Int. Journal for Housing Science, Vol.34, No.2 pp. 105-115, 2010
Published in the United States

EXPERIMENTAL STUDY OF HYGROTHERMAL PERFORMANCE

A.S. Guimarães, V. Abrantes, T. Silva
Faculty of Engineering
University of Porto (FEUP)
Portugal

ABSTRACT

The buildings hygrothermal behaviour has been studied in last few years by the Physics of Constructions group from FEUP [1]. The study of hygrothermal performance is essential to characterize the quality of inner environment allowing the knowledge of the thermal answer from buildings envelope when subject to inside and outside climate variations. We understood that would be of great benefit to get some results that allow the characterization of hygrothermal behaviour from constructive elements. The aim of this article is to compare the results from the experimental analysis of temperature, relative humidity and partial vapour pressure variations inside a church, with exterior variations, envelope characteristics, inner water vapour production and ventilation conditions.

Key words: Humidity, Temperature, Pathologies, Condensations, Hygrothermal.

0146-6518/02/ 105-115, 2010

Introduction

The constructions built in the past, despite being important historic buildings, are quite degraded and need repair interventions, which is very complex in this type of buildings, whose identity should be preserved.

Churches are good examples of historic constructions, with high importance, revealing difficulties to deal with its pathologies.

In the most situations, humidity is the main factor responsible for building's pathologies and degradation, affecting its durability, aspect, and also user's health and safety [2].

The main objective of this work was to carry out an experimental campaign analyzing the temperature, relative humidity and water vapour pressure variations inside a church, due to the exterior climate variations, envelope characteristics, water vapour production inside the church and ventilation conditions of that place.

The measurements taken, allowed us to obtain a range of the main hygrothermal parameters, in different work conditions (mass periods, functioning or closing of the church) which could serve to compare with other churches.

The Hygrothermal Performance

Hygrothermal Variations

General Aspects

In a general way, thermal exchanges between the buildings and the environment are caused by climate, especially through the air temperature and humidity, besides rain, wind and solar radiation. The constructive characteristics and the building's performance are two factors that will also influence thermal and hygrothermal variations inside the places. In relation to the constructive elements, thermal inertia from the walls, that express the resistance offered by a construction to the change of its thermal state, has direct influence in thermal variations. The performance of the buildings interferes so far as it assumes obvious influence on the energetic consumptions in view of demands from the various activities.

Humidity in Churches

Humidity is one of the most important pathologies demonstrations in historic buildings in Portugal [3], and so that is interesting to report some of the mains aspects which may be on its origin.

The big thermal inertia of the constructions, the lack of thermal insulation and the low rates of air ventilation, creates a very cold inner atmosphere with very high relative humidity, except in summer and in part of autumn [4].

Façade's materials, namely, whitewash mortar and clay, hardworking in councils, have great ability to absorb water and that leads to a big accumulation of humidity in walls.

Atmosphere precipitation may cause infiltrations, through old tiles, finish on roof, holes or openings.

The occupation conditions in churches are directly connected with inside water vapour production, presenting highest values for vapour production in mass periods, reflecting on humidity's atmosphere and envelope.

Thermal Inertia

Thermal inertia expresses the ability of a constructive element to contradict temperature variations inside the room, due to the fact of keeping heat within the building's structure. This property gives it warmth dissipate function, avoiding fluctuations and temperature peaks during day, transferring heat later.

The old buildings, in general, have great thermal inertia because their walls are made of big thickness stone. This characteristic creates a delay between inside and outside air temperature, playing an essential part in constructions thermal behaviour.

Two concepts related to thermal inertia that were analyzed in this experimental study, are the reducer and thermal delay.

Thermal reducer is the difference between the energy that falls upon exterior's surface and the one who reaches the interior's surface. That is the capacity of envelope to reduce the thermal amplitudes.

Thermal delay is the time interval that takes place when the heat absorbed on exterior reaches the interior's surface of the envelope, depending this time on the thermal inertia of the wall.

Ventilation

The importance of air's renovation inside buildings is quite obvious when we analyze situations of large production of water vapour. Churches, in particular, exhibit high levels of this parameter in mass periods, being essential extract that humidity's excess to avoid other type of phenomenon like condensations.

