

Chapter 2

Experimental Studies on Hygrothermal Behaviour of ETICS

2.1 Setting up the Test

2.1.1 Preliminary Tests

A preliminary test was carried out to assess where, in a façade, was surface condensation more severe: near the corners or in the middle of the wall. The test was performed on a building located in the University of Porto campus. Devices were set up on the North façade covered with ETICS of a technical building located close to the Building Physics Laboratory weather station, which collected the necessary climate data for this study.

T-type thermocouples were used to assess surface temperature and were placed in a square grid of 0.7 m (Fig. 2.1). The façade under study has the configuration indicated in Fig. 2.2. The average values of the outdoor climate variables, for the test period (14/01/2009 to 25/01/2009), are presented in Table 2.1. Before the measurements were carried out, thermocouple calibration procedures were performed.

Figure 2.3 shows that there was no significant variation between the temperatures measured by each thermocouple. However, when assessing surface condensation, the differences become clearer. Surface condensation will occur when surface temperature (T_s) drops below dew point temperature (T_{dp}), calculated as a function of temperature and relative humidity of the ambient air. By analogy with the concept established by Zheng et al. (2004), the difference between T_{dp} and T_s may be called Condensation Potential in degrees (CPd , in $^{\circ}C$), which implies condensation for positive values. The accumulated value of the product of positive CPd by its lasted time (in h) during a period may be called Condensation Potential Equivalent in degrees ($CPEd$, in $^{\circ}C$ h) and allows estimating the amount of water vapour available to condensate and points to the risk of condensation.

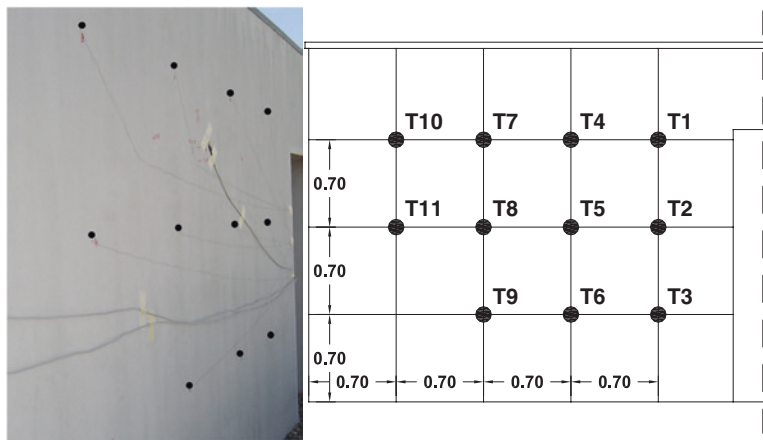


Fig. 2.1 Thermocouples location on the North façade of the building

Fig. 2.2 Configuration of the wall under study

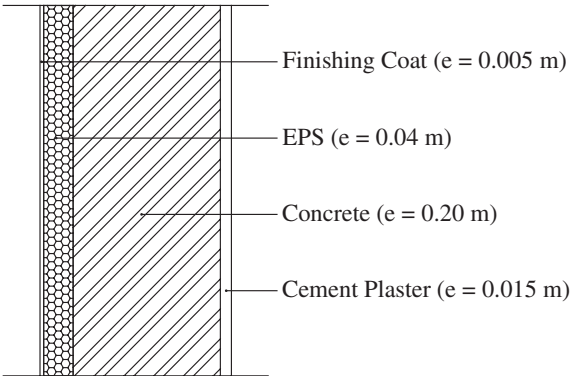


Table 2.1 Outdoor climate (average for the test period)

Climatic parameter	Average value
Temperature	9.9 °C
Relative humidity	88 %
Global radiation emitted by the sun	117 W/m ²
Radiation emitted by the sky	345 W/m ²
Wind velocity	1.8 m/s
Wind direction	158°
Rain (accumulated)	144 mm

Figure 2.4 shows that surface condensation is higher at a distance of 1.4 m from the ground and from the left edge of the façade. These results are confirmed by Fig. 2.5 that displays the positive *CPEd* considering the average temperatures on each line and row. Higher surface condensation occurs at 1.4 m from the ground

