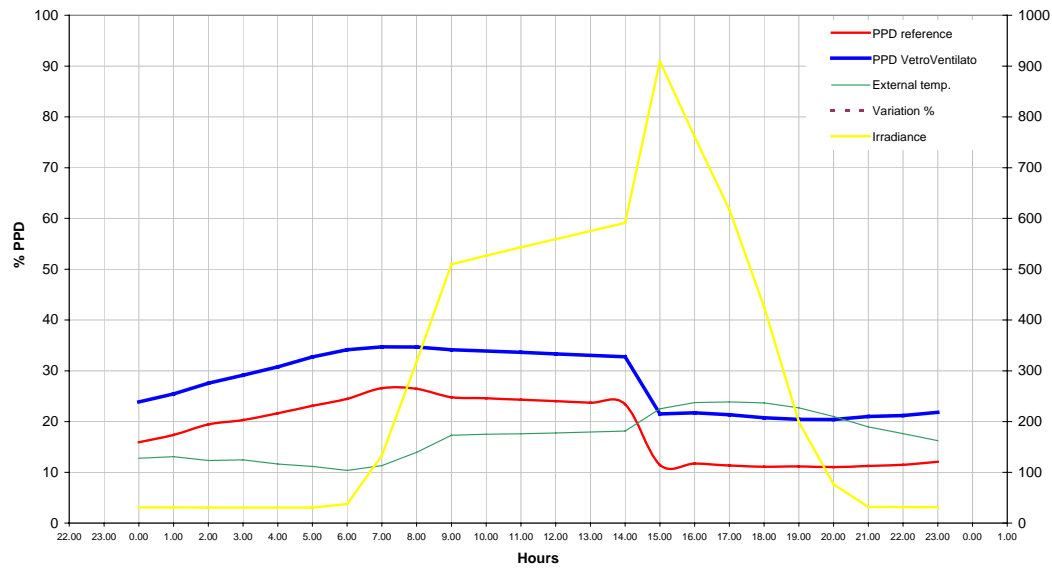
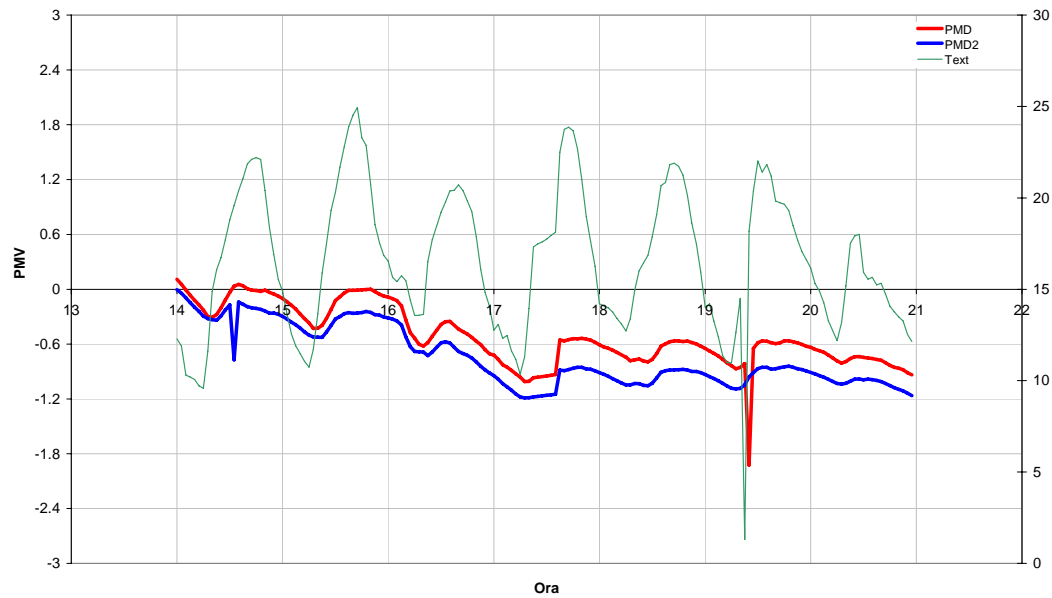Figure 49. PPD trend in Summer – Behaviour A

Figure 50. PMV trend in Summer – Behaviour A

The PPD (Figure 50 and Figure 51) is better in C3 by about 10%, reaching an optimum value, with a feeling of well-being "neutral". This indicates that on a sunny day with temperatures reaching 30 °C the use of air conditioning is not necessary, while in C2 , air conditioning would ensure the conditions of well-being.
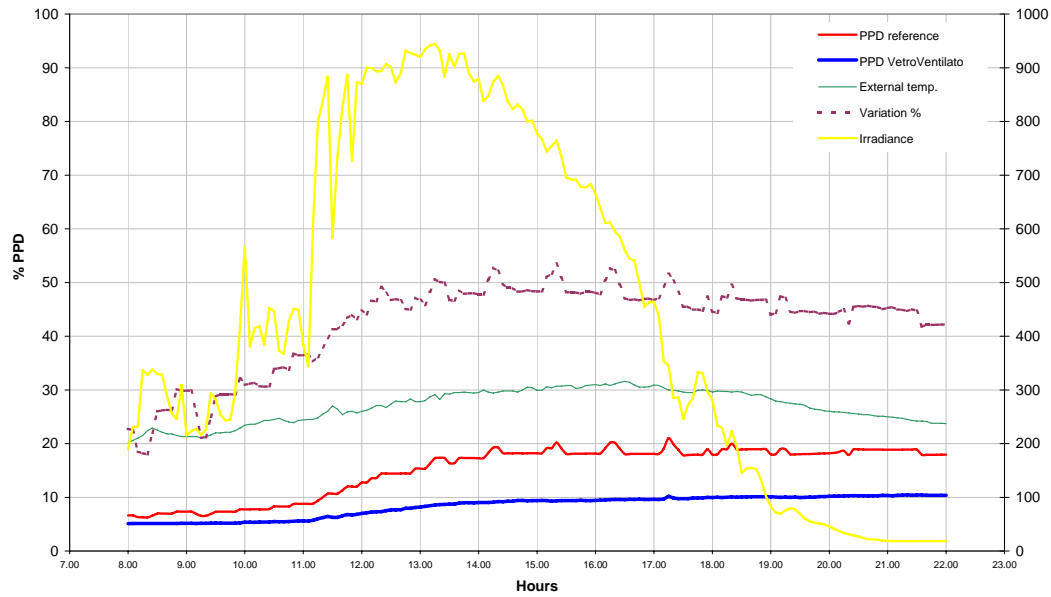
Figure 51. PPD trend in Summer – Behaviour B
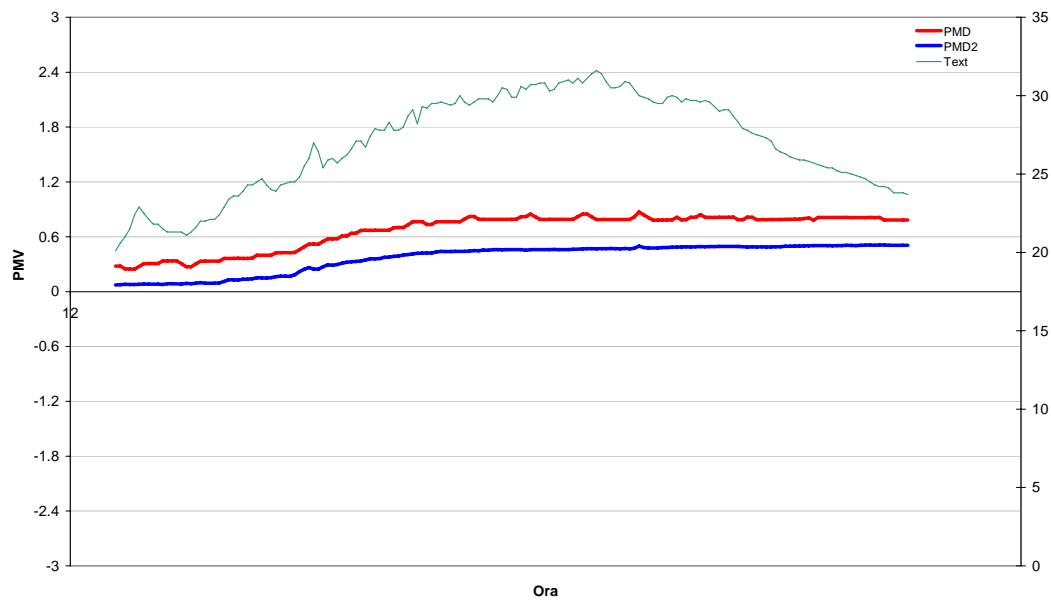
Figure 52. PMV trend in Summer – Behaviour B