Space ventilation is in fact a very important mechanism in relative humidity reduction, so far as it allows the admittance of exterior air, usually dry, and the extraction of interior air, transporting some humidity in shape of water vapour with it [5].

The Need of Experimental Studies

The study of churches hygrothermal behaviour is fundamental to characterize the quality of inner environment, allowing through that analysis, the knowledge of thermal answer from buildings envelope when subject to inside and outside climate variations, as well as to value the influence of thermal inertia from the walls on temperatures stability and the necessity of rooms ventilation on the water vapour extraction.

This type of studies is also useful to identify the norms of intervention to carry out in order to eliminate or minimize the pathologies found on these buildings. Now a bigger preoccupation is to recover and rehabilitate the older constructions that constitute the national inheritance exists.

In this way, we understood that would be of great benefit to have available results that allow the interpretation and characterization of hygrothermal performance from constructive elements.

Experimental Studies

Generalities

A manner to know the hygrothermal behaviour inside a construction is to carry out experimental studies. We realize a group of measurements in a church located on Porto's city, to value its performance. The results obtained expressed the real hygrothermal behaviour of the church, due to the climate variations, and its constructive and functional characteristics. The analysis of these values allowed us to working out and to interpret a set of graphs that may be useful to comparison with other studies eventually realized.

Building's Description

The building analyzed in this work was the Santo Ildefonso, which is at one extremity of Battle Square in Porto (Figure 1).

Figure 1 : Santo Ildefonso Church (main façade)

This church was built as from 1709 over the foundations of Santo Ildefonso Chapel that was in ruins, staying concluded at 18 July of 1739. It's firm a platform on top of a big staircase. Its façade is regular, formed by two bells towers, finished by spheres and fantastic facades in each surface. The granite walls are thick, being the façade covered with glazed tiles by Jorge Colaço (1932), portraying Santo Ildefonso living scenes and allegories to holy communion. Inside, the plant is polygonal in proto-baroque style with a vault roof of wood and adornment plasters repeated in walls. It has also six altar niches and two pulpits, being the floor made of wood. The high chapel (Figure 2) exhibit the panel of golden cut decorated with plaster Works, incorporating a vault roof with two sides and a central lantern.

Figure 2 : Interior of Santo Ildefonso Church (high altar)

Anomalies Description

During the visits carried out in the Church, it was possible to identify signs of humidity presence inside the building, such as: dark spots on lower zones of walls (Figure 3) and condensations on roof corners (Figure 4).

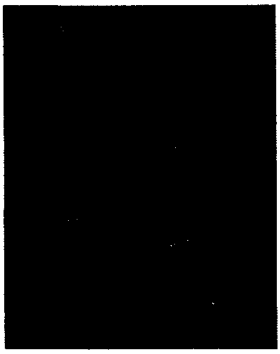

Figure 3 : Humidity spots on walls

Figure 4 : Roof condensations

Rehearsal's Description

Measurements Equipments

For the realization of the intended measurements along this study, we used two electronic equipments of signs acquisition – HOBO RH / Temp Data Logger, from Onset Computer Corporation – one to carry out the measurements inside and other on the outside. These Data Loggers have reduced size and have software that is installed on a computer. They can be programmed for timetables readings, being that information later loaded on the computer.

Measure Parameters and Equipments Localization

To value the hygrothermal behaviour from a local it's necessary to know the main hygrothermal parameters, more specific, the temperature and relative humidity. Thus one equipment was placed inside the church and the other one on the exterior, to measure the interior and exterior temperatures and relative humidity of the building. The first one was located on the pulpit and the second one at the bell tower.

Measurements Period

The measurements were carried out during nearly 4 months. The registers began on 07/11/2007 and ended on 21/02/2008. The data acquisition, either temperature or relative humidity, was done from ¼ at ¼ of hour, to check better the environment changes, in particular inside the church during its use.

Results

Temperature

Exterior's temperatures revealed large fluctuations along this measurements period, while interior's temperatures were almost constant during each day, revealing a smaller oscillation, besides external fluctuations (Figure 5).