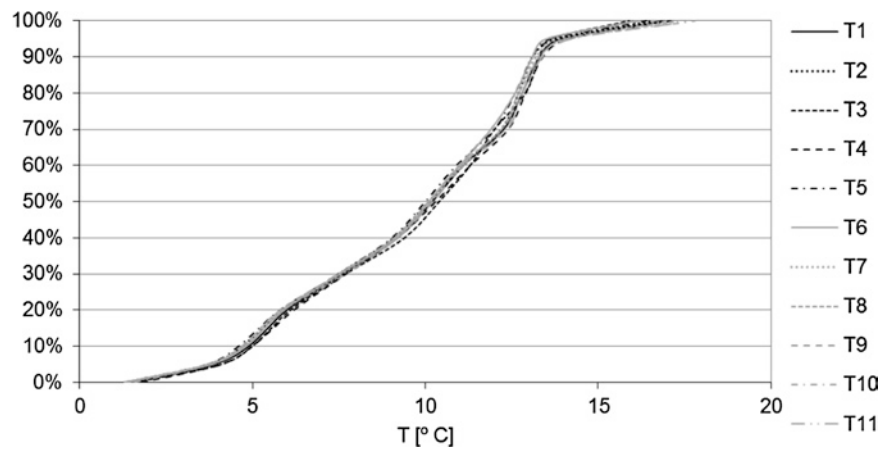


Fig. 2.3 Surface temperatures measured by each thermocouple for the period under study

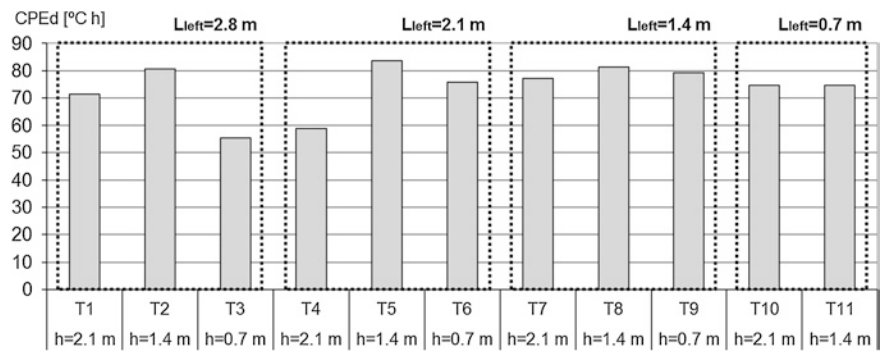


Fig. 2.4 CPed corresponding to the position of each thermocouple for the period under study

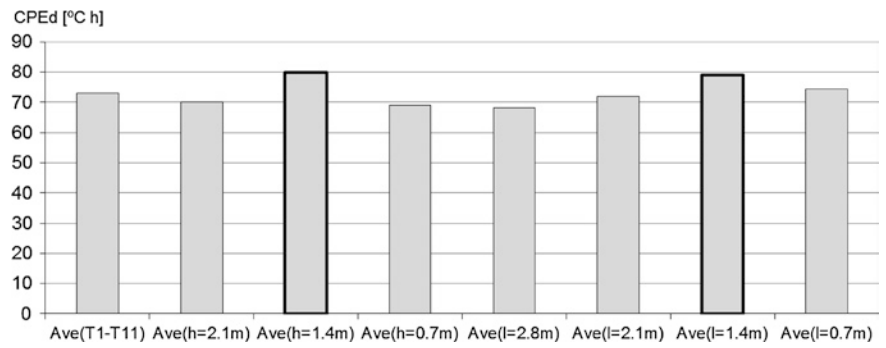


Fig. 2.5 CPed by line and row for the period under study

and at 1.4 m from the left edge of the façade, corresponding to the middle of the façade.

Surface temperature during the night depends on the heat transfer on the surface, which consists of two components: convective heat transfer and radiative heat transfer. Assuming that for the façade under study, the incident long-wave radiation is constant, the variation on the surface temperature is due to the convective heat transfer (Hagentoft 2001).

The convective heat transfer depends on the wind, which has different effects on the façade, being higher in the corners and lower in the middle. For that reason, heat transfer by convection from the air to the surface is higher in the corners, which increases surface temperature and decreases condensation (Simiu and Scalan 1996). Studying the current area of a façade is therefore a conservative approach of the reality.

