HOT-BOX TESTS FOR BUILDING ENVELOPE CONDENSATION ASSESSMENT

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ABSTRACT

A common architectural feature of curtain wall facades is constituted by a transparent double-glazing unit mounted in front of a recessed interior metal panel. It is typically installed in spandrel areas, where it's required to provide to the façade not only surface consistency but also depth.

To evaluate condensation risk on this type of envelope element, an experimental program has being carried out on a typical facade panel (Shadow-box) provided by Permasteelisa. The specimen performances were investigated using a guarded hot-box and an extensive 3-dimensional temperature monitoring has been carried out under various steady-state winter conditions. The temperature on the glazing and surrounding frames has been compared to the dew-point temperatures. Particular emphasis has been given to the pressure equalization between the outdoor environment and the inner space of shadow-box. Moreover the applicability of the temperature factor, proposed in European Standards, is also investigated as condensation risk indicator on wall internal surface.

KEYWORDS

Condensation test, climatic chamber, *shadow-box*, advanced facades, temperature factor.

INTRODUCTION

There are a number of national and international standards that regard window and façade production and built up. Many of these standards specify the testing procedure to determine product performance from different point of view: thermal transmission, water penetration, air leakage, structural strength and so on. Anyway from manufacturers and standardization organisations there is still demand for accurate, practical and reliable tools to assess the performance of fenestration products respect to condensation risk. In this research an experimental test of condensation risk has been carried out on a typical façade panel, named *shadow-box*, provided by Permasteelisa. The aims of the work were to evaluate the performances of the specimen for special design conditions and investigate the applicability of the *temperature factor,* proposed in European Standards [1] as condensation risk indicator on wall internal surface, as well as performance index for a façade panel like *shadow-box*.

The system is constituted by a transparent double-glazing unit mounted in front of a recessed interior metal panel leaving an inner pressure-equalized space. It is typically installed in spandrel areas, where it is required to provide to the façade not only surface consistency but also depth. A schematic section of the shadow-box is shown in Figure 1. A typical temperature profile occurring through this type of curtain wall is also reported with the following boundary conditions: t_1= -4°C, RH_1=90% (outdoor design conditions); t_2= 22°C, RH_2=40% (indoor design conditions).