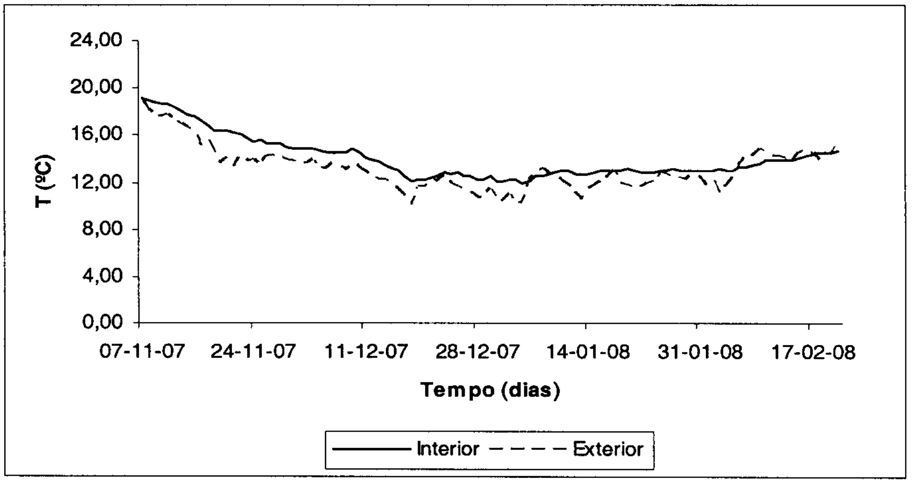

Figure 5 : Daily rate middle temperatures between the beginning of day 07/11/2007 and the end of day 21/02/2008

It's possible to conclude that the interior of the church has thermal stability. We also checked that church's inner temperature during this measurement period (winter), were almost always higher than the ones who were felt outside, except in some days on January and February.

Relative Humidity

Relative humidity, either it's outside or inside, also revealed great fluctuations (Figure 6).

A daily rate analysis to the church's behaviour allowed us to check that inner relative humidity started to increase around church's opening timetable, due to the admission of exterior humidity. By its turn, in mass periods, relative humidity inside the church revealed itself very close to relative humidity variations felt outside, which is explained by the fact that, in those occasions, church's doors were often opened approaching the values. We also checked that, in general, relative humidity inside the church was lower to the outside one.

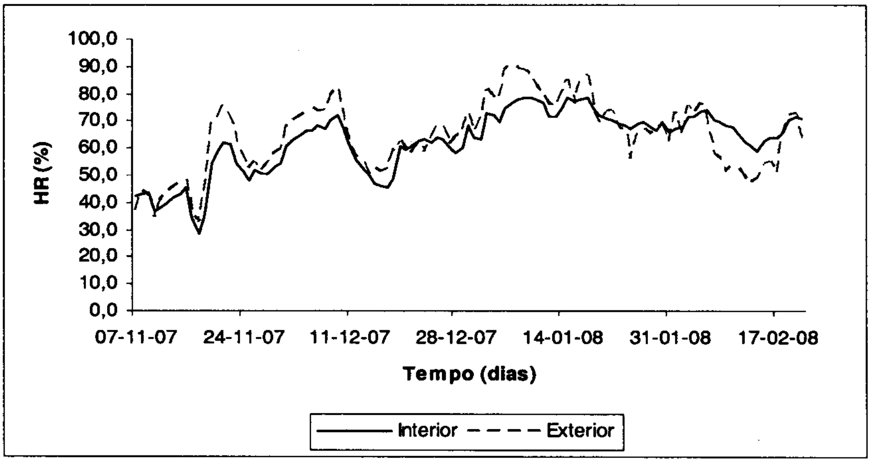

Figure 6 : Daily rate middle relative humidity between the beginning of day 07/11/2007 and the end of day 21/02/2008

<u>Water Vapour Pressure</u>

With the knowledge of temperatures and relative humidity, was possible to determine the partial water vapour pressures. The analysis of its values demonstrate that both pressures were very close, being the interior pressure, sometimes, higher than the exterior's one (Figure 7).