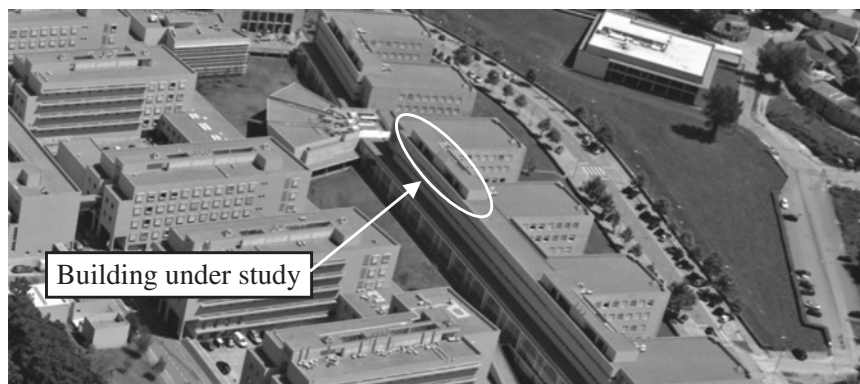
2.1.2 One-Year in Situ Tests

The one-year in situ test campaign was carried out from March 2009 to February 2010. Instruments were set up on the façades covered with ETICS of a building located in the University of Porto campus, whose walls face the four cardinal directions (Fig. 2.6). The walls under study are indicated in Fig. 2.2. No measurements of the materials properties were performed. The devices set up on the façades provided information about the surface temperature (T-type thermocouples), wind-driven rain (WDR gauges set up as described by Nore et al. 2007) and superficial relative humidity (humidity and temperature probes) on the four façades (black dots on Fig. 2.7). They were coupled to a data acquisition system, collecting data every 10 min. At the same time, climate parameters were also collected, every 10 min, by the Building Physics Laboratory weather station, located near the building under study (Fig. 2.7). Air temperature and relative humidity were also collected inside the building. No air conditioning was used inside the building during the test campaign. The annual averages of the outdoor and indoor climate are presented in Tables 2.2 and 2.3. Information regarding the accuracy and calibration of the surface devices and about the weather station is given by Barreira (2010).

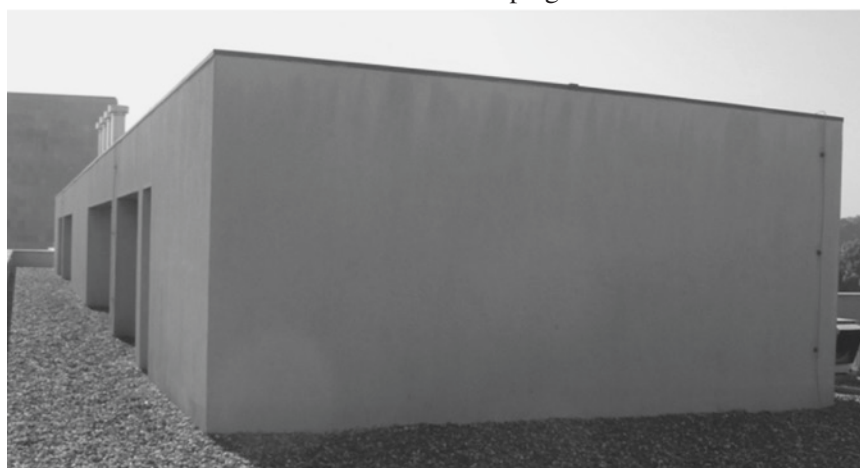
2.2 Results

2.2.1 Surface Temperature

Figure 2.8 shows the surface temperature of the façades under study and the dew point temperature, during two days of May 2009. During daylight, when the sky is clear, the differences between the surface temperatures are very obvious. The east



Aerial view of the campaign site



General view of the building (North and West façades)



East façade



South façade

Fig. 2.6 Building under study, located in University of Porto campus—Portugal

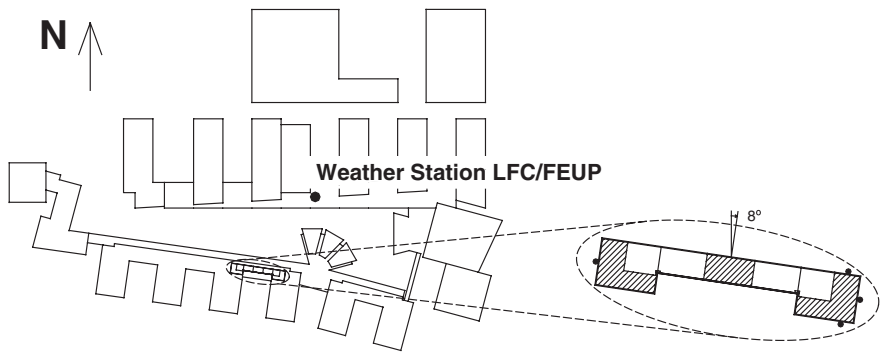


Fig. 2.7 Layout with the surface devices and weather station locations

Table 2.2 Outdoor climate during the test campaign (annual average)