5.3.2 Inactive VetroVentilato

A similar configuration to the previous paragraph is considered here (air-conditioning system switched off), but with the Ventilated window turned off. A trend of comfort very similar to what has been possible to verify in the energy consumption is assumed. In reality, although the average temperatures of the cells are almost identical (Figure 52), the C3 relative humidity are lower on average of 5%. This difference leads to a significant variation of the comfort for the benefit of C3.
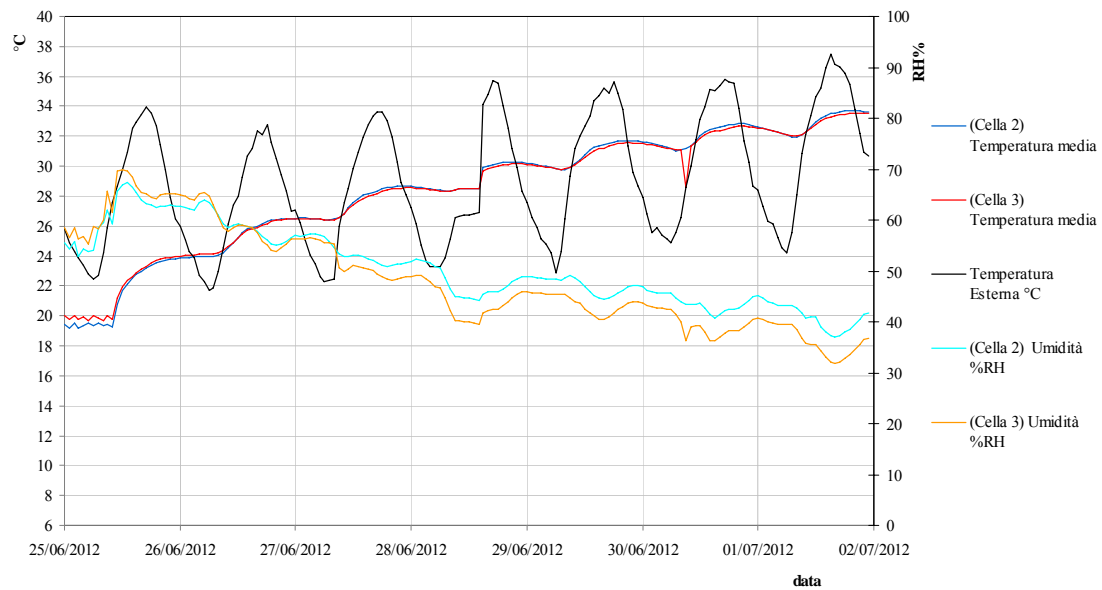
Figure 53. Average temperatures and relative humidity with VetroVentilato inactive – summer comfort

The Figure 53 shows the PPD index of the two cells. Confirming what has been said previously the relative humidity lower is directly proportional to PPD. The thermal comfort therefore is better by a value of 5-8%.

Figure 54. PPD trend with VetroVentilato inactive

Therefore, considering the differences of the obtained results with the same configuration, it is once again demonstrated what happened with regard to measured surface temperatures when the ventilated window was off. These results are owing to the different distance of the blinds from the internal panes of glass.

6 WINTER EXPERIMENTATION

6.1 Energy consumptions
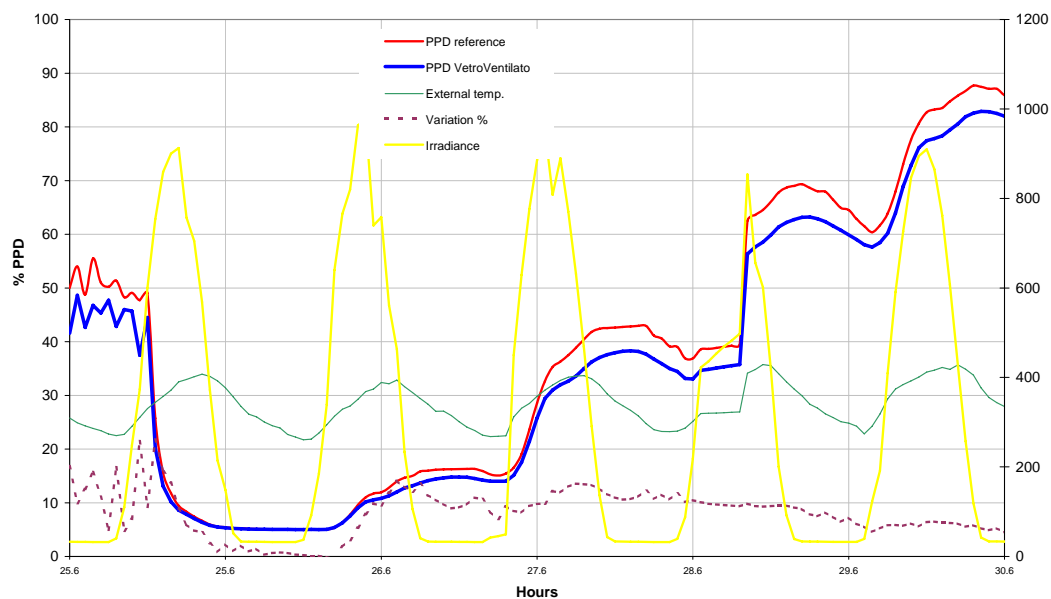
6.1.1 Active VetroVentilato

The comparison of the winter consumptions shows that the sample cell behaves better with a reduction of the consumption by around 13%.