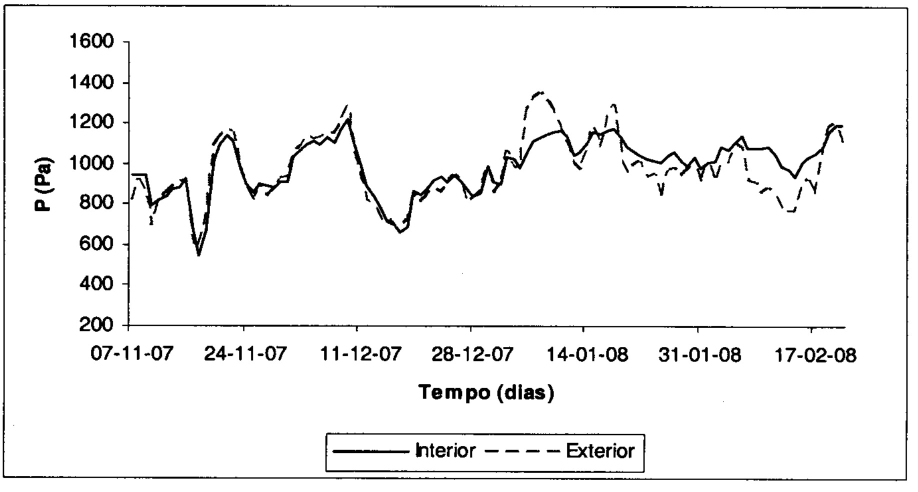

Figure 7 : Partial water vapour pressures between the beginning of day 07/11/2007 and the end of day 21/02/2008

This has to do with the large water vapour production inside the building in mass periods, founding it, in most of cases, a few ventilated, accumulating the water vapour on the inside. In this way, the peaks of inner vapour pressure correspond to mass periods, while its reduction is owed to the church's ventilation periods, leading to the extraction of water vapour accumulated on the inside.

Daily Thermal Amplitudes and Thermal Delays

Calculations were made on the daily thermal amplitudes and the daily thermal delays. Thermal amplitudes revealed higher values on the outside of the church. By the other hand, temperature's variation on the inside was very small, maintaining it constant during a few days (Figure 8).

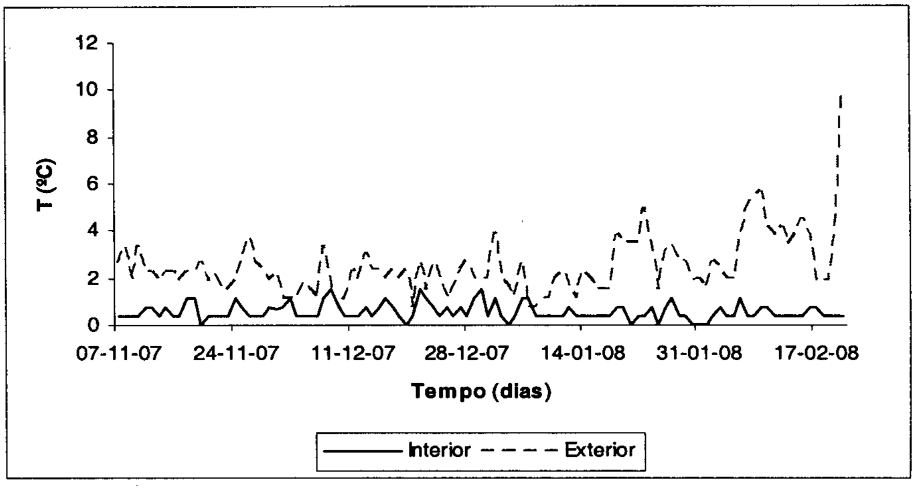

Figure 8 : Daily rates thermal amplitudes between the beginning of day 07/11/2007 and the end of day 21/02/2008

This behaviour shows with clarity the effects of walls thermal inertia that amortize the temperature's peaks, keeping a constant and comfortable atmosphere inside the church. It was also visible that the incensement of exterior's temperatures by turn of February, which led to higher thermal amplitudes on the outside, didn't make it felt inside the building. Thermal delay, in several days, was so exalted that not even affected interior's temperatures, in those same days. This means that, in these cases, the temperature inside the church didn't suffer any increase, despite the rise of temperature on the outside. Once again we confirm the thermal inertia's effect that delays the heat transmission through its accumulation inside the constructive elements (Figure 9).