Climatic parameter	Transducer	Average value
Temperature	Pt100 sensor	15.4 °C
Relative humidity	Hygrometer sensor	72 %
Global radiation emitted by the sun	Pyranometer	254 W/m ²
Radiation emitted by the sky	Pyrgeometer	335 W/m ²
Wind velocity	Anemometer	1.4 m/s
Wind direction	Vane	170°
Rain (accumulated)	Rain gauge	874 mm

Table 2.3 Indoor climate during the test campaign (annual average)

Climatic parameter	Average value
Temperature	20.3 °C
Relative humidity	69 %

and south façades achieved higher values during the morning and the west façade at the end of the afternoon. The temperature of the north façade was the lowest. It presents a peak at daybreak that is related with direct solar radiation incident on the north façade, due to its rotation of about 8° (Fig. 2.7). When the sky is cloudy, the differences during daylight are smaller and almost independent from orientation (see 17th May in Fig. 2.8).

During the night (Fig. 2.9), surface temperatures were quite constant and very similar regardless of orientation. The small differences on surface temperatures are due to direct solar radiation incident, during the day, both on the façades and on the ground near the building, which vary with orientation. In fact, although ETICS external rendering has very low thermal capacity that restricts the heat storage after sunset, the higher is the surface temperature achieved during the day the higher it will be during the night. On the other hand, the ground near the building

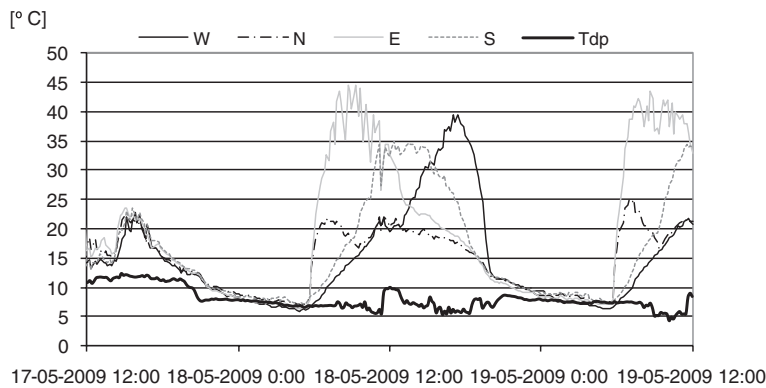
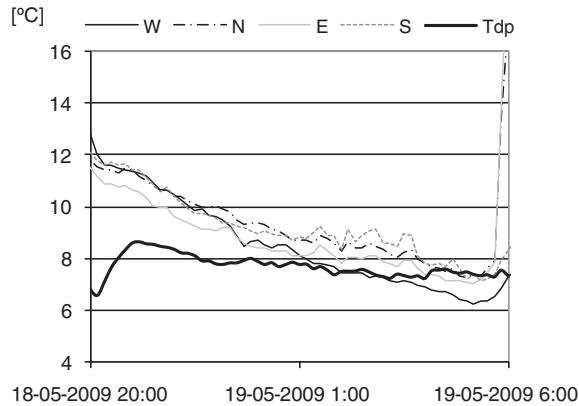


Fig. 2.8 Surface temperatures and dew point temperature during two days of May 2009

Fig. 2.9 Surface temperatures and dew point temperature during dawn of 19th May 2009



absorbs different amounts of radiant heat due to direct solar radiation during the day due to shading by the building. Therefore, the heat that is released by the ground during the night and reaches each façade of the building also varies with orientation.

During this test campaign, in most of the days, during the night, the south façade had the higher temperature and the west façade the lower one. The surface temperature on the north façade wasn't the lowest as it was expected. That may be related with the rotation of the façades, about 8° clockwise from north, and with the exposure to the wind of the north façade, which is aligned with the main façade of the building unlike the other façades (Figs. 2.6 and 2.7), which may benefit from heat exchange by convection during the night.