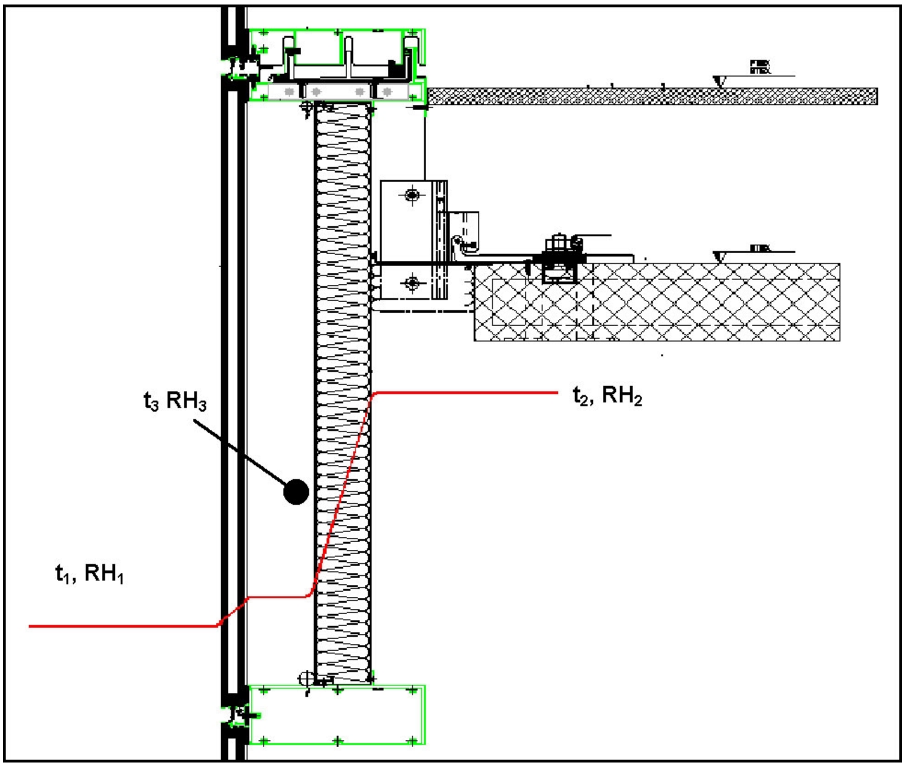

Figure 1 – Temperature profile through the shadow-box, vertical section

The thermodynamic conditions of the outdoor air (1) and of indoor air (2) are shown in Figure 2. In order to lowering condensation risk in the system, the equalization of vapour pressure between outdoor and inner cavity of the panel has been promoted and small narrow holes were drilled in the aluminium frame. With perfect equalization of vapour pressure between outdoor and the shadow-box internal chamber, the air inside the shadow-box presents the same vapour pressure p_v of outdoor air. In the psychrometric chart of Figure 2 it is also possible to identify the thermodynamic air condition occurring inside the shadow-box (3), which is at the same specific humidity x, as outdoor air, but with a higher temperature. Therefore the air status inside the shadow-box reaches a lower value of relative humidity than outdoor air, as indicated by moving along the dotted line: condensation will not occur inside the shadow-box, if good pressure equalization is guaranteed.

DESCRIPTION OF THE SPECIMEN AND THE EXPERIMENTAL APPARATUS

The condensation test on the Shadow Box is performed by means of a climatic chamber which characteristics meet the recommendations of EN ISO 8990 “Determination of steady state thermal transmission properties. Calibrated and guarded hot-box” [2]. A scheme of the apparatus is in the Standard. Shadow box is embedded in a test wall with high thermal resistance (R = 3,2 m^2 K W^{-1}), composed by two wood sheets, 18 mm thick, and 100 mm of polystyrene foam. The wall is positioned in front of the metering box between cold and hot boxes. The tightness is assured in order to avoid air leakage between the hot and the cold chamber.

