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Effect of façade surface finish on building energy rehabilitation

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ABSTRACT

Outer façade finishes affect the energy balance in buildings and thermal conditions in urban environments. To rise to the challenges presently posed by climate change, strategies must be designed to reduce energy demand, mitigate greenhouse gas emissions and adapt the urban environment. As a substantial part of building envelopes, façades also play a predominant role in consolidated cities, for they impact thermal balance while also defining the outdoor space.

Three optical parameters (colour, solar reflectance and emissivity) are studied to characterise the surface properties of enclosures and analyse their effect on three construction systems: the standard enclosure found on buildings in Madrid and two solutions to improve its thermal performance via energy rehabilitation.

The findings show that since the surface features of elements govern temperature on outer façade surfaces, suitable design can lower the energy demand for thermal conditioning and improve both indoor and outdoor urban habitability.

1. Introduction

The properties of materials used in building envelopes play an essential role in their thermal response and environmental impact. Primarily two effects must be considered. Firstly, envelope characteristics directly affect the heating and cooling loads generated to ensure indoor comfort (Akbari et al., 1997). According to the literature (Alchapar and Correa, 2015), the temperature of envelope surfaces exposed to solar radiation may rise by 20–40 °C depending on the material. Surface materials can be used to modify surface temperature, lowering the energy demand to heat or cool the indoor environment (Cheng et al., 2005).

Secondly, envelopes constitute an essential element in the urban structure, affecting the quality of the urban environment, especially in connection with the heat island effect, i.e., the well-known fact that temperatures are higher in cities than in less densely populated and rural areas. These circumstances have a heavy impact on building energy demand and indoor comfort. Suitably chosen envelope materials can also affect the local microclimate and mitigate heat waves (Roetzel et al., 2010).

Some strategies proposed in the literature are directly related to the enclosure surface. Examples include the use of lighter colours to absorb a selected range of solar radiation; high solar reflectance, high emissivity cold materials (Santamouris et al., 2011); green façades with growing climbing plants or evaporative systems; or new thermochromic materials with properties that vary depending on the temperature (Gobakis et al., 2015). Wintertime conditions can also be improved with Trombe walls, whose dark tones absorb sunlight (Dabaieh and Elbably, 2015). Solar chimneys, in turn, in which heat gain in higher areas is used to force a draught, enhance ventilation (He et al., 2016).

Building energy rehabilitation is one of the primary medium-term objectives for the building construction industry in Europe. The primary aim is to improve environmental quality and energy efficiency. This study addresses energy rehabilitation in multi-family social housing built in large Spanish cities from 1940 to 1980, i.e., between the end of the Spanish Civil War and the entry into effect of building code NBE-CT-79, which contained the country's first thermal requirements for enclosures (Oteiza et al., 2015). Over half of the buildings presently standing in Spanish cities were built in that timeframe. Dually affected by the absence of building requirements and the post war scarcity of materials, these buildings fail to come even close to meeting today's energy standards (Dalle et al., 2010). The implications in terms of energy loss, lack of environmental comfort and unnecessary costs are obvious.

A previous paper (Alonso et al., 2016) described the results of monitoring energy consumption in three façade systems. One, the typology prevailing in social housing built in the city of Madrid during the period studied (M1), consisted in non-insulated cavity

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walls. The other two systems were innovative solutions proposed for the energy rehabilitation of the aforementioned representative enclosure: a tile-based ventilated façade (M2) and an external thermal insulation system (M3). That study found energy consumption to be highest in façade system M1, while the energy efficiency obtained with solutions M2 and M3 was significantly affected by the season of the year and façade orientation. These observations prompted an analysis of external surface characteristics of each module to quantify their impact on indoor thermal comfort and the surrounding microclimate. The results of that analysis are discussed hereunder.

2. Methodology. Instrumental techniques and test methods

2.1. Parameters considered in the analysis

The properties of the three opaque enclosures were analysed using a number of techniques to monitor three rehabilitation-related parameters and determine the energy balance (Berdahl and Bretz, 1997). The first was the exterior finish colour used in traditional architecture to adapt buildings to the local climate and recently proposed by some authors as an inexpensive approach to lowering cooling demand in warm seasons (Cuerda and Neila, 2012).

Surface colour is related to the response to radiation in the visible range, where solar output is greatest, but accounts for a much smaller fraction of the solar spectrum than the near-infrared range. For that reason, solar absorptance, an optical property encompassing the entire range of solar radiation, was the second parameter studied to define heat absorption and accumulation and consequently enclosure temperature (Santamouris, 2014).