Figures 2.10 and 2.11 display the average, maximum and minimum surface temperatures measured for the period under study, monthly and annual, respectively. On average, surface temperatures were higher during spring and summer

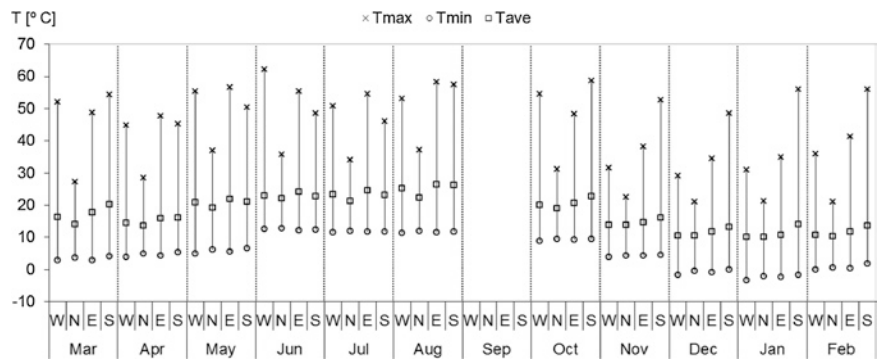
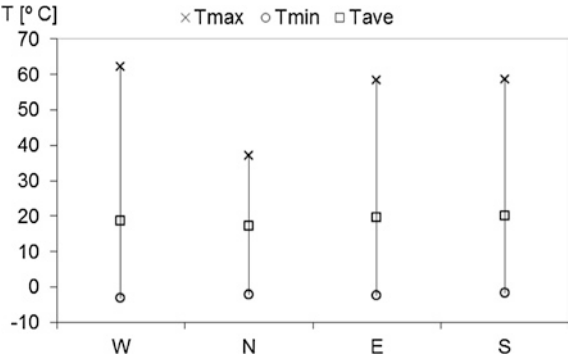


Fig. 2.10 Monthly maximum, minimum and average surface temperatures measured during the test campaign

Fig. 2.11 Annual maximum, minimum and average surface temperatures measured during the test campaign



than in the colder months. The south façade had the higher average surface temperature during autumn and winter and during the warmer months surface temperature was lower than the temperature on the west and east façades due to the position of the sun in the horizon. The east façade had always higher average surface temperatures than the west façade. The north façade had always the lowest average surface temperatures. These results were expected and are related to the effect of direct solar radiation on each façade (Barreira and Freitas 2013).

Normally, the west façade had the lowest minimum surface temperature, followed by the east, north and south façades. The maximum surface temperatures achieved on each façade are related with the intensity of direct solar radiation incident on the façades during the day and, normally, follow the same trend as the average surface temperatures. The north façade presented the lowest maximum surface temperatures, as almost no direct solar radiation reaches its surface.

2.2.2 Exterior Surface Condensation

Figure 2.12 shows that hourly CPd was always lower than $2.4\text{ }^{\circ}\text{C}$ and, on average, was around $0.4\text{ }^{\circ}\text{C}$. Although the major differences had occurred during the cold seasons, on average, there was no significant variation along the year. The accumulated values of $CPEd$ (only the positive temperature differences were considered, the negative values were taken as equal to zero) point to higher risk of condensation during November, December and April. During July and August, the risk of condensation was also significant (Fig. 2.13), which is related with Porto climatic conditions, as during summer night's high relative humidity and mild temperature lead to high T_{dp} , worsen the risk of condensation.

Considering the annual accumulated $CPEd$ (Fig. 2.13), the west façade presented higher risk of condensation, followed by the east, north and south façades. The second lowest amount of condensation on the north façade is due to its higher

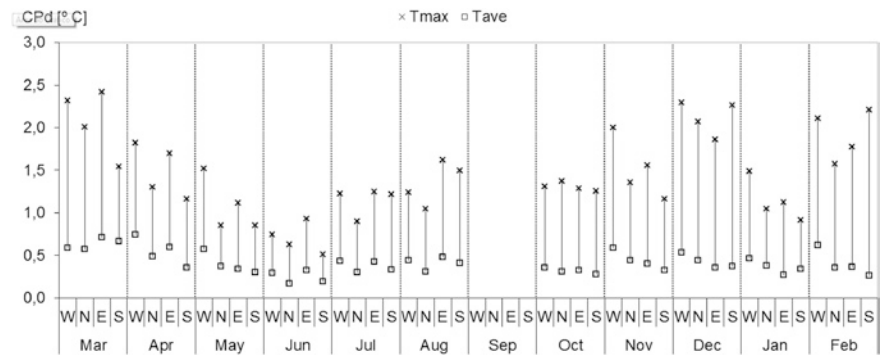


Fig. 2.12 Maximum and average values of hourly CPd obtained during the test campaign