For temperatures above 0 °C there are slight improvements related to the efficiency of the dynamic system . The energy saving increases when the temperatures increase.
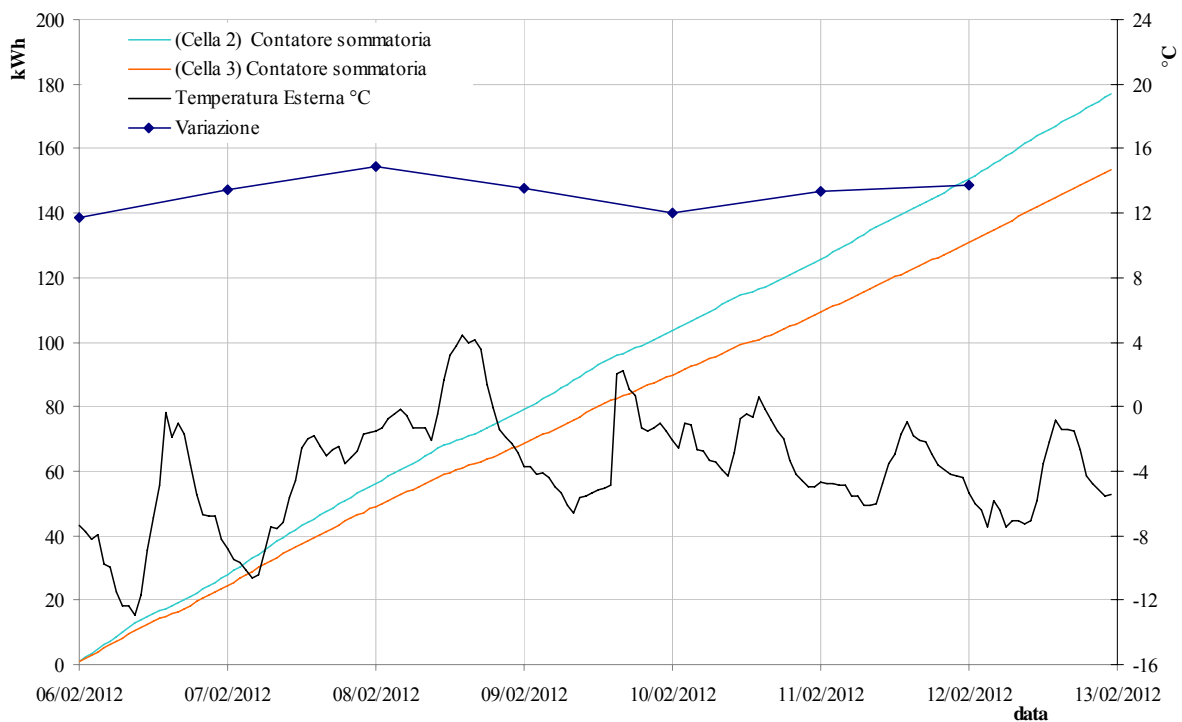

Figure 55. Energy consumption from 6/02/2012 to 12/02/2011

The different energy behaviour of the cells is shown more clearly in Figure 60.

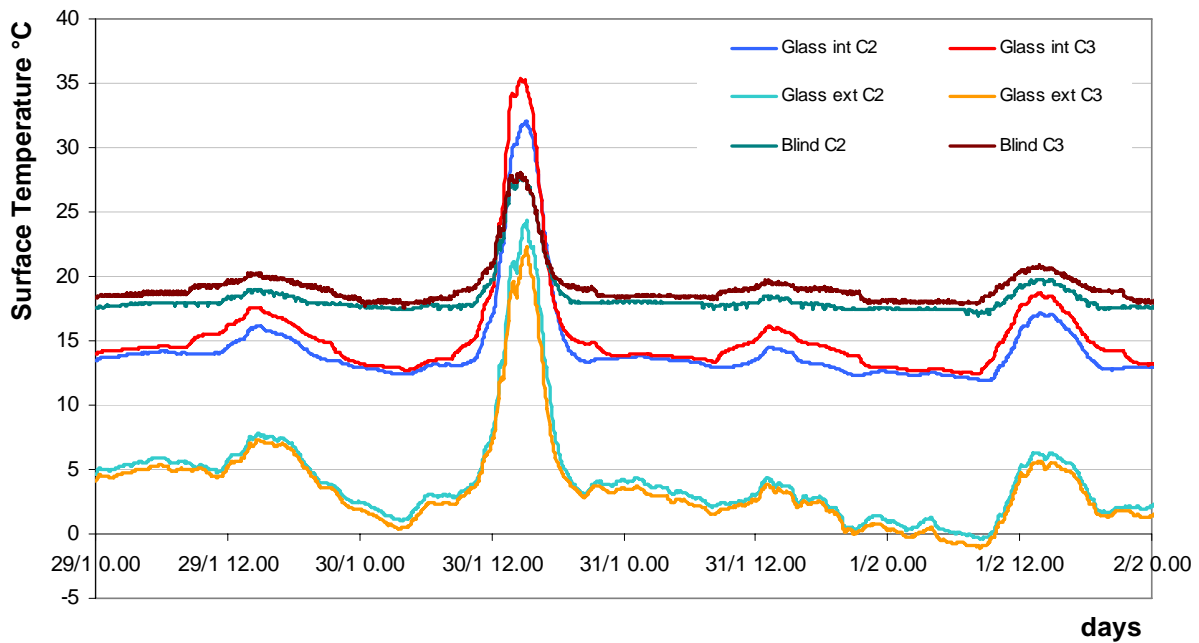## 6.2   Surface temperatures: active VetroVentilato

Figure 56. Surface temperatures of windows in Winter

The trend of the surface temperatures is observed at three points: blind, and inside and outside glass. It should also be noted that the day of 30 January was clear, while the other days were cloudy. Starting from the external glass, the surface temperatures of the glazing ("Glass ext C2" and "C3 Glass ext") are similar; the glass reference temperatures are a little higher because this window disperses more than C2 window and thus is affected by the greater outgoing heat flux.

The internal surface temperatures ("Glass int C2" and "C3 Glass int") however already show some differences. The red line shows an average temperature trend higher than the blue line, characterized by the behaviour of the ventilated glass active. The internal surface temperature of the glass is maintained higher by the air flow at 20 °C that touches the glass and ensures that the heat is not lost through the window, but directed towards the extractor.

The test cells assume the same energy behaviour at night because the dynamic window is switched off and has the same configuration of a traditional window.

The blind temperature of the reference cell is consistently lower (curve "Blind C2") compared to that of the sample cell (curve "Blind C3"), except during the hours of greater insolation, where the differences vanish. The explanation resides in the functioning of the dynamic glazing. The blind temperature of the ventilated glass is very close to the set point temperature, allowing high levels of comfort to be maintained near the window.

6.2.1   Inactive VetroVentilato

The trend of winter consumption and surface temperatures is similar to the same configuration in the summer (Figure 57 and Figure 58).
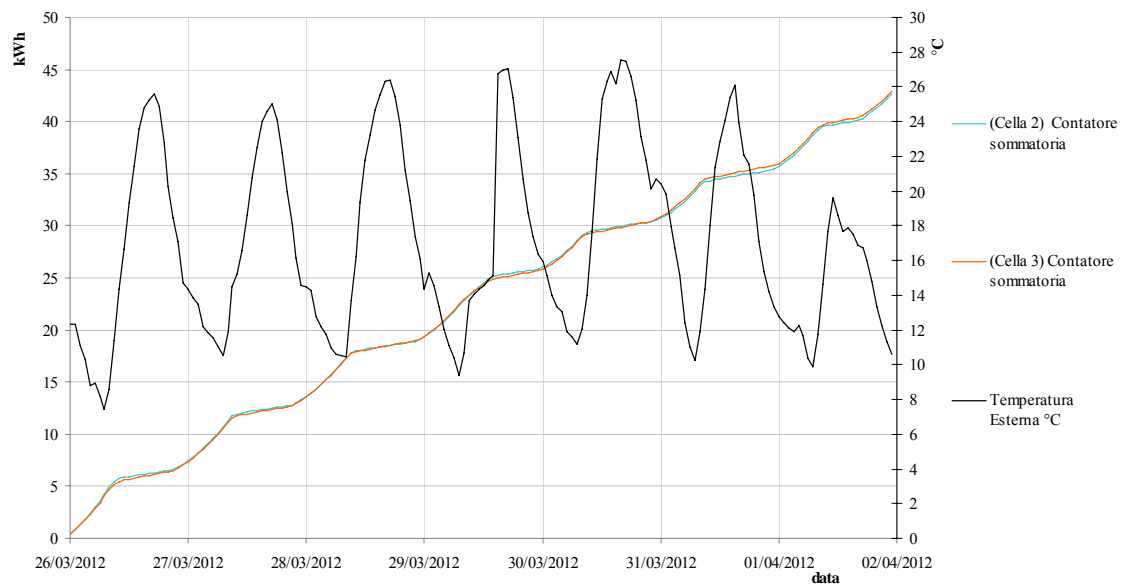
Figure 57. Comparison between the energy consumptions with VetroVentilato inactive in Winter