The surface finish emissivity of the enclosure material in the far-infrared, which also affects energy demand, was the third parameter explored. As this factor expresses the capacity of a material to emit and absorb heat, it is used to calculate radiation heat exchange between surfaces or between objects and the sky. It depends on an element's exposure to the sky, It is also applied to compare energy emissions between a given element and a blackbody (Ciocia and Marinetti, 2012).

One of the practical implications of these properties is that in Mediterranean climates, low emissivity finishes reduce heating energy demand more efficiently than light coloured, high emissivity painted surfaces, which conversely lower cooling demand peaks more efficiently than dark finishes in the summertime (Ascione et al., 2010).

The impact of outer surface optical properties (colour, solar absorptance and emissivity) of three construction systems on indoor thermal comfort and the urban environment was analysed in this study. Energy simulation models developed to explore the effect of these parameters on construction system performance were calibrated with experimental data and optical characterisation.

2.2. Façade construction systems analysed

Three types of enclosures were studied: a standard enclosure for buildings in Madrid (labelled M1) and two retrofits chosen to improve its thermal performance (labelled M2 and M3). The full-scale models built are depicted in Fig. 1. As full details of their properties and criteria for their choice are described in Alonso et al. (2016) they are discussed only briefly here.

- **M1:** base façade consisting of a double wall separated by an air space. This is the type of enclosure normally found in Madrid housing built between 1940 and 1980, today in need of energy rehabilitation to meet the standards in place (Oteiza et al., 2015). The model was built with two fired clay brick wythes separated by a non-ventilated cavity and faced with cement mortar on the outside and plaster on the inside.
- **M2:** base façade cell + a 'DIT' ventilated façade solution. This first of the retrofits chosen bears official domestic technical approvals ('DIT'[1]) credentials. It was fitted to the M1 base wall and dimensioned to a degree of insulation compliant with the national technical building code (CTE, 2006). It had a fired clay brick finish.
- **M3:** base façade + an ETE-ETA ETICS (external thermal insulation composite system) solution. This second retrofit, bearing European Technical Approvals (ETE-ETA) credentials, was dimensioned as in solution M2. The outer base wall was rendered.

The initial surface colour of the three enclosures was intentionally similar, despite the difference in the finish materials, to mimic the aesthetics of residential buildings built in the period studied (M1) and prevent colour from affecting the energy efficiency assessment of the two rehabilitation systems (M2 and M3). The full-scale models built are depicted in Fig. 1.

2.3. Monitoring energy performance of full-scale test cells

Sample façades M1, M2 and M3 were tested in Madrid, facing south, exposed to the outdoor environment in three identical cubic cells, highly insulated and monitored for over 1 year, as described in detail in Alonso et al. (2016).

Energy performance was conditioned by the local Mediterranean climate. Madrid's altitude (657 m) cools its winters with periodic snowfalls and minimum temperatures dipping to below 0 °C (32 °F). In contrast, the city's summers are hot, with temperatures of around 30 °C (86 °F) and often rising to 40 °C (104 °F). Given its altitude and dry climate, Madrid's nights are substantially cooler than its days in the summer months.

All three cells were fitted with a Schneider SCR110 sensor, centrally positioned indoors to measure air quality based on temperature, relative humidity and CO_2 to the following precision values: temperature (T), ±0.5 °C; relative humidity (RH), ±2%; CO_2, ±2%.

Local weather data were also recorded at a meteo station located on site to measure factors particularly relevant to outer surface characterisation (Fig. 2). They included solar radiation (which heats the surface depending on incident angle and intensity), wind (which cools the surface depending on velocity and affects air convection in the surface air layer), and outdoor temperature (which also heats or cools the surface by convective heat transfer). Other authors have explored the effect of these surface parameters on indoor conditions: temperature and solar radiation (Bansal et al., 1992), degrees-day and summer solar radiation (Ascione et al., 2010), and radiation, temperature, wind speed and specific humidity (Carnielo and Zinzi, 2013).

The three enclosures studied were monitored by sensors installed in each layer, which collected data at 10 min intervals. This detailed information was used to analyse the response to weather conditions. The thermocouples in these sensors featured a precision of ±0.5 °C and type T, class 1 solid 2 × 0.5 mm wire, individually insulated with Teflon and bundled in Teflon sheaths.

[1] Innovative product assessment. The technical approvals certificate – "Documento de Idoneidad Técnica, DIT " is a voluntary document issued by the Eduardo Torroja Institute for Construction Science (IETcc) certifying that non-traditional or innovative construction materials, systems of procedures have been assessed to be fit for use in buildings and/or civil works.