Thermal performance of a supply-air window with triple heating glazing inserted in building envelope

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Abstract. Nowadays, no one ignores that the building envelope plays a major role in terms of energy consumption and greenhouse gas production. Successive regulations have mainly resulted in a reinforcement of thermal insulation and an improvement of the airtightness of the envelopes. But this often results in poor estimations of consumption, condensation problems on the walls and poor air quality.

Our project consists in analyzing the contributions of a glazed, supply air and heating façade component that provides the ventilation, the heating of the building and the recovery of solar and fatal energy. It is based on a supply-air window of type "Paziaud" in which a heating glass has been inserted. A prototype has been installed on the façade of a building and has been extensively instrumented. Measurements of surface temperatures and air temperatures, pressure difference and velocity are completed in an original way by a fluxmetric instrumentation placed in the ventilated air gaps of the window and on the surfaces in contact with the interior and exterior environments.

This paper will allow us to share and discuss the first results obtained in this in-situ configuration. Our experimentation highlights the difficulties that arise in the interpretation of measurements in real sites, more or less disturbed during the day and at night by the variations of meteorological parameters. It is also a question of coming back to the definition of the performance indicators by comparing theoretical formulas and practical results. In particular, it is necessary to take a closer look at the definition of the outside temperature, which is involved in the expression of a surface transmission coefficient adapted to the component and to discuss an efficiency factor for the window which functions as an exchanger. It is also important to take into account the different heat sources (solar radiation, electricity and recovered waste heat), the heat convective exchanges coefficients that take place in the air gaps and the definition of performance indicators.

Keywords. Heated Supply air window, Experimental prototype, Heat fluxmeter, Building ventilation
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1. Introduction

This project (NTE-VARIETO supported by ADEME (French ecological transition agency) is conducted in the framework of a collaboration between two French university laboratories, the LGCgE (University of Artois - Béthune) and the LASIE (University of La Rochelle) and also with a joinery company (Ets RIDORET). The objective is to obtain information allowing the characterization of the performances of a supply air heating window. This window of the Paziaud type [1] is relatively well known. Originally, its operating principle is to allow the transfer of air renewal through the window by circulating between three panes forming a U-shaped channel. In this configuration, the air circulation is ensured by the depression of the building under the effect of a mechanical controlled or natural assisted ventilation device. The air that circulates in the window is the fresh ventilated air and here the interest being that in winter, it is introduced more or less preheated in the building. The preheating is achieved by convection by recovering part of heat losses by transmission and some of the incident solar energy absorbed by the glazing. In recent years, the work of Gloriant [2,3] and Greffet [4] have allowed significant progress in the study of these windows and have also allowed the transition to industrialized component through official technical notice and to the consideration by the building thermal regulations.

In the "VARIETO" project, the interior glazing is replaced by an electrically powered heated glazing.

This disposition must allow to propose an element of the building envelope which is also a heat emitter. The contribution to heating is made both by a warm air supply (fresh air heated in the window) and by radiation and convection on the interior surface. The heated glass can reach a surface temperature of about 45°C, (maximum chosen for the safety of the occupants). In this project, the LGCgE is in charge of several experiments, one of which concerns the implementation of a ventilated heating window in-situ on the south façade of a building of the University of Artois in Béthune. This one is the subject of this paper.

2. Experimental device

- This prototype of window has the advantage of being able to be open as a fan-like model (figure 1 and thus allow us to access to all the six sides of the three panes.

- The exterior glazing is 6mm thick, without any special treatment.

- The central glazing is 4mm thick with one low-emissivity face (the one facing outwards and which will be numbered "3" in this work).

- The interior glazing is 8 mm thick. It is a laminated glass, two panes of 4mm each, with a resistive film of some µm thickness at the interface which will act as a heating resistor. This resistive film, like the low-emissive coating, has an attenuating effect on the transfer of solar (visible) radiation.