Winter consumptions are identical and therefore it can be confirmed that the two cells have the same energy behaviour for the winter period.
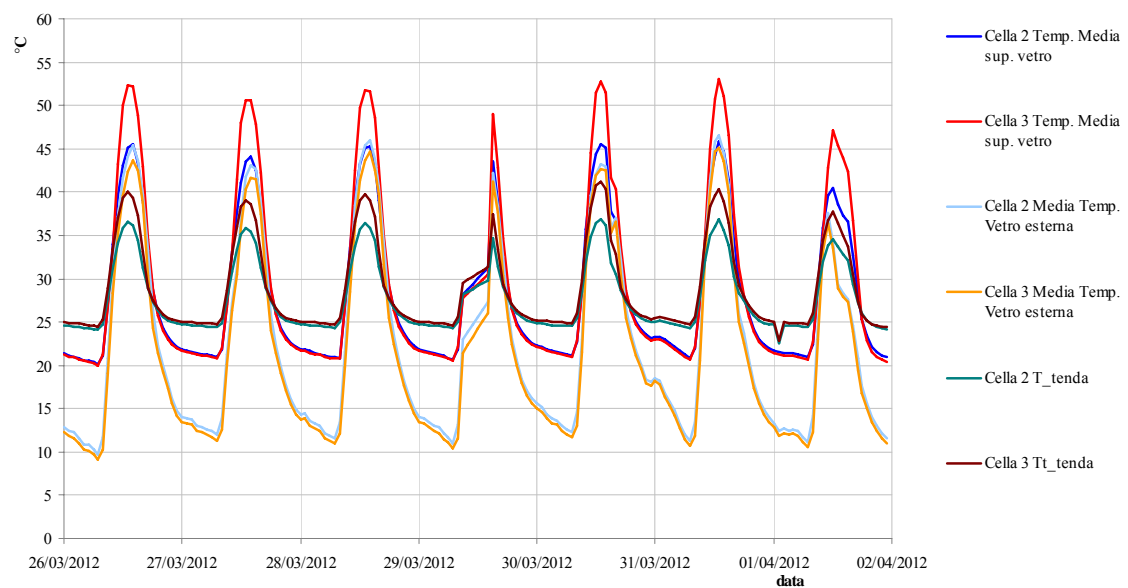
Figure 58. Surface temperatures of the windows with VetroVentilato inactive in Winter

In parallel, the trends of the surface temperatures have the same differences as the summer case and are justified for the different position of the blind in the two windows.

6.3 Energy Signature

In order to determine the Energy Signature of a building, it is necessary to collect a representative data set over an extended period of time as regards energy consumption.

The data is collected daily. Although in most cases a weekly basis is considered, in the present experimentation there are two small cells with an inertial behaviour of reduced dimensions whose

energy loads are constant. A precise accuracy of the results also is required. The daily or hourly readings allow sometimes imperceptible anomalies or differences to be measured. The installed instrumentation in the cells allows this requirement to be achieved.

In addition to its recognized purpose of pre-diagnosis and awareness of the end user, in this research the Energy Signature is used to verify the data project, for example, the thermal transmittance, through the energy consumptions.

The thermal transmittance calculation of a window in operating conditions is very complicated. To date there are computational tools, in accordance with the standard ISO 15099, which allow the trend of thermal transmittance and the solar factor in the presence of forced ventilation inside a cavity of the window to be studied and the dependence on air flow rate to be evaluated.

The experimental campaign allows consumption to be monitored and better energy performance of a dynamic window than a conventional one to be verified. It can be difficult to measure the respective thermal transmittance directly. The thermal transmittance is a laboratory indicator, whose result is obtained in absence of radiation.

In this experimental campaign the presence of radiation is an intrinsic condition and therefore an indirect measurement of the thermal transmittance takes account this error by evaluating a global indicator of heat loss of the dynamic window. The Energy Signature methodology has been adopted, aimed at calculating heat losses from which it is possible to indirectly calculate the variation of the thermal transmittance of any envelope element.
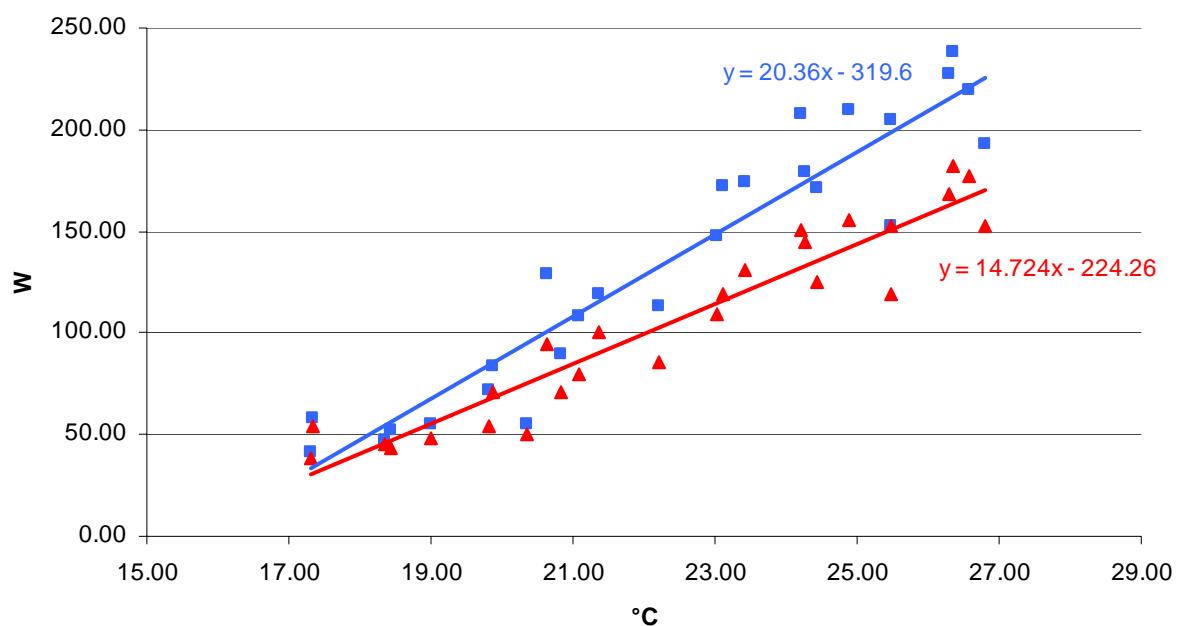

Figure 59. Energy Signature in Summer

Figure 58 shows the trend of the summer Energy Signature relative to the energy consumption in cooling conditions thanks to a heat pump. When the summer temperature increases so do the

consumptions and the electric power. The slope of the characteristic curve, unlike the winter one, does not represent the total losses of the envelope.

