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Hygrothermal performance evaluation of traditional brick masonry in historic buildings

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ABSTRACT

Existing buildings account for 40% of total green gas emission in the atmosphere [1,2]. Historic and heritage buildings are part of this building stock, and the need for improving their energy performance, despite the derogations for officially protected ones, is supported for achieving the European 2020 Energy Strategy aims [3].

However, when dealing with these buildings, not only are the intervention measures constrained by possible architectural preservation requirements, but also the preparatory building diagnosis itself: only non-destructive and non-invasive monitoring techniques are, reasonably, allowed. Therefore, during onsite energy auditing, ad-hoc monitoring protocols should be adopted.

In this study, an indirect non-invasive envelope monitoring, for evaluating brick masonry hygrothermal behavior, has been proposed and applied in a heritage building in Antwerp (Belgium). The suggested method is aimed at onsite evaluating the thermal performance of buildings traditional masonry and at quantifying the extent of its alteration due to the moisture distribution variation.

Areas detected as wet during iterative passive infrared thermography and environmental monitoring, showed thermal transmittance values more than three times higher than the dry ones on the same masonry surface.

1. Introduction

Existing buildings in Europe account for 40% of total green gas emissions in atmosphere. The urgency upon their energy refurbishment is, hence, agreed and economically sponsored by the EU State Members [1,2]. The attention in reducing building energy demand is currently increasing also with regard to historic and heritage buildings [3].

Since, in these buildings, heat losses through opaque components produce the highest impact on the overall energy balance [9], internal or external masonry insulation has been considered, for some time now, a consolidated retrofitting praxis.

However, when implementing such techniques in historic buildings, their effectiveness should be assured either considering the materials' compatibility or the long term variation of the existing masonry hygrothermal behavior [10–12]. A preliminary onsite monitoring activity for quantifying the hygrothermal masonry performance in its current state, is fundamental.

Therefore, not only should the retrofitting strategy be considered non-harmful for the building, but also the preliminary diagnosis itself. This poses a serious scientific and methodological problem as several monitoring techniques cannot be implemented in historic and heritage contexts due to their invasiveness.

The problem cannot be avoided by simply neglecting preliminary onsite measurement campaigns. Indeed, due to the heterogeneous and anisotropic masonry behavior, alongside with local deterioration processes (responsible for material physical properties variations), the masonry hygrothermal dynamics need to be verified in their current conditions. Experimental onsite monitoring and successive laboratory analysis are thus strongly recommended as opposed to mere notional calculations. However, due to the aforementioned constraints imposed by preservation requirements, often only indirect assessment methodologies are implementable [13–15].

In this contribution, a description of possible hygrothermal envelope-assessment inaccuracies, increased as a consequence of lack of onsite monitoring campaigns, as well as methodological

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Definitions and abbreviations

Notional and experimental data the authors refer to notional data (e.g. physical characteristics) when these are Standard-based calculated or simulated as defined by Fokaides et al. in [4] and to *experimental data* when these are in situ or in lab measured (e.g. thermal conductance according to the EN 9869) [5]

Historic building the authors refer to historic buildings when these have documented historic and/or architectural interest; see Art 1, comma 1–2 in [6]

NDT Non-Destructive Technology

IRT InfraRed Thermography

Quasi in contact hygrothermal parameters the authors refer to quasi in contact hygrothermal parameters when the physical quantities are measured quasi in contact with a given envelope surface, in [7]

Thermal inhomogeneous layers the authors refer to thermal inhomogeneous layers as the opposite of *homogeneous layer*, defined in EN ISO 6946; *Section 3 Terms and definitions*. The building components with inhomogeneous layers, such as mixed stone-mortar masonry or double brick leaf with central filled cavity masonry, cannot be calculated by following the procedure in 6.2.2–6.2.5; *Section 6 Total thermal Resistance*; EN ISO 6946 [8]