Fig 1 The prototype of parietodynamic window

The instrumented window (Fig 2) is located on the south façade of one of the buildings of the Faculty of Applied Sciences in BETHUNE. The objective is to carry out in-situ measurements by recording the external climatic conditions (air temperature, sunlight, IR radiation, wind speed), the heat fluxes passing through the glazing and the surface temperatures and air temperatures in the window. In this paper, we will focus on winter nights. These are the periods for which the interpretation of the measurements is the simplest. Indeed, when the window is exposed to solar radiation, the measurements of heat fluxes and surface temperatures are difficult to exploit.

Fig. 2 Instrumented window on the south façade of a faculty building in Bethune

In addition to the air temperature measurement, a pyranometer, a pyrgeometer and an anemometer are used to characterize the outdoor environment. The figure 3 shows the layout of thermocouples and tangential gradient fluxmeters.

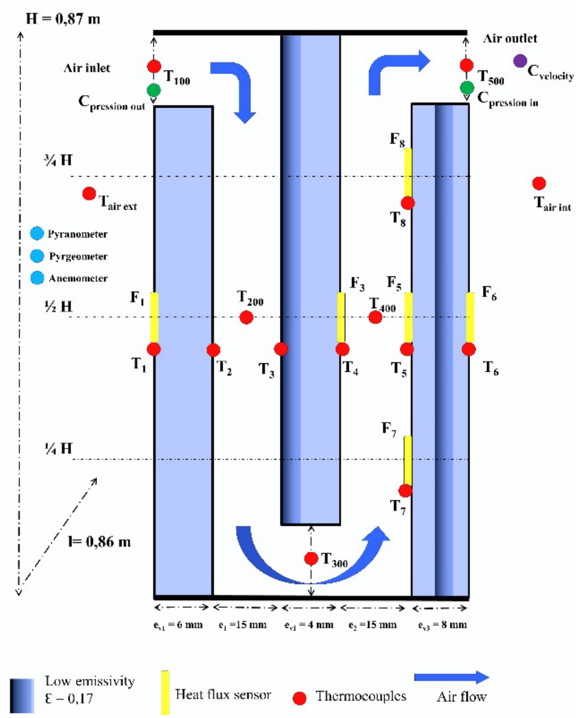

Fig 3 Sensors localization in the prototype

One of the particularities of a supply-air window is the variation that exists in the thermal flux densities for each of the panes (Figure 4). We aimed to highlight this particularity by placing in the window, thermal flux sensors (numbered from 1 to 6 according to a horizontal plane) and two others (7 and 8) arranged on the internal face of the heating glass (face 5) and at different heights (see Figure 2 and 3).

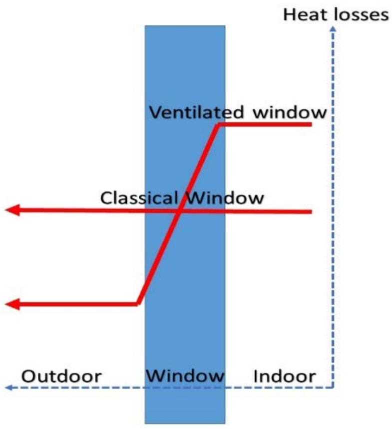

Fig 4 Comparison of the evolutions of the heat flux through a conventional window and in a parietodynamic window

These tangential gradient fluxmeters (Figure 5) were developed by our laboratory several decades ago [5]. They are now manufactured by the Captec® company and calibrated by our team. They have a very low thickness (< 0.2 mm) and thermal resistance and are well adapted to our measurement problem. These sensors have an average sensitivity of about 20 microvolts for an heat flux density of 1 W/m².

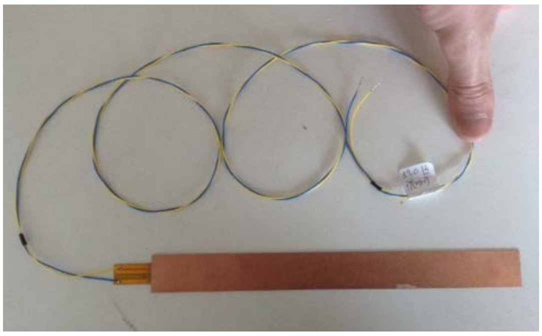

Fig 5: View of one of the fluxmeters used to instrument the supply air window

Originally made of raw copper, the faces of the fluxmeters were painted here to obtain an emissivity close to that of the glazing on both faces (~0.87). After gluing them with a very thin layer of thermal grease, the visible faces, facing the outside, were covered with a white adhesive to limit the absorption of solar radiation during the day.

