Construction and Building Materials 51 (2014) 383–394

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Effect of solar radiation and humidity on the inner core of walls in historic buildings

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HIGHLIGHTS

- Monitoring constructions materials by means of wireless sensor networks.
- Solar radiation and humidity effects in historic buildings of Cultural Heritage.
- The impact of outdoor conditions on the inner wall and microclimatic conditions.
- Relationship between thermal lags and tendencies with comfort inside the buildings.

ARTICLE INFO

Article history:
Received 23 April 2013
Received in revised form 8 October 2013
Accepted 31 October 2013
Available online 28 November 2013

Keywords:
Monitoring
Masonry
Impact of climate
Thermal lag
Heritage
Thermal comfort
Weathering

ABSTRACT

The structure of historic buildings and the materials used in their construction, along with outdoor conditions, affect indoor temperature and humidity. The walls of San Juan Bautista Church at Talamanca de Jarama, Madrid, Spain, exhibit differences in water absorption, whose explanation is to be found in the various types of construction involved in its over seven centuries of building history, the weather conditions and the walls orientation. The south wall fluctuations in inner temperature and humidity produce 11–16 h thermal lag and a very low decrement factor ensuring comfortable interiors all year round with minimal fluctuations in temperature.

Contents

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0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.10.068

1. Introduction

The climate to which a building material is exposed has a very direct effect on its indoor temperature and humidity, which can be controlled by the wall structure [1–3]. Temperature and humidity distributions vary with building and wall orientation, while solar radiation, wind and rain affect not only wall surfaces but their inner cores as well.

The impact of outdoor conditions on the inner wall and on the indoor temperature and humidity of different rooms is more complex in heritage buildings, which throughout their service life often undergo a number of restorations involving different building materials and construction techniques [4]. Moreover, heritage buildings exhibit wide architectural variability due to the long construction times involved, often measured in decades or even centuries in the case of cathedrals. Such variability can be attributed to factors such as changes in works supervision, the depletion of the initial quarries, alterations the initial design for technical or aesthetic reasons or complete overhauls of architectural style [5].

Such buildings are generally also the object of enlargements or rehabilitations to repair damage due to earthquakes, fire or acts of war. The effects of climate on a building's structure can hardly be understood without a knowledge of its construction history. Diligent assessment also includes a study of the building's urban surrounds and how they have changed since it was built, including factors such as the presence of adjacent buildings or trees or the type of outside pavement, which can affect the degree of solar radiation and the impact of rain and wind on wall surfaces.

Moisture, one of the agents of decay in historic buildings, is transferred to their structure primarily by capillary absorption, condensation, rainwater infiltration or leaking pipes. The causes of material decay can be gleaned from information on variations in temperature and humidity [6], which favour chemical decay through dissolution and oxidation, physical decay via salt crystallisation [7,8] or biodeterioration in the form of microbial colonisation [9,10]. Once the microclimatic conditions prevailing in walls are determined, the causes of decay can be established and guidelines defined for their restoration and conservation [11–13].

Moisture in building façades shortens the durability of their materials and raises maintenance costs. It also affects indoor insulation from the elements, to the detriment of environmental control system performance and consequently energy savings [14].

Moreover, wall construction systems affect indoor environmental conditions and comfort levels: a single layer of a homogeneous material performs very differently in this respect from multiple layers of different materials with different thicknesses and thermo-hydraulic properties [13,15–18].

The variations expected in weather conditions in the decades to come due to climate change will induce significant decay in buildings [19,20]. In the region of Madrid, the high temperature is expected to rise by 3–4° by 2060, while precipitation is estimated to decline by 2–20% [21].

Monitoring the parameters to be studied is one of the imperatives microclimatic research [22,23]. Sensors must be positioned to favour continuous data collection not only inside and outside the building, but inside the walls themselves.

The present study aimed to establish the impact of outdoor conditions on the temperature and humidity inside the walls of a twelfth century building, instrumented with a network of wireless sensors.

2. Church construction

San Juan Bautista Church at Talamanca de Jarama, Madrid, Spain (W3°30′54.0″, N40°44′46.0″), a building with a historic-artistic monument listing since 3 June 1931, was chosen to study the effects of climate on the inner cores of walls. The church is sited at an elevation of 655 m above sea level in a rural environment with a Mediterranean climate. The mean annual temperature is 14 °C and the area's 445-mm yearly rainfall is recorded primarily in spring and autumn.

This twelfth–thirteenth century Romanesque building originally consisted of a single nave headed by a stone apse, which is all that presently remains of that initial structure. The central nave was demolished in the sixteenth century to enlarge the temple, which was rebuilt in Renaissance style. The new central nave is connected to two side naves by wide span basket arches resting on sturdy columns whose flowery capitals also support a Mudéjar style wooden ceiling [24]. The Baroque bell tower was built later, between the seventeenth and eighteenth centuries. By the nineteenth century, the south façade and bell tower of the church was severely damaged by time and the elements. On the occasion of its reconstruction beginning in 1885, the nave was widened.

The church now measures 36.50 × 12.70 × 10.50 m. The walls are 50 cm thick in the nave, 60 cm in the apse and 100 cm in the proximity of the bell tower.

The church lies at 40–50 cm below street level. It is sited in a square with ample space around its main façade, which faces west and south. No trees or other elements outside the building presently alter the solar radiation to which these façades are exposed. Nonetheless, two structures on the building itself cast shadows on the south façade: the tower and the portico at the entrance on that side of the church.

The church apse and its two entrance portals are made of locally quarried dolostone ashlars [25] (Fig. 1a). The indoor columns are also made of this material.

The variation in the façade masonry mirrors the changes in construction techniques over time. The north façade is characterised by bonded brick corners and panes of rubble masonry comprising large rough-hewn siliceous stone bordered by courses of brick. It rests on a 53-cm high rubble stone dado made of similar material and rendered on the inside with clay mortar (Fig. 1b). On the more carefully designed south façade, the fill consists mostly of limestone rubble separated horizontally by two rows of brick (Fig. 1c), although a few quartzite and even an occasional granite stone are also visible, along with Visigoth adornments. The whole wall rests on an 80–90-cm high limestone ashlar dado. This façade has three large inwardly tapered windows. The rubble masonry dado in this wall must have been added as a cladding for the interior brick dado.

The main, eastward facing portal has ashlar stone quoins bonded to the north and south walls, an 85-cm high limestone ashlar dado and a rubble masonry wall alternating with a few rows of brick. The portal is adorned with a semicircular arch and a triangular pediment with Renaissance-type Tuscan columns. The south portal, positioned close to the church tower, is protected by a canopy roof resting on two columns (Fig. 1a).

The church inside walls are rendered with a 5–7-cm layer of cement, in turn surfaced with several coats of plaster and paint. This indoor surfacing has been damaged by capillary water to a height