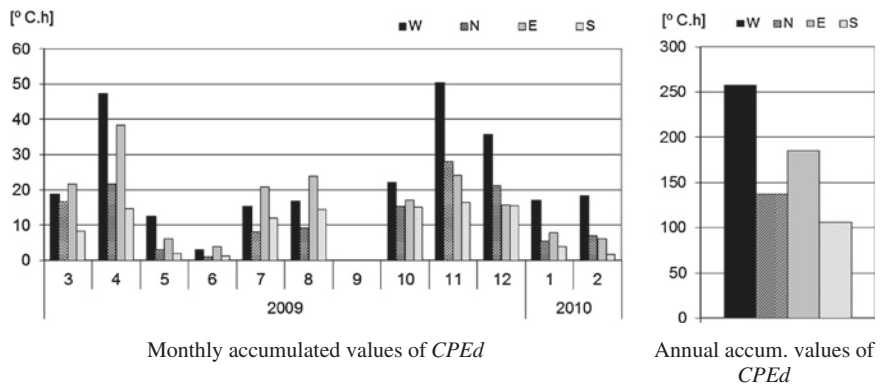


Fig. 2.13 Monthly and annual accumulated values of $CPEd$ obtained during the test campaign

exposure to the wind, which increases surface temperatures during the night and reduces the difference between T_{dp} and T_s .

These results are somewhat consistent with the ones obtained by Zillig et al. (2003) and Holm et al. (2004) supported by numerical simulation performed with WUFI®, considering climatic data from Holzkirchen and a wall covered with ETICS (10 cm of polystyrene). Indeed, hourly maximum and average values of CP_d are similar, although the periods of condensation and the risk of condensation are quite different not only in terms of quantity but also considering the variation of condensation with orientation. Of course, these differences in the results may be due to different climatic conditions and specific in situ conditions.

2.2.3 Wind-Driven Rain

WDR measurements show that, on a yearly basis, the south façade was more exposed to rain, followed by the west, east and north façades (Fig. 2.14). These results are consistent with the ones obtained by Henriques (1993), concerning the relation between the amounts of WDR that impacts a vertical surface facing the four cardinal directions. Regarding the quantity of rain itself, the values are quite different because the period under study was not the same and Henriques (1993) calculated WDR through a semi-empirical method using climatic data (horizontal rain, wind speed and direction) from a weather station located far from the building under study. On a monthly basis, the amount of WDR was higher during autumn and winter and very small during warmer months.

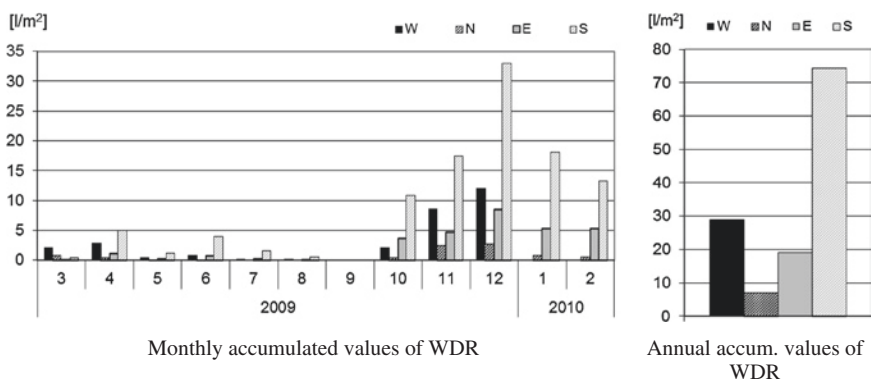


Fig. 2.14 Monthly and annual accumulated values of WDR obtained during the test campaign

2.2.4 Surface Moisture

Figure 2.15 shows the variation of superficial relative humidity with surface condensation and WDR on the west façade during one day of May 2009. Whenever surface condensation occurred or rain reached the façade relative humidity equalled 100 %. Figure 2.16 displays the accumulated hours of surface saturation (superficial relative humidity equal to 100 %) for the façades under study. Measuring superficial relative humidity gave rise to several problems related with the calibration of the sensors. After some time in use, the measured values stopped being accurate and the sensors had to be disconnected. Similar problems were also reported by Venzmer et al. (2008).