Type T thermocouples were used for air and surface temperatures measurements. For surface temperatures measurements, the thermocouple junctions have a diameter of about 0.1 mm. They were bonded to the glass with an adhesive heat-conducting aluminum pad, a few mm in diameter. This was then covered with a white adhesive in order to reflect as much as possible the solar incident radiation on the probe. A Kapton adhesive, which has transparency and emissivity properties similar to those of glass, was used to keep the very fine thermocouples wires in position, so as not to disturb the air flow between the panes. On the low emissivity face of pane (number 3), a thermocouple has been glued with a very small (some mm diameter) reflective and low emissivity aluminum pad to reduce as much as possible the effect of the probe on the measurement.

The air temperature measurements in the window are made with T-type thermocouples of 0.05 mm diameter. At the window exit, a plenum was installed and connected to a 100 mm diameter PVC duct, itself connected to an air extractor (Figure 7)

Fig 7 View of the experiment

3. Experimental results - Simple supply-air window

The graphs 8, 9, 10 and 11 show us the first measurements made (16 to 18/11/2019) without activation of the heating resistor. We are then in the case of a classic supply-air window. The average airflow measured at the extraction is 23.45 m³/h. This flow rate is representative of common values, between 15 m³/h and 30 m³/h at the level of the air inlets with classic joineries.

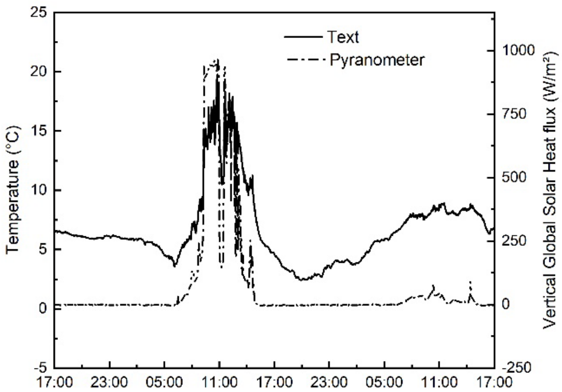

Fig 8 Global solar irradiation and outdoor temperature.

The figure 8 shows two days recordings of outdoor temperature and solar global radiation. On the first day, the incident solar radiation measured by the pyranometer reaches a maximum of almost 1000 W/m². This value is very important. This is due to a white roof under the window reflecting part of the incident radiation that it receives. It can be observed that the outside temperature seems to be also strongly affected by this.

The T100 thermocouple that measures the air temperature at the window entrance gives almost identical results (Figure 10). The outside air temperature measured very locally is not the same as the one that would be measured under shelter by a weather station. It is close to the temperature of the air entering the window (T100) and therefore probably also to the temperature of the air near the exterior glass surface. This point is particularly important to emphasize when determining performance indicators.

3.1 Temperatures

On the figure 9 we can observe the evolution of the surface temperatures of glazings for these two days. We note, here again, that the solar radiation is undoubtedly disturbing the measurements.