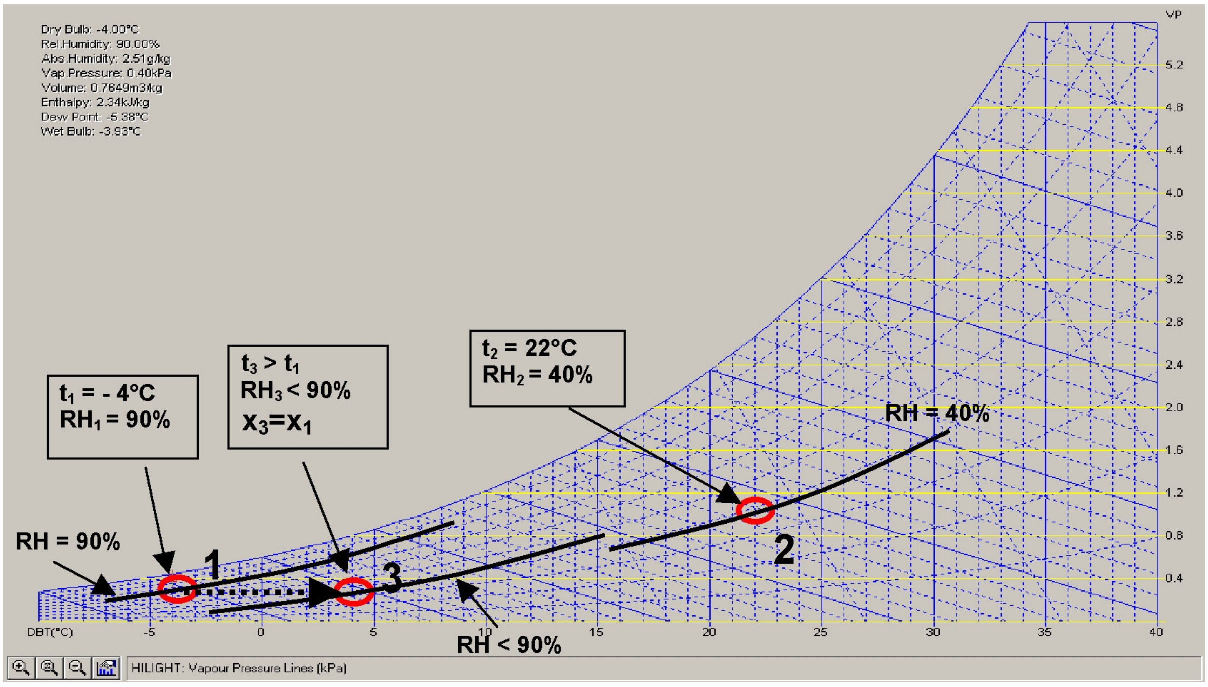

Figure 2 - Thermodynamic conditions 1, 2 and 3 in the psychrometric chart.

The shadow box was in connection with the cold chamber as far as vapour pressure is concerned, by means of equalization holes in the profiles. A suitable control ring on the wall guarantees a prevalent monodirectional thermal flux and the boundaries of the test wall are accurately insulated to avoid thermal losses.

Forty thermocouples (type T – 0,25 mm wires diameter) are installed on the frame and on the glazing. In the Metering and Cold boxes air temperature sensors (thermocouples) and humidity probes (capacitive sensors) are positioned. Inside the shadow box a termocouple (T type 0,25 mm diameter) and a humidity sensor (mirror sensor) are positioned for the evaluation of air parameters (see Figure 3).

The test started on the 30th of July 2001. In order to equalize the vapour pressure between the cold chamber and the internal chamber of the shadow box and to guarantee a steady state behavior before condensation assessment, the temperature and the Relative Humidity in the cold chamber (external conditions) and in the hot chamber (internal conditions) are maintained for 25 hours. The conditions obtained in the Metering and Cold chambers are reported in Table I.