There is no clear correlation between the accumulated hours of surface saturation (Fig. 2.16) and the façades humidification due to condensation (Fig. 2.13) and WDR (Fig. 2.14), which points to the major influence of the drying process on surface water content. However, during November and December, surface condensation and accumulated hours of surface saturation follow the same trend regardless WDR. During the warmer months (June and July), when surface condensation is less intense, WDR seems to increase its influence on surface saturation, especially on the east and west façades.

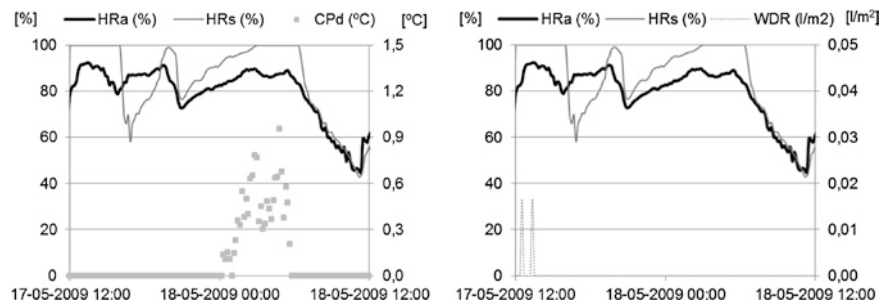
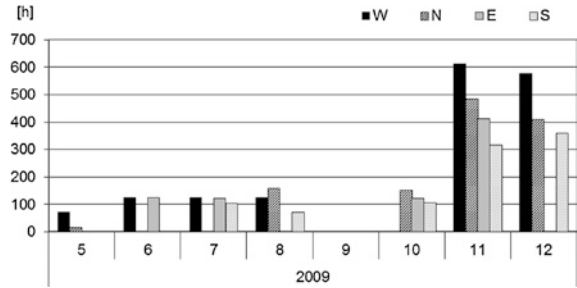


Fig. 2.15 Relative humidity of the air and relative humidity, condensation and WDR on the west façade (May 2009)

Fig. 2.16 Accumulated hours of surface saturation (superficial relative humidity equal to 100 %)



2.3 Discussion of the Results

During the night, surface temperature doesn't differ much with orientation (Figs. 2.8 and 2.9). The small differences are mainly due to direct solar radiation incident on the ground during the day, which varies with orientation, and is released during the night as long-wave radiation. For the building under study, the west façade presented higher risk of condensation, followed by the east, north and south façades. The North façade did not have the lowest surface temperature during the night (Figs. 2.8, 2.9, 2.10 and 2.11). That may be related with the rotation of the façades, about 8° clockwise from North, and with the exposure to the wind of the North façade, which is aligned with the main façade of the building unlike the other façades (Figs. 2.6 and 2.7).

The comparison between the risk of surface condensation (Fig. 2.13) and the defacement of the façades under study (North and West façades present more colonization by microorganism than the East and South façades that almost have no biofilm on its current surface) points to the influence of the drying process in the surface water content and biological growth. Lower temperatures on the North façade during daylight (Figs. 2.8 and 2.11) may restrict the evaporation of the condensation and rain water and increase the risk of biological colonization. The West façade had the highest amount of condensation (Fig. 2.13) and the second highest amount of WDR (Fig. 2.14). The surface temperature reached during the end of the day may not be enough to decrease the water content on the surface and restrict biological growth. The South façade, although having less risk of condensation, had the highest amount of WDR, more than double measured in the West façade. As it is not defaced on its current surface, the drying process may have a key role in surface water content on ETICS.

The important role of the drying process is also supported by the measurements of superficial relative humidity, as there is no clear correlation between the accumulated hours of surface saturation (Fig. 2.16) and the façades humidification due to condensation (Fig. 2.13) and WDR (Fig. 2.14).

According to the obtained results, external surface condensation (Fig. 2.13) is more preponderant to surface water content than WDR (Fig. 2.14), as it occurred during all the year at equivalent intensity. During spring and summer, rain did not reach the façades for longer periods pointing to its smaller influence. Of course, the water run-off along the surface and, specially, its accumulation may increase the influence of WDR in the risk of microorganisms' colonization.

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