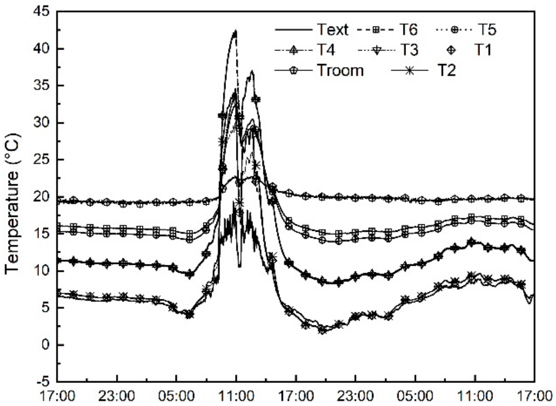

Fig 9: Ambient and surface temperatures

On the other hand, at night and on cloudy days, the measurements seem to be directly exploitable and very interesting. We can clearly see on the figure 9 the decrease in temperature from the inside to the outside of the building. The temperature differences between the two sides of the same pane are very small (at the limit of the measurement accuracy). One could not use this difference to deduce the flux through the glass by conduction heat transfer.

These results are complementary to the air temperatures (Figure10) flowing through the window. (See also Figure 3). The temperature T500 is measured in the plenum at the window outlet.

Here again the solar disturbance is such that the results of fluxmetric measurements cannot be easily exploited during the day.

Nevertheless, the white surfaces of the fluxmeters are very small compared to those of the glazing so the heating of the air by parietodynamic effect is clearly preponderant. It is of the order of 6 to 8°C during the night or when covered sky. It rises to a maximum of 15°C when the sun shine.

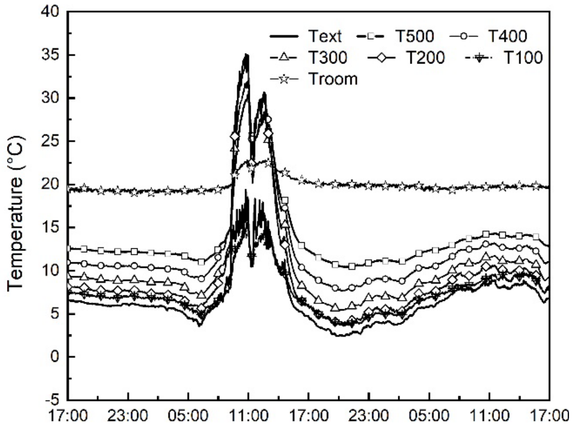

Fig 10 : Air temperatures

3.2 Heat fluxes

Finally, the figure 11 represents the evolution of the flows for the same period.

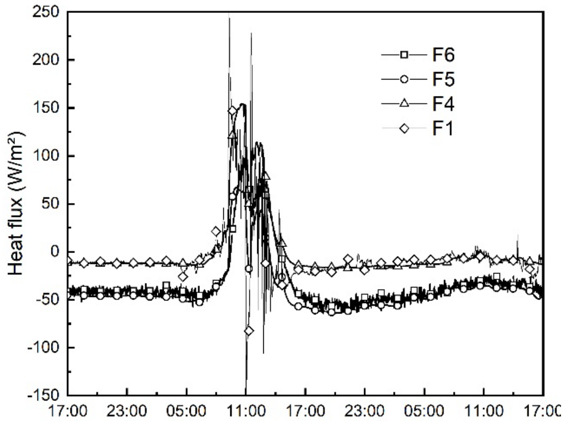

Fig 11 : Heat fluxes through the window

Here again the sunny period is not exploitable. It is interesting to note that the F1 (exterior glazing) and F4 (intermediate glazing) flows are very close and relatively low. This confirms that the outer air gap is not very active in terms of heat recovery, as it was noted in simulations in previous work [6]. In the second air gap, the increase in air temperature from the bottom to the top causes that F7 > F6 > F8. The fluxes F5 and F6 measured at mid-height on either side of the inner pane are very close.

3.3 Performances Indicators

By defining different control areas, Gloriant in his thesis [3] proposed performance indicators for the supply air window. If we consider control zone "1" (Figure 12), the fresh air enters the zone at the outside temperature as for a conventional window and it is the flux at the outside glazing that is used to calculate the U-value. This is the same definition used by Wright [7].