The slope of the two interpolating lines implies something more. It indicates ,for example, the amount of energy used to remove the heat entering into the cells, mainly due to the thermal losses and to solar gains. Consistent with the graph of Figure 38 the consumptions of the sample test-cell are lower than the reference cell.

Such a behaviour not only resides in the capacity of the sample test-cell to dissipate less, but also in the ability to remove more heat with the fan in the frame.
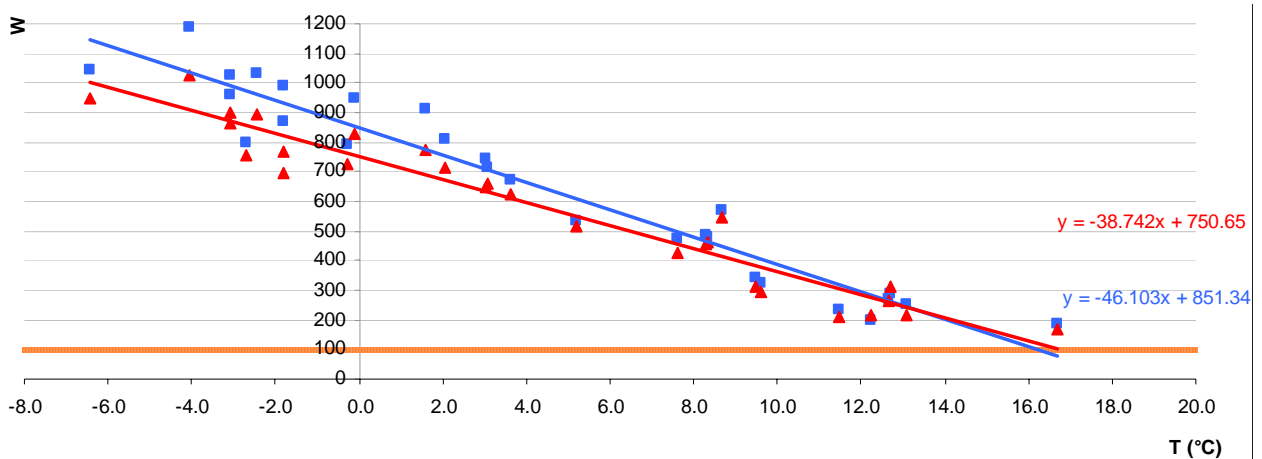

Figure 60. Energy Signature in Winter

In winter the Energy Signature slope shows the amount of thermal transmission and ventilation losses of each cell.

This graph allows several considerations to be achieved:

- sizing of thermal power of the plant;
- external temperature of shutdown of the plant;
- envelope behaviour at different external temperature;
- storage capacity of the heat.

The first consideration emerges when comparing the required power, for example at the design temperature at Milan (-5 °C). The reference test-cell requires an electrical power of 1100 W against a required power of the sample cell with dynamic component equal to 950 W. This reduction leads to a cheaper heat generator being installed during the sizing.

The second aspect shows the orange line, which identifies an average consumption from electrical equipment. The intersection point of the two lines with the orange line shows the set point temperature of the plant. The first cell turns off at 16 °C while the second one at almost 17 °C. Despite the sample cell saving more energy, it turns off at a higher external temperature.

This evaluation is explained by the inherent ability of the dynamic window to extract heat and to reduce losses. Therefore, at times of the year when the temperature range is higher (typically in Spring and Autumn) already around 16 °C it is more convenient to turn off the VetroVentilato system.

Introducing the third consideration, it might be interesting to create a logical control that turns off the fan of the glass at a given outdoor temperature (11 ° C) allowing the window to acquire a behaviour represented by the blue line, more efficient for higher temperatures (obviously until the terms of the conditioning).

The final evaluation is given by the comparison of the slopes. It suggests a significant reduction of the heat loss that allows more uniform and better conditions of comfort to be maintained.

6.4 Improvement of thermal transmittance

Comparing the traditional window and VetroVentolato, with an active fan, the first window behaves better than the first. The inactive VetroVentilato has shown that the consumptions are equal to those of the traditional cell.

It is possible to attribute the better behaviour of the VetroVentilato window to two characteristics. The first one is the capacity to exploit the convective movement on the internal glass surface. The second one is the very close location of the blind to the ventilated area. However, these characteristics allow the ventilated window to obtain better results because the thermal transmittance decreases.

In real operating conditions, the main difficulty is to determine the thermal transmittance reduction of the window and this improvement is due to the proximity of the blind to the internal glass.

The Energy Signature was used.

In order to define the coefficient of global thermal losses H_{tot} , all surfaces of the experimental cells, their thermal transmittances, thermal bridges and the air change rate are considered. This term identifies the slope of the line in the Energy Signature method.

The coefficient of global thermal losses of design in both the cells is equal to 45.2 [W/K]. Comparing the slope of the blue straight line (reference cell in Figure 59), equal to 46.1 with H_{tot} a negligible difference is observed.

The comparison between the slopes of the straight lines interpolating energy consumption of the respective cells shows that the reference cell is the most expensive. In fact, the sample cell with VetroVentilato (red curve) shows a lower slope and lower consumption. Its measured slope is equal to 38.7.

This means that the reference cell has a coefficient of loss greater than 7.4 [W/K]. Considering that all the surfaces, their transmittance and thermal bridges are invariant between the cells (except the

windows), it is clear that the thermal transmittance of the VetroVentilato window is the only variable. As mentioned previously this reduction is due to the ventilation and the distance from the blind.

Firstly the efficiency of the blind near the window was quantified. Thanks to the differences recorded between the reference window and the VetroVentilato window, in two different configurations (ventilation active and inactive), it was possible to quantify the contribution of the blind placed in proximity of the internal glass.

The improvement was estimated in about 38%. In this way it was possible to define improvement due to the ventilation rate.

The experimentation indicates an improvement in the thermal transmittance, for the air flow rate set at 20 m^3/h, of about 0.59 W/m^{2}K. The result, in line with the geometrical characteristics, has been obtained by removing the thermal losses of the up frame and the spacers of the double glazing. Theoretical calculations identify an improvement of about 0.55 W/m^{2}K, with an air change rate of 20 m^3/h, validating the experimental results.

6.5   Energy saving

The achievable energy saving in the winter period depends on the climatic conditions and mainly on the external temperature. For temperatures between -7 and +17 °C the average energy saving with the VetroVentilato is equal to 10% compared to a traditional window. Temperatures less than zero indicate a saving of about 13%, while for external temperatures close to 17 °C the energy saving decreases to 5%.
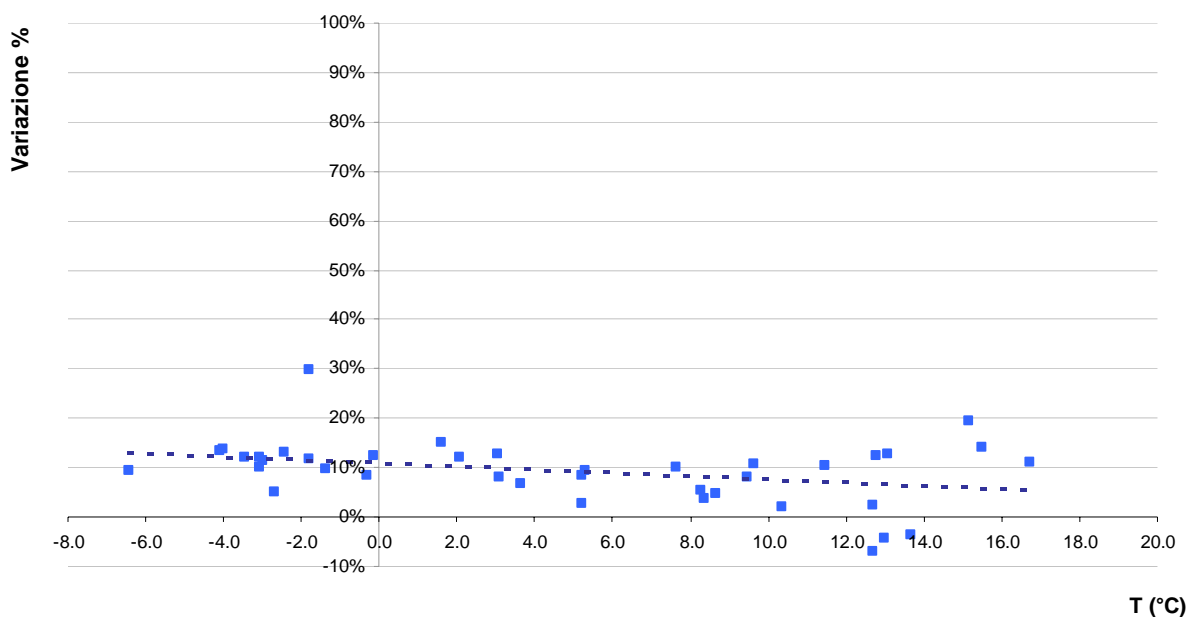