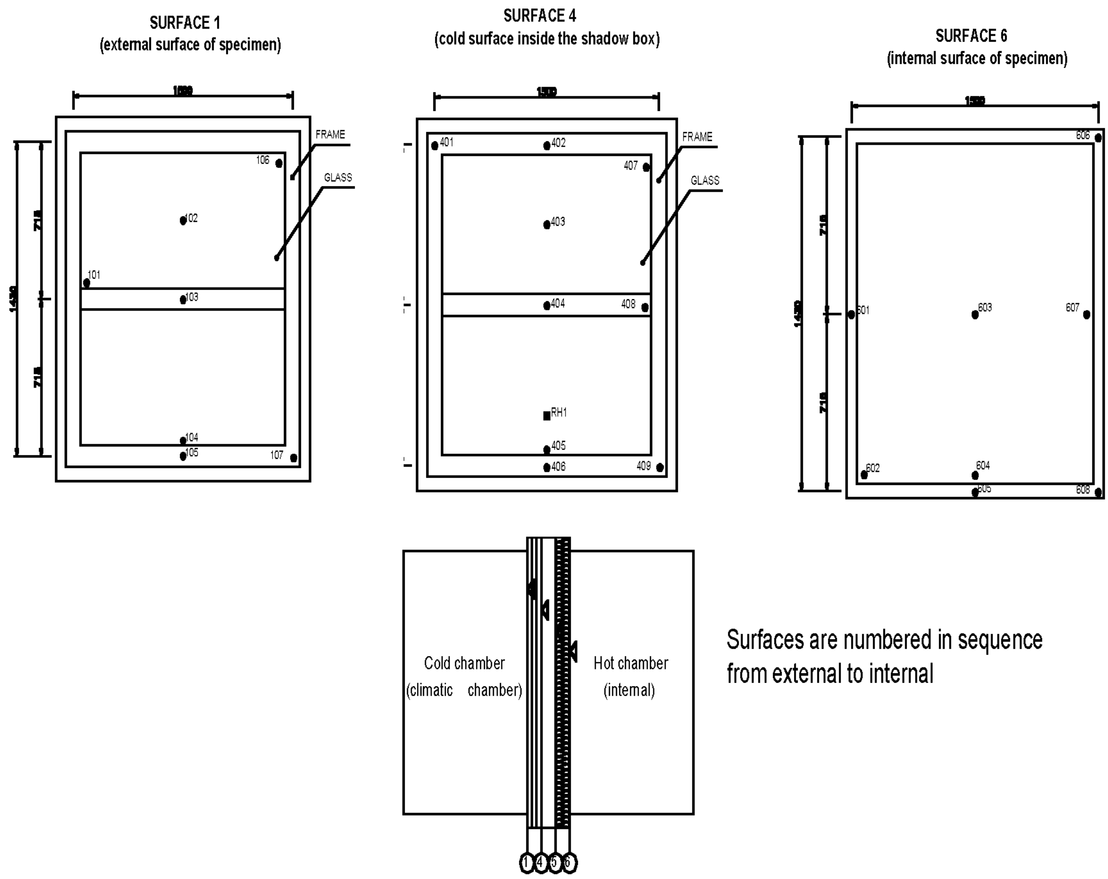

Figure 3 – Position of the temperature probes on the shadow-box system.

Table I: Conditions in the Metering and cold boxes (Internal/external design and test conditions)

	Internal design conditions	Internal test mean conditions	External design conditions	External test mean conditions
air temperature	22°C	22.2°C	-4°C	-4.4°C
air relative humidity	40%	56%	90%	91.2%

RESULTS, ANALYSIS AND DISCUSSION

Condensation assessment in the shadow box cavity, on the cold surface (face 4). The measurements have been repeated every 5 minutes between 16:00 and 17:00 (July, the 31st). The measured surface temperatures on the cold side of the shadow box, the air temperature t_{air}, and the Relative Humidity RH_{air}, inside and outside the shadow box are reported in Table II. To avoid condensation the minimum surface temperature ($t_{surface,min}$) has to be higher than the dew point temperature (t_{dp}) for air conditions occurring inside the panel. The minimum measured surface temperature on side 4 of the *shadow-box* system was always higher than the dew point temperature.

Condensation assessment on the internal surface (face 6). The temperatures measured on the shadow box surface facing the metering box and the temperature and relative humidity of air inside the metering box are reported in Table III. As in the previous assessment, the surface temperatures are compared with the dew point temperature t_{dp} corresponding to internal design conditions of t_i=22,0°C and RH=40% (t_{dp} = 7,8 °C). Also in this case the surface temperatures are higher than design dew point.

Table II. Measured data inside the shadow box (all temperatures are expressed in °C)

Time	***16:05***	***16:10***	***16:15***	***16:20***	***16:25***	***16:30***	***16:35***	***16:40***	***16:45***	***16:50***	***16:55***	***17:00***	***mean***
t_{air}	10.0	10.0	10.0	9.9	9.8	9.9	9.8	9.7	9.9	9.8	9.9	9.9	9.9
RH_{air}	75%	77%	77%	77%	77%	77%	75%	75%	76%	75%	74%	75%	76%
$t_{dew\ point}$	***5.8***	***6.2***	***6.2***	***6.1***	***6.0***	***6.1***	***5.6***	***5.5***	***5.9***	***5.6***	***5.5***	***5.7***	***5.9***
t_{401}	12.7	12.7	12.6	12.7	12.7	12.7	12.6	12.7	12.7	12.6	12.5	12.5	12.6
t_{403}	7.3	7.2	7.1	7.1	7.1	7.1	7.0	7.2	7.2	7.2	7.1	7.1	7.1
t_{405}	8.0	7.9	7.9	7.9	7.86	7.9	7.8	8.1	8.0	7.9	8.0	8.0	7.9
t_{406}	12.0	12.0	12.0	12.0	12.1	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
t_{408}	9.5	9.5	9.4	9.4	9.4	9.4	9.5	9.5	9.5	9.5	9.5	9.5	9.5