$$U_e = \frac{F_1}{T_{int} - T_{ext}} \quad (1)$$

If we consider the control zone "2", this time, the air enters the zone after being preheated in the window's air gaps. The U-value is defined from the value of the flux at the interior glazing:

$$U_{dyn} = \frac{F_6}{T_{int} - T_{ext}} \quad (2)$$

In winter, this coefficient will be much greater than the previous one because of the increased transfers through the first glazing (from inside the building). But a large part of this energy is recovered by the ventilation air which is preheated and returns to the control zone. It is therefore necessary to add to the U-value another value which will be an indicator of the efficiency of heat recovery by the air in the supply air window.

$$\eta_{dyn} = \frac{T_{preheated\ air}(T_{500}) - T_{ext}}{T_{int} - T_{ext}} \quad (3)$$

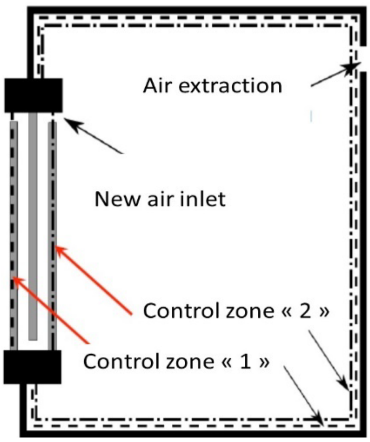

Fig 12 Control zones for defining performance indicators

Using the flux densities and the measured temperatures, we can estimate the Ue of the window with and without activation of the heated glass. To do this, we will take into account the measurements of thermal flux in pane 1. In the middle of the night from 17 to 18/11 the flux F1 is equal to about 10.8 W/m^2 on average. We note that F6 is a little noisier, due to exchanges by natural convection with the air of the room whereas the fluxmeter F5 is in contact with a laminar air flow in forced convection at low speed. The average temperature in the room for the same period is 19.5°C and the average outside temperature is about 6°C.

This gives us an "experimental" U_e in the order of 0.8 W/m^2°C for a simple supply air window, a U_{dyn} of 3.22 W/m^2°C and a recovery efficiency η_{dyn} = 0.45. These calculations are based on the average values of the flows and temperatures measured over the period.

The U_e (U_g) should be lower for a conventional supply air window than for an efficient triple glazing. This value is indeed quite high, far from the lower theoretical values obtained in modelling [2]. To improve the results, in reality the outdoor temperature to be taken into account experimentally is different from the air temperature because the IR radiation measured by a pyrgeometer gives here an environmental temperature of -7°C for the same period. Taking this temperature into account will tend to increase the temperature difference between the indoor and outdoor environments and the experimental U-value will be reduced. It should be noted that the measured outdoor temperatures are generally assimilated to air temperatures for heat loss calculations. Our results are indicative of an inaccuracy difficult to remove but generally accepted in the calculations. On the other hand, it is the air temperature that must be used for the energy balance on the ventilation air.

The advantage of the supply air window being here to preheat the fresh ventilated air, the energy balance is always very favourable even if the value obtained for the Ue is relatively high compared to the expected results based on models. It must be taken into account that these models were developed on 2-dimensional window diagrams, without taking into account the effects of the frame of the joinery, the thermal bridges and the sealing defects which can exist between the air gaps. The truth is probably somewhere in between.

4. Heated supply air Window

We now look at the behavior of a supply air window with active heated glazing. We are now in December. Over the period from December 1 to December 5, it appears very sunny days, with a very clear sky which increases the difference between the air temperature and the environmental temperature deduced from the pyrgeometer measurements. (ex Fig 13)

The days from the 6th to the 8th (not very sunny) will be more adapted to the analysis of our measurements (see Fig 14).