Figure 61. Energy saving trend in Winter

In summer, however, the results are more evident. The energy saving depends on the external temperature, starting with a value close to 17 °C there is a saving of about 12%, for an average daily temperature close to 27 °C the saving increases by up to 30%.
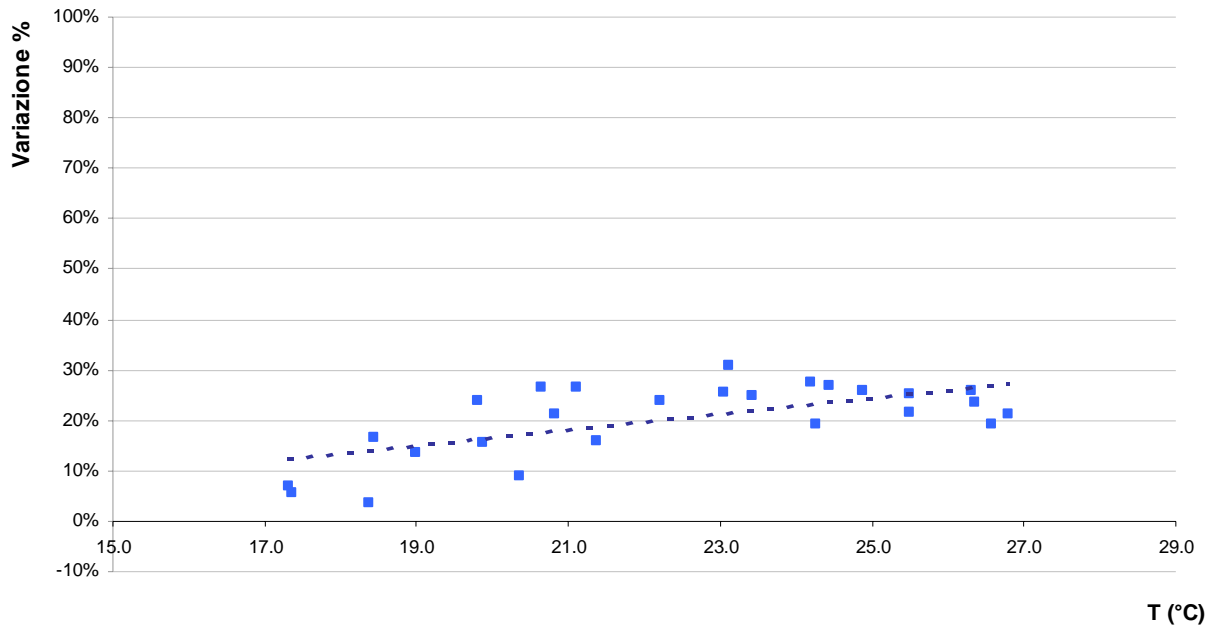

Figure 62. Energy saving trend in Summer

These results are obviously contextualized in Milan (climatic zone "E"). However the analysis can be extended to the different contexts in which temperatures close to the range obtained in the experimental campaign can be recorded. Considering, for example, a city whose average temperature in the summer period is about 19 °C, the energy saving will be approximately equal to 15%. For a city with an average temperature of 26 °C the savings will be of over 25%.

7   Projection of the results

This section describes the behaviour of measured consumptions for the two cells in relation to certain variables (environmental variables and intrinsic variables to the window: external average temperature [° C] for the whole day). Then the results, obtained experimentally, were extended to the Italian provinces starting from the standardized weather data (source CTI).

7.1   Italian weather data

Below are images of Italy and its provincial borders.

Figure 62 and Figure 63 show the average temperatures of the cooling and heating period.
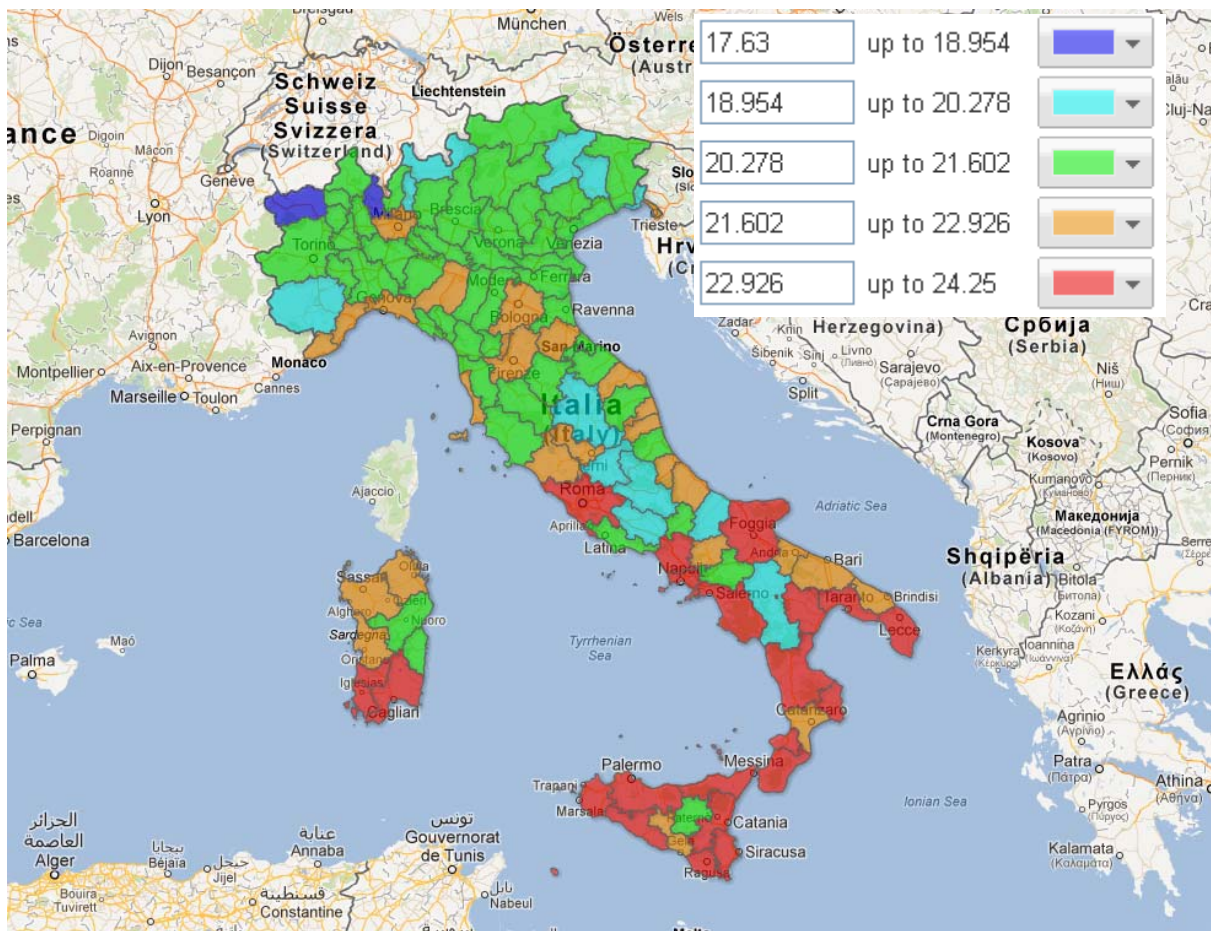