Table III: Data on internal surface of shadow box (all temperatures are expressed in °C).

time	***16:05***	***16:10***	***16:15***	***16:20***	***16:25***	***16:30***	***16:35***	***16:40***	***16:45***	***16:50***	***16:55***	***17:00***	***mean***
t_{602}	18.1	18.1	18.1	18.1	18	18.1	18	18	18	18	18	18	18
t_{603}	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9
t_{604}	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.4	19.5	19.5	19.5	19.5
t_{605}	14.1	14.1	14.1	14.1	14.1	14.1	14	14.1	14	14	14.1	14	14.1
t_{606}	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8
t_{608}	12.6	12.6	12.5	12.5	12.5	12.5	12.5	12.7	12.6	12.7	12.6	12.6	12.6

THE TEMPERATURE FACTOR

As far as *the thermal quality* of the building envelope is concerned, it is meaningful to calculate the temperature factor as defined in [1] and [2]:

$$f_{Rsi} = \frac{t_{si} - t_{out}}{t_{int} - t_{out}} \qquad [1]$$

where t_{si} is the internal surface temperature, t_{int} is the indoor air temperature and t_{out} is the outdoor air temperature. The European standards [1] propose the calculation of the surface temperature factor during the winter season and, evaluating the maximum monthly value of temperature factor, it is possible to define the minimum value of the overall thermal resistance of the building envelope $R_{t,min}$ necessary to avoid surface condensation risk. This value is dependent on the climatic data and on the internal moisture generation: for this scope an internal vapour generation class and a maximum value of 80% for Relative Humidity are fixed. Following the Standard procedure [1] to evaluate the condensation risk, different internal vapour generation rates are fixed; in this case, two different levels are examined: low and medium (high vapour generation rate is for kitchens, swimming pools, etc). For office buildings, the medium generation is to be considered. Table IV shows the calculated values for the minimum surface temperature $t_{s,min}$ and for the temperature factor. Considering the indoor surface 6, the surface temperatures proposed by the calculation are $t_{s,min}$ = 4,7 °C for low vapour generation and $t_{s,min}$ = 10.0 °C for medium. Both values are lower than the measured ones (Table III). The temperature factors calculated according to [1] are always lower than the minimum measured one f_{Rsi} = 0,639.

Table IV: Calculated values for temperature factor

t_{out} [°C]	p_{sat} [Pa]	Φout [%]	$p_{v,out}$ [Pa]	Δp [Pa]	p_{int} [Pa]	p_{sat} [Pa]	$t_{si,min}$ [°C]	t_i [°C]	f_{Rsi} [-]
Medium	*vapour*	*generation*							
-4.4	422	91.2	385	540	979	1224	10.0	24	0.506
-4.4	422	91.2	385	540	979	1224	10.0	22	**0.544**
-4.4	422	91.2	385	540	979	1224	10.0	20	0.588
Low	*Vapour*	*generation*							
-4.4	422	91.2	385	270	682	853	4.7	24	0.320
-4.4	422	91.2	385	270	682	853	4.7	22	**0.344**
-4.4	422	91.2	385	270	682	853	4.7	20	0.372

COMMENTS AND CONCLUSIONS

The *shadow-box* passed the condensation test both for the internal surface and for the inner equalized cavity. Different outdoor and indoor environmental conditions can be verified by means of the *temperature factor* as a condensation risk indicator on wall internal surface, even if more work has to be done to validate the reliability of this methodology in different scenarios. The future research activities will focus on the transient condition, when the vapour pressure equalization is occurring. The delay time necessary to equalize the vapour pressure is an important aspect in this regard and it is function of the equalization hole dimensions.

In order to match the performance requirements specifically requested for fenestration products, accurate, practical and reliable tools can be realised paying attention to national and international standards that address many of the performance factors, such as thermal transmission characteristics and condensation resistance.

References

[1] EN ISO 13788. July 2001. Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods. European Standard.

[2] EN ISO 8990. August 1996. “Determination of steady state thermal transmission properties. Calibrated and guarded hot-box”.