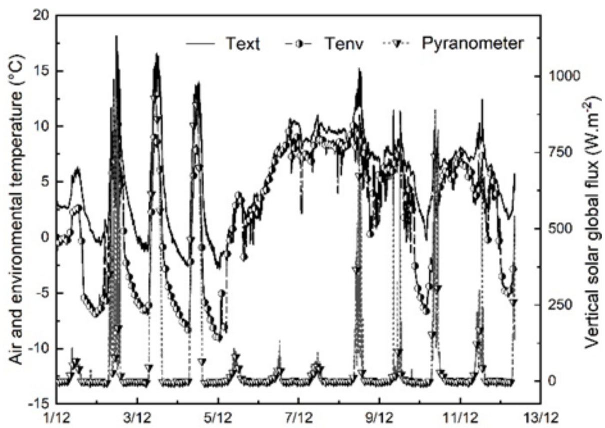

Fig 13 : Global solar irradiation and outside temperatures

It should be noted that from the first of December, the power supply to the window is 208.7 Volts, which is equivalent to a power dissipated by Joule effect in the window of about 354 W/m^2, with an average air flow rate in the window of 23,45m^3/h.

In this paper we will focus on the period from 6 to 8 December. The graph below Fig 14 represents the evolution of the outdoor and indoor ambient temperatures as well as the different temperatures of the glazing. It allows to realize the impact of the solar radiation on these values. The sunny periods do not seem conducive to reliable analysis given the solar radiative disturbances on the measurements.

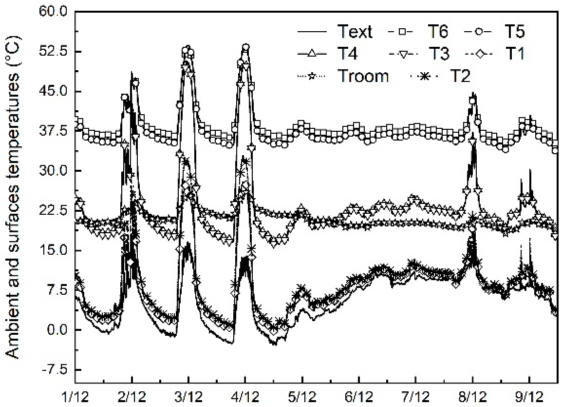

Fig 14: Glazing temperatures and ambient temperatures

Looking in more detail at the temperature curves of the glass panes, we can see that they go well in pairs with small differences between the two sides of each pane. On the other hand, the differences are important between the panes. The heated glass has an average temperature of about 37 °C while the temperature of the intermediate glass is around 22,5 °C. This difference is important and undoubtedly has consequences on the evolution of the exchange coefficients in this air gap. In the same way, in the external air gap, the difference is significant (about 12°C) between the two panes, probably reinforced by the low-emissivity coating on side 3. The external pane remains cold, close to the external air temperature.

4.1 Heat flux

On figure 15, we can note that the heat flux F6 becomes negative (according to the conventional direction we have chosen, positive heat flux is oriented from the inside to the outside). The flux is reversed here because the heated inner pane is active.

At the heart of this glass, a deposit of metal oxides forms a flat, heating electrical resistance. The night conditions are very stable. As in the case "without heating", the temperatures increase between side 1 and side 6. (Figure 16) A significant decrease in the value of the flux can be observed as one moves from the inside to the outside. The difference corresponds largely to the energy recovered by the air coming from outside at about 9°C and blown into the room at about 22°C. This is a very interesting result that the valuew of the F4 and F1 fluxes are very low. This indicates a priori a very good recovery of the power supplied by the electric power supply and of the heat losses crossing the window.

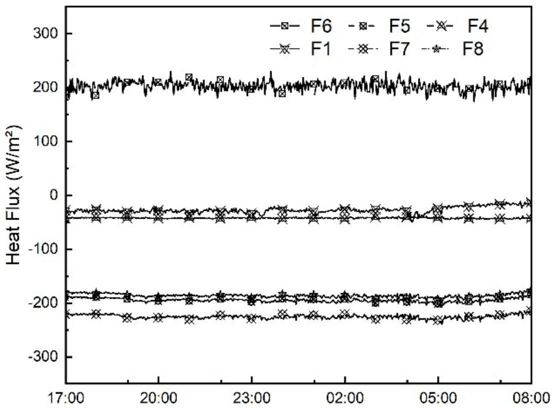

Fig 15 Thermal heat flux in the window between 07/12 at 5 pm and 08/12 at 6 am

A power of about 354 W/m^2 is injected into the heating element. The average thermal flux F5 measured is 195 W/m^2. The F6 flux is on average (and in absolute value), 203 W/m^2. The sum of the two fluxes exceeds the 354 W/m^2 supplied to the heating glass.