Nomenclature

T	air dry bulb temperature (°C)
T_{dw}	dew point temperature (°C)
RH	relative humidity (%)
MR	air mixing ratio (g/kg)
EMC	equilibrium moisture content (%)
q	density of heat flow rate (W/m^2)
U	thermal transmittance (W/m^2 K)
R_{si}	internal surface thermal resistance (m^2 K/W)
R_{se}	external surface thermal resistance (m^2 K/W)
R	thermal resistance (m^2 K/W)
λ	thermal conductivity (W/m K)
Λ	thermal conductance (W/m^2 K)
h_i	internal surface film coefficient for heat transfer (W/m^2 K)
h_e	external surface film coefficient for heat transfer (W/m^2 K)
Θsi	surface temperature indoor (°C)
Θse	surface temperature outdoor (°C)
ω	material moisture content by weight (%)
$\Theta_{si\,\min}$	minimum surface temperature indoor (°C)
$\Theta_{si\,\max}$	maximum surface temperature indoor (°C)
$\sigma\Theta s$	mean surface temperature indoor (°C)
Θsi	surface temperature on the point (°C)
Θi	air indoor temperature (°C)
Θe	air outdoor temperature (°C)
$\sigma\Theta i$	mean air indoor temperature (°C)
$\sigma\Theta e$	mean air outdoor temperature (°C)
Θ_d	indoor dew point temperature (°C)
μ_s	surface temperature factor
μ_{sm}	minimum surface temperature factor
μ_s^*	modified surface temperature factor
μ_h	heterogeneity surface temperature factor
Δ_T	temperature gradient indoor–outdoor of the dry bulb air temperature (°C)

problems encountered in the current praxis are discussed in Section 2. Moreover, an overview on current standards and instrumental monitoring methodologies for opaque components hygrothermal performance evaluation is given in Sections 3 and 4.

Finally, an indirect monitoring methodology aimed at evaluating masonry thermal performance and its variation according to moisture distribution is discussed in Section 5.

The methodology implemented in Vleeshuis Museum in Antwerp is described in Section 6, obtained results are discussed in Section 7, while conclusion are drawn in Section 8.

Although this contribution focuses on the results of a specific case study, the described monitoring procedure can be applied in cases in which the preparatory diagnosis to the building refurbishment is limited by preservation building requirements.

2. Building opaque components thermal evaluation: technical and methodological problems for its definition

Since opaque components (especially walls) account for the most extensive envelope surface in historic buildings [9], their correct thermal performance evaluation is fundamental for delivering effective retrofitting strategies.

The lack of onsite thermal component evaluation, such as in case of analyses solely based on standardized or notional data, might result either in inaccurate or unrepresentative building envelope evaluations or even in improper intervention proposals [16].

In this paragraph, an overview of the widely reported causes of discrepancy between experimental and notional calculated or simulated thermal performance (expressed by the *U* value) of existing building opaque partitions is given.

Although the reported issues refer mainly to buildings masonry, few of them have been encountered during different materials or components evaluation. The mentioned discrepancies are generally caused by the lack of knowledge on:

a) Component inhomogeneities or inner geometric discontinuities (e.g. materials decay, cracks);
b) Exact materials stratigraphy, percentage of mortar, eventual consistency of filled cavities;
c) Dynamic effect of moisture distribution into the masonry or part thereof;

Differences up to 30%, between experimental and notional *U* values in cavity and timber frame walls were found by S. Doran as a consequence of construction defects not predictable within the calculations [17]. The same percentage of deviation between calculated and measured *U* values, caused by a lack of information on hygrometric material properties and percentage of used materials,[1] was found by Baker while investigating thermal properties of construction elements in traditional Scottish buildings [18]. The results from the study demonstrated that 44% of the measured walls had *U* value lower than the calculated or simulated one, 42% of the measured *U* values were in compliance with the values from the computations and only 8% of the measured walls had *U* values higher than the simulated or calculated ones. The potential sources of uncertainty referred by the author were mainly ascribable to the lack of detailed information on: wall stratigraphy, ratio and typology of stones and mortar, wall cavities and specific thermal properties of materials.

Onsite building monitoring, together with laboratory and numerical analyses, aimed at evidencing the extent of energy losses

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[1] Percentage of used material such as brick-mortar ratio; see Section 8; p. 31 in [18].