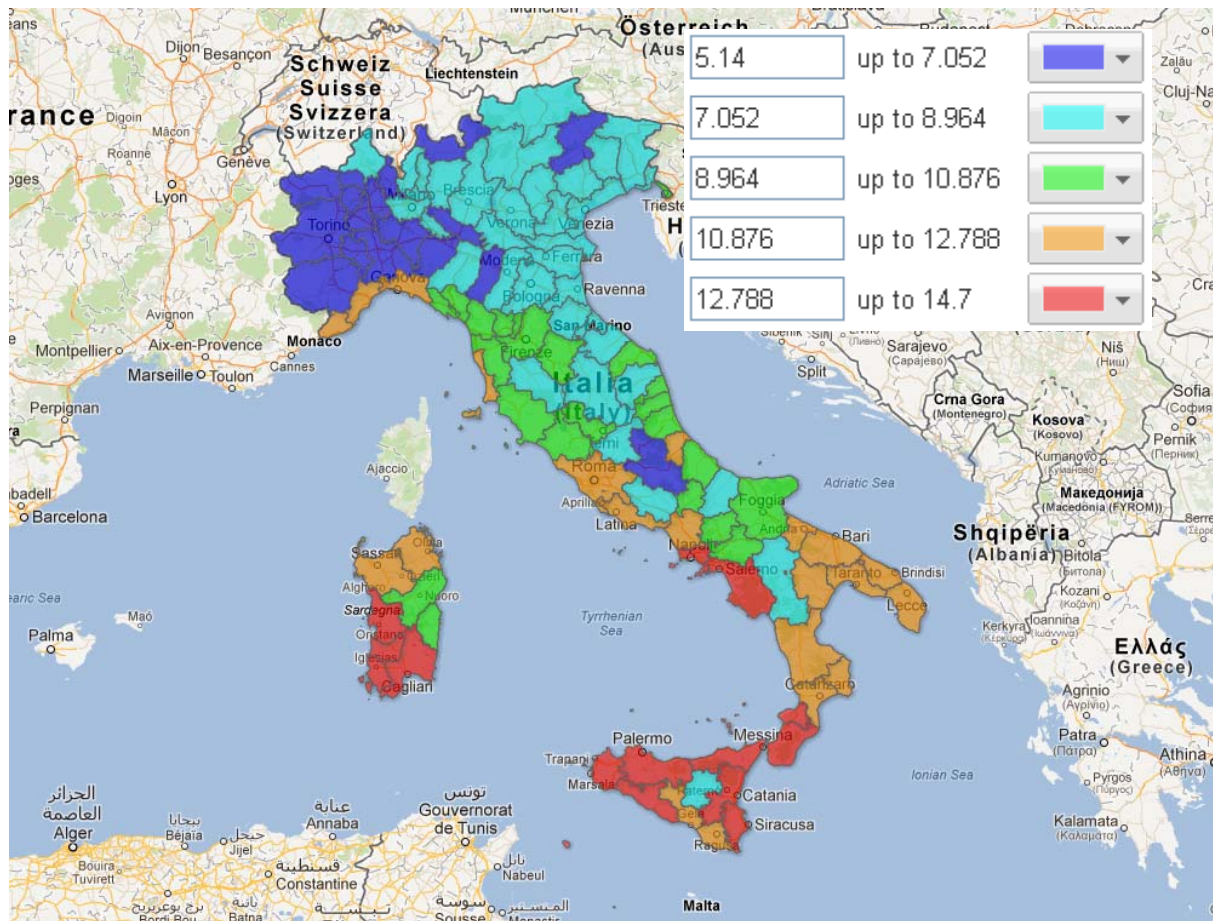Figure 63. Average temperatures in cooling period - Italy

Figure 64. Average temperatures in heating period - Italy

7.2   Interpretation of results

The following results compare the measured energy saving of the two cells and visible in Figure 60 and in Figure 61.

The energy contribution of a window varies depending for example on the envelope, the shape factor or the transparent surface compared to the floor surface.

The coloration identifies the percentage of saving between the sample cell with VetroVentilato and the reference cell with a traditional window.

In the winter period a coloration increasing from soft pink to a deep red indicates in which provinces the best performances of VetroVentilato (deep red) are observed ; similarly as regards the coloration from light blue to dark blue in summer.

The following analysis carries out a transversal evaluation about the energy behaviour of the two experimental cells hypothetically placed in all climatic zones. However, the cells have been designed with reference to the construction standards of the climate zone "E" and therefore the graphs are beyond considerations with reference to the minimum national requirements.