4.2 Temperatures

As in the previous test, we can see (figure 16) that the temperature differences between the two sides of the same pane are very small (maximum 1.3°C for the heated pane).

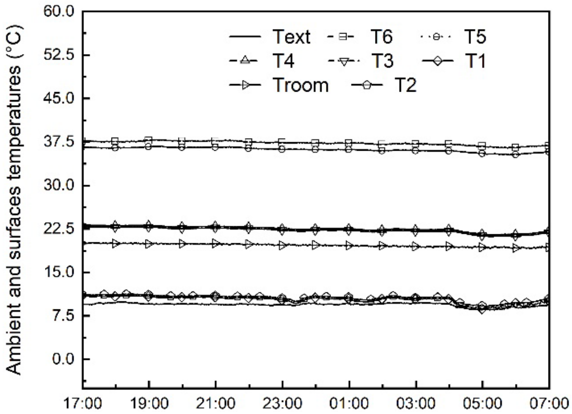

Fig 16: Surface temperatures of glazing in the window between 07/12 at 5 pm and 08/12 at 6 am

The average surface temperature of the heated glass is then around 37°C, transforming the glass into a radiator/convector. A flow of fresh air at an average temperature of 22,5°C (T500 - figure 17) is blown into the room (while the outside air temperature is around 9.5°C on average. The gain in fresh air preheating is therefore about 12.5°C. Here the energy gain by the air is relatively equivalent if we consider the two air gaps. (T300-T100 ~5,2°C) and T500-T300 ~6,7°C, which does not correspond to the expected results. The T300 temperature measured near the frame of the joinery and at the change of direction of the airflow is probably disturbed.

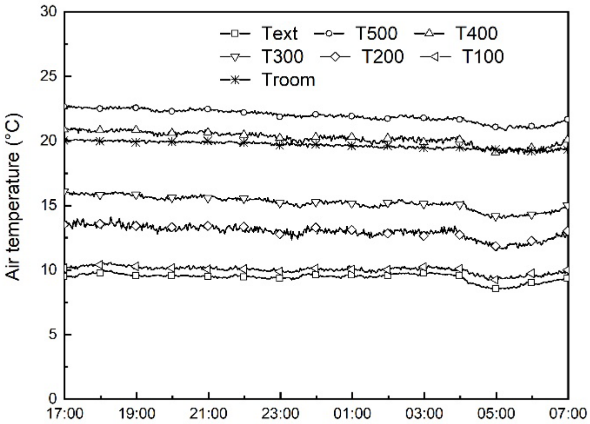

Fig 17: Temperatures of air circulating in the window between 07/12 at 5 pm and 08/12 at 6 am

Since the low-emissivity layer of the central pane is located on side 3 (exterior side), it does not prevent the absorption of energy transfer by radiation from the heated pane. The central pane then transmits heat into the two air gaps. It is conceivable that turning this low-emissivity pane inward would result in greater heating of the heated pane and an imbalance in convective transfers between the two air gaps. The question arises as to the best efficiency between the two options. The first experimental results presented here allow to highlight the role of preheater of fresh air played by the window and the role of heat emitter when the interior pane is heated. Figure 7 gives us an output flux (F1), in absolute value, of 26 W/m². Figure 6 shows an interior temperature of 19.5°C and an exterior temperature of 9.5°C. In the end, we have a Ug of 2.6 W/m²°C.

The average thermal power win by the air on the considered period is about 100W (0,34Wh/m³.K x 23,45m³/h x12,5°C) that we have to add to the power transmitted to the room by the interior glazing (~200 W/m² x (0,87x0,87 m²) = 151,4 W. The electric power furnished to the window *Pelec* is (354W/m²) x (0,87x0,87 m2) = 266W

Then we can think that there is about 15 W which are dissipated in the window through the frame, and we can hope that a majority of this power is transmitted to the room.