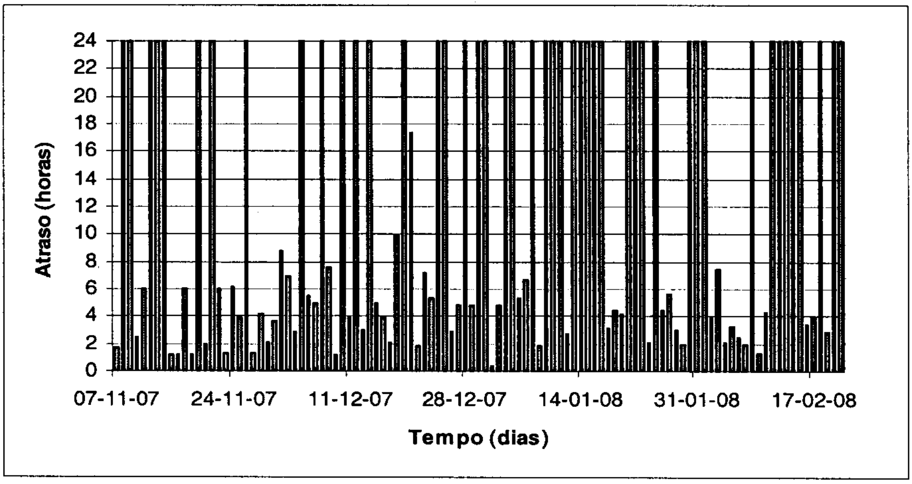

Figure 9 : Daily rate thermal delay between the beginning of day 07/11/2007 and the end of day 21/02/2008

Conclusion

Although this work falls upon only one building, it allows, through an experimental study, to identify and characterize the hygrothermal behaviour from old constructions with the same characteristics. In syntheses, the analysis carried out on the Santo Ildefonso Church, about the hygrothermal behaviour, allowed us to conclude that:

- Church has thermal stability, revealing temperatures that vary slowly in order to the thermal inertia of the construction;
- The great thickness of granite walls is responsible for excellent thermal inertia, that causes the delay between inside and outside temperatures;
- Relative humidity is high inside the church, specially on winter, sometimes reaching levels near to saturation, provoking condensations;
- When church stays open, like for example on cleaning days, inner relative humidity follows very close the exterior's relative humidity;
- Partial water vapour is also great on buildings' interior, specially in mass periods, due to the big water vapour production in these hours;
- The rates of air circulation is reduced, which causes the accumulation of water vapour on the interior, increasing humidity on church's air and making favourable the occurrence of condensations;
- During the night, air circulation is because church is totally closed;
- Humidity shows up inside the building, mainly under the shape of dark spots on walls and condensations on covering;
- The great levels of inner humidity are extremely undesirable for the conservation of art works.

In the presence of a behaviour like this, and because the church's ventilation is not enough to reduce relative humidity on the inside, we propose a more careful ventilation, allowing air circulation on warm periods of the day and to favour inner water vapour evaporation. Other measure to be introduced would be the examination of the covering to check if broken tiles doesn't exist that are not securing the water-tightness.

References

1. Freitas, V., Humidade e Patologias. Últimos desenvolvimentos. 6as Jornadas de Construções Civis, pp. 31-48, FEUP, Porto, 26 de Novembro de 1998.
2. Freitas, V., Transferência de humidade em paredes de edifícios – Análise do fenómeno de interface. Tese de doutoramento, FEUP, Porto, 1992.
3. Henriques, F., Formas de manifestação da humidade em paredes. 6as Jornadas de Construções Civis, pp. 49-64, FEUP, Porto, 1998.
4. Melo, A.; Maldonado, E.; Sousa, H.; Lourenço, P., Estudo articulado das anomalias do edifício da Igreja – Mosteiro de S. João de Tarouca.
5. Pinto, P., Caracterização de barreiras pára-vapor e sua aplicação. Tese de mestrado, FEUP, Porto, Abril de 2002.
6. Teixeira, A., Caracterização experimental do funcionamento de sistemas de ventilação da base das paredes para tratamento da humidade ascensional. Tese de mestrado, FEUP, Porto, Dezembro de 2007.