7.3   Extrapolation of the results

It can be observed that cell 3 (with VetroVentilato) is always cheaper than cell 2 in winter. The map also shows that for the Northern regions, for which the temperatures of February are between 2 to 3 °C, the energy saving of the cell 3 is more than 10% respect to cell 2. For the Provinces of the South (especially the larger islands), however, in February the temperatures are milder and generally above 10 °C and the percentage variation of the C3 is + 6%.
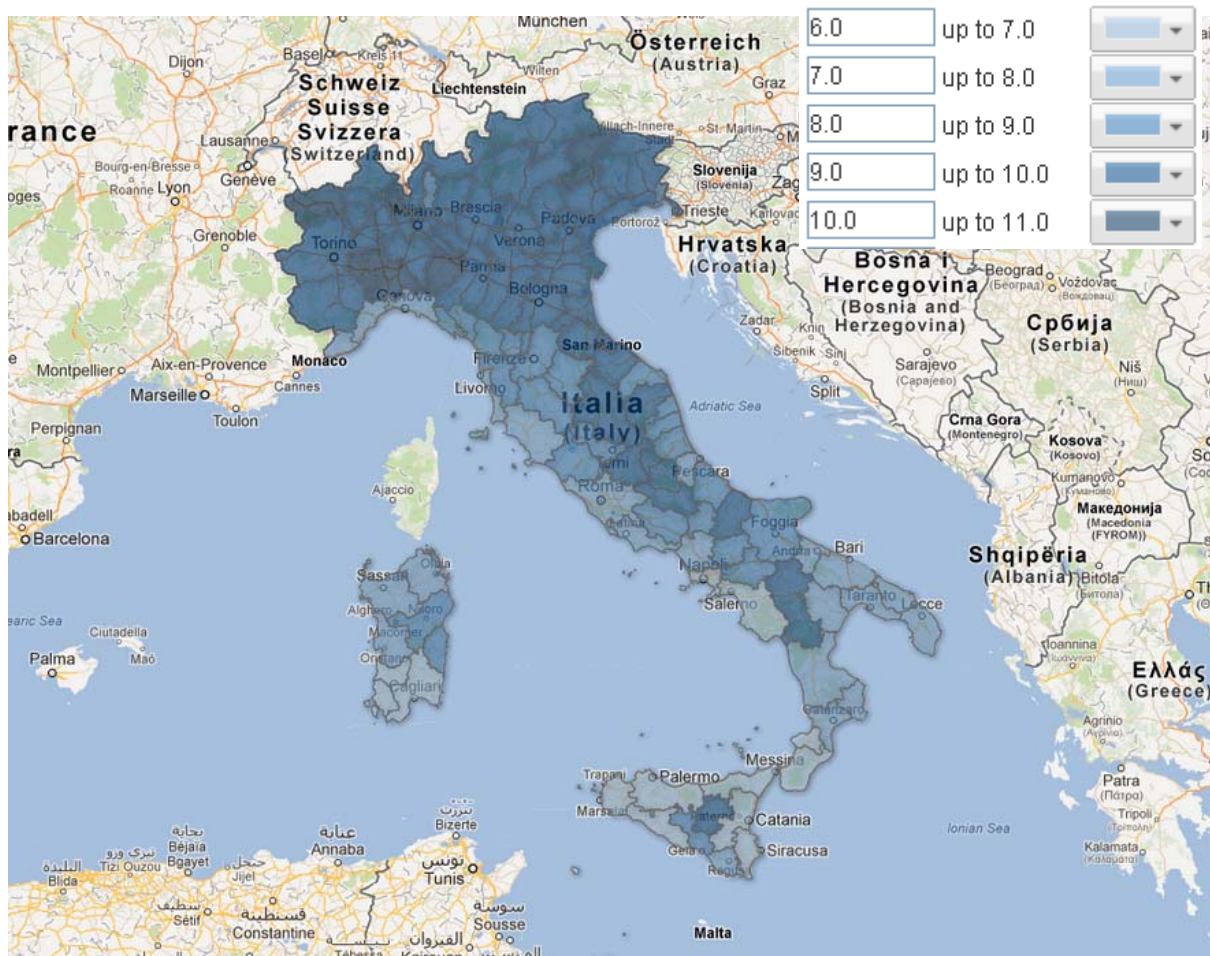

Figure 65. Energy saving, expressed as a percentage, in Winter - Italy

The temperatures of July ar etaken into consideration in order to define the summer trend,. Even in this case cell 3 is considerably more convenient than cell 2 with a saving of between 17% (in the provinces where the external temperature of July is equal to that of about 20 °C) and 28% (where the average external temperature of July is over 26 °C).
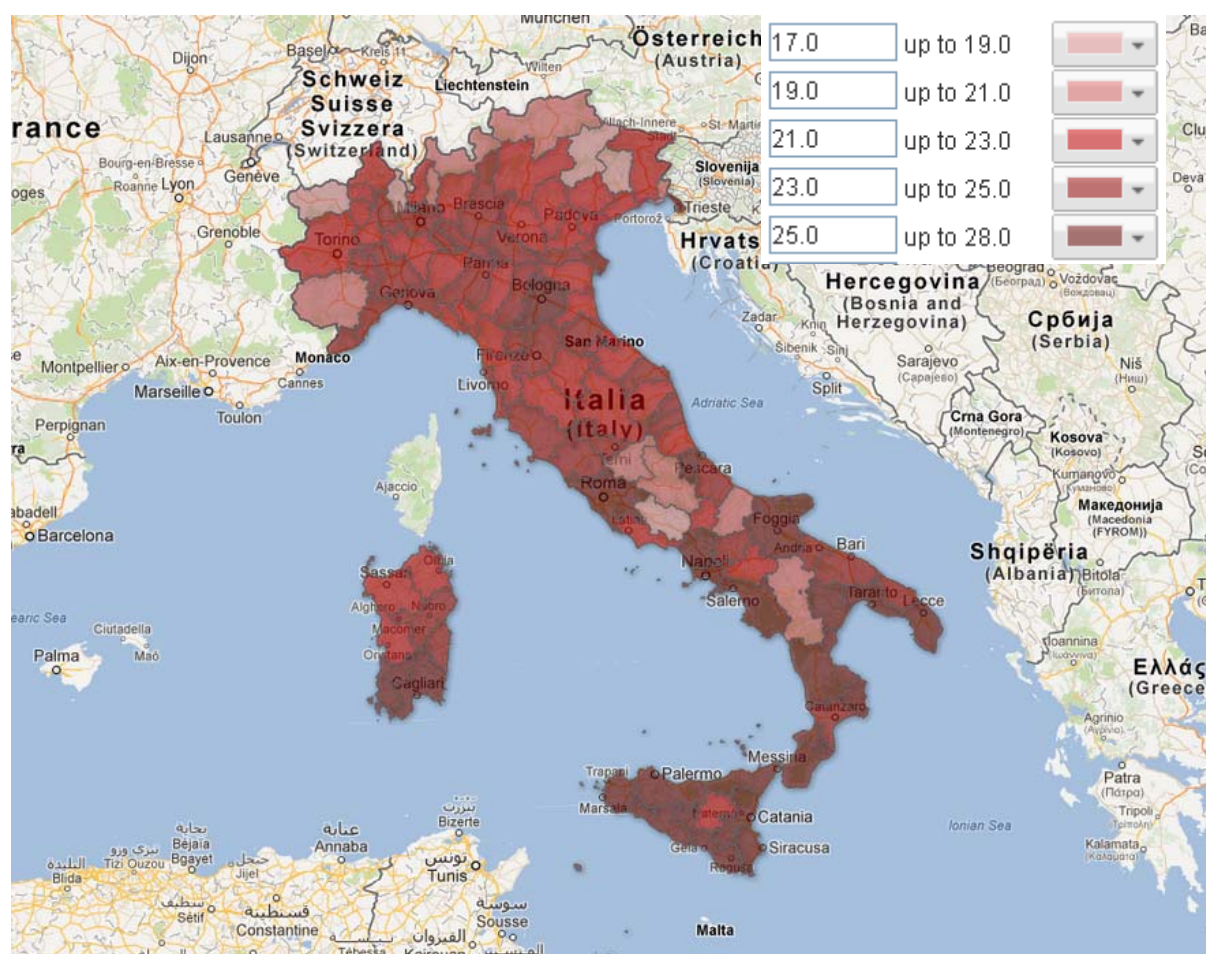
Figure 66. Energy saving, expressed as a percentage, in Summer - Italy

8 Conclusions

The experimentation allowed the energy behaviour and the comfort of the VetroVentilato window to be characterized. In particular, the proposed configurations showed the variation of the thermal transmittance under dynamic conditions and highlighted the real improvement of the thermal comfort and the energy savings achievable.

These considerations are fundamental for the design of a building, not only in compliance with the minimum requirements imposed by law, but also in order to size and properly manage energy flows and the control logics of a dynamic system. The main difficulty of exactly using a dynamic system is to regulate the timing and the air change rate of ventilation.

These indicators are parameterized as a function of climatic variables. It is necessary to define preventively control logics that will optimize the efficiency. A possible optimization of the ventilated system could involve the introduction of a heat recovery system thus ensuring further energy savings.

With this in mind, it would be interesting to carry out a subsequent experimentation by adjusting the VetroVentilato window with a heat recovery system to ensure a further improvement in the performance of about 25% in both summer and winter.