We have to consider that the power supplied is distributed over the entire surface of the glazing while the measurements made by the fluxmeters are local (in the center of the window). The fluxmeters are sensitive to the dissipation of the electrical energy supplied, but also to the different exchange conditions with the interior environment of the room and the air flow from the outside through the window. We must not forget that the sweep of the glazing surfaces temperature is not uniform and that there are probably dead zones related to the 3D geometry of the flow. These results must be taken with caution.

Indeed, in the case where the glazing is heated, new performance indicators are to be proposed.

4.3 Performance indicators

To characterize the performance of this window, i.e. to evaluate how well it insulates, the energy it provides and the energy consumed, it is necessary to define indicators of performance by blowing and the heat lost from the interior of the room (exponent "off" or "on" depending on whether the window is heated or not) [8,9,10]

Thermal flux entering the interior space

$$\mathrm{F}_{int}^{on} = \mathrm{F}_{air} + \mathrm{F}_{int} \text{ (W/m}^2\text{)} \quad (4)$$

where F_{air} is the power gained by the fresh air in relation to the glazed area of the window (W/m²).

F_{int} is the heat flux density for the glazing on the interior side (heated room)

Heat transmission coefficient

$$U_g = \frac{\mathrm{F}_{ext}^{on}}{T_{int} - T_{ext}} \text{ (W/m}^2\text{K)} \quad (5)$$

F_{ext}^{on} the heat flux density for the outer glazing representing here the heat losses

Window efficiency

$$E_w = \frac{\mathrm{F}_{ext}^{off} + \mathrm{F}_{in}^{on}}{Pelec} \quad (6)$$

F_{ext}^{off} the flux density that would exist if the heated window was not activated.

Efficiency of the heating film

$$E_{film} = \frac{\mathrm{F}_{int}^{on}}{Pelec} \quad (7)$$

Equations 4, 5, 6 and 7 define the performance indicators. From the measurements of heat flux, temperature and power, we can evaluate the energy performance of the window. A coefficient classically noted g (ISO 15099 [11]) will be used in the presence of solar radiation.

calculation of the coefficient g

$$g = \frac{F_{transmis} + (F_{éch} - F_{int})^{sol} - F_{ext}}{F_{sol\,incident}} \quad (5)$$

It is difficult at present to determine precisely the values of the performance factors of the heated window because they are based on the evaluation of heat fluxes transferred to the environments at any time. We show that it is possible to measure these fluxes correctly at night but very difficult to do so when the window is under the influence of sunlight. It is also difficult to know the share of energy recovered from the heat losses, from the solar absorption of the glazing and from the power supplied to the heated glazing by using Kurnitski's equations.

In these equations there is an "off" and an "on" heatflux depending on whether the heating is activated or not. And it is currently difficult to find the value of one when measuring the other. A numerical simulation model is actually built to solve this problem.

5. Conclusion

In this paper we have presented the first results of an experimentation aiming at better understanding the functioning of a heated supply air window and establishing performance indicators. These results show the interest of the window in terms of preheating or heating of new ventilation air. Here we are in a room of about 350 m^3 with 5 windows of the same dimensions and equipped with hot water radiators. In an application framework, it will be necessary to dimension the window surfaces according to the room to be heated. There are undoubtedly great advantages to using heated windows. In fact, it eliminates the problem of cooling of the interior glazing in winter in the case of ventilated windows, thus eliminating the risk of condensation and improving thermal comfort. Another advantage is the removal of heat emitters that take up space in the room. However, the calculation of the Ug-value gives here apparently too high values, they are equivalent to that of a normal triple glazing. In the case of the addition of a heating glass, the first results are interesting but to be confirmed in detail. We can show here the problem of the definition for the performance indicators when a façade component is also an essential part of the ventilation system and also an heat emitter highly perturbated by meteorological parameters. (global sun radiation and outdoor temperature (air and environment).

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Data sharing not applicable to this article as no datasets were generated or analysed during the current study.