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The effect of high thermal insulation on high thermal mass: Is the dynamic behaviour of traditional envelopes in Mediterranean climates still possible?

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A B S T R A C T

The paper aims at studying the effect of both high thermal insulation and high thermal mass techniques in buildings dynamic behaviour in Mediterranean climates. The two techniques can lead to conflicting requirements when considering winter and summer conditions, or even high daily temperature ranges. Therefore, the best solution for the summer can be the worst solution for the winter. It is necessary to identify insulation measures that conserve the mass dynamic behaviour.

Experimental investigations were carried out on a single-family house to characterize the behaviour of two walls with different thermal inertia. Thermal simulations made it possible to explore different retrofit configurations also including dynamic strategies. The solutions were compared on comfort, energy savings and global cost.

The study shows that the most suitable intervention is the maximization of the internal heat capacity and the introduction of an external insulation layer sealed in wintertime and ventilated in summer, thus maintaining the existing massive envelope seasonal dynamic behaviour by alternatively maximising thermal barrier effect and heat loss. Considering this, the authors introduced a recently patented dynamic system that reduces both summer discomfort levels and consumption, respectively, of about 20% and 43% respect to the worst retrofit solution.

1. Introduction

The energy saving regulations developed on the last years have focused their attention on the problem of heating consumption reduction (common to all European countries) without considering that in hot summer Mediterranean climates the predominant need is to guarantee indoor comfort during the warm period.

This has led, even in warmer countries as in Italy, to the imposition of thermal transmittance limit values, through stationary or periodic parameters. So, even in such climates, lightweight and super-insulated building envelopes have been adopted in new constructions. Moreover, in existing buildings retrofit, considerable thicknesses of insulation layer were placed either on the external or internal side of the wall, regardless of the relative position between mass and thermal insulation.

However many authors have already shown that different insulation–mass configurations differently impact on both heating–cooling consumptions and indoor comfort with a different and often opposite effect on the various aspects. The optimal stratigraphy varies based on the considered operational conditions (intermittent use [1], continuous use [2]), climate (extreme climate or with variable temperature range [3]) and the specific analysed aspect between energy efficiency [4,5], comfort [6–8] or costs [9,10]. So that the best solution identification is still an open question and it could be with internal insulation (in studies focused on winter performance [1,11]), with external insulation (in studies focused on summer performance [2,12–16]), or with insulation

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Nomenclature

q	volumetric flow through the opening (m^3/s)
ΔP	pressure difference across the opening/crack (Pa)
n	flow exponent varying between 0.5 for fully turbulent flow and 1.0 for fully laminar flow (–)
C	flow coefficient, related to the size of the opening/crack (–)
P_w	wind surface pressure relative to static pressure in undisturbed flow (Pa)
ρ	air density (kg/m^3)
v_z	mean wind velocity at height z (m/s)
C_p	wind pressure coefficient at a given position on the surface (–)
U	thermal trasmittance (W/m^2 K)
$C_G(\tau)$	global cost referred to starting year τ_0 (€/m^2)
C_I	initial investment cost (€/m^2)
$C_{a,i}$ (j)	annual cost for component j at the year i (€/m^2)
R_d (i)	discount rate for year i (–)
$V_{f,\tau}$ (j)	final value of component j at the end of the calculation period (€/m^2)
C_m	replacement costs (€/m^2)
C_o	operation cost (€/m^2)
R_R	real interest rate (–)
p	timing of the considered costs (–)

placed on both sides of the wall [1,9,17,18]. Very rarely studies have been performed on a multidisciplinary simultaneous evaluation of the different aspects.

Focusing on the summer comfort optimization it is established in literature that thick insulation layers, imposed by energy savings standards, whatever their position, act as a thermal barriers avoiding the heat loss with overheating risks. This has led to the increasing importance of the thermal mass in all climates [19–22]. In hot summer Mediterranean climate building envelopes with heavy "storing" masses that dynamically adapt to seasonal variations, were found to be preferable. The traditional architectures are examples of a very close relationship with the specific climate because they have dynamically adapted to the external environment without the use of the systems but through the adoption of passive strategies such as high massive envelopes [23–25] and natural cross ventilation [26].

For new and retrofitted envelopes, various authors demonstrated that dynamic configurations should be preferred: not insulated walls [6,23]; walls with seasonal deactivation of the insulation layer [27,28]; walls with recently developed dynamic finishing materials (PCM) [29]. Between the above mentioned solutions, the former (not insulated solutions) are not suited for both summer and winter period; the dynamic insulation is mainly designed to enhance the indoor ventilation rather than maximize the dynamic behaviour of the massive layers of the envelope that should be a priority in the retrofit of existing massive envelopes; PCM materials work on the latent heat storage rather than on the interaction between natural ventilation and mass.

Another solution to enhance the dynamic interaction with the environment is the ventilated external insulation layer, which consists in an external insulation separated from the internal massive wall by a channel that can be either ventilated in summer or closed in winter. This solution should resolve the posed question. The system was originated in Northern Europe with various patents [30–32] but has been rarely applied owing to its installation complexity and the poor winter thermal performance of the air vents, which are generally made of thin aluminium plates. For this reason, our research group has studied a pre-assembled system with air vents made of insulating material (registered trademark MUnSTa®) [33]. This type of system could improve the dynamic behaviour of the inner mass but no studies in literature were performed on performance quantification.

Fig. 1. External view of the case study.

In summary, various authors highlighted the overheating risk of the super-insulated envelopes newly introduced by the energy saving standards, but the quantification of the benefices (on comfort, consumptions and global cost) of restoring the dynamic behaviour of the mass through the introduction of a ventilated layer is still lacking.

The paper aims at studying the effect of both high thermal insulation and high thermal mass techniques in the dynamic behaviour of buildings in Mediterranean climates also considering the effect of natural ventilation (cross and interposed in the building elements).

A multidisciplinary study was carried out including: an experimental investigation on a traditional detached building; analytical simulations of comfort levels and energy consumptions to define the most beneficial mutual position between mass and insulation and to check the effect of the introduction of natural ventilated cavities on the external envelope; global cost comparison between different scenarios; integrated evaluation between the various aspects (comfort, energy saving, global cost).

2. Phase, tools and methods

2.1. Phases

The research was carried out through experimental activities and analytical simulations according to the following phases:

- On-site monitoring during summer and an intermediate season on four rooms (two at the ground floor and two at the first floor), characterized by different envelope inertia so as to assess the thermal performance and to obtain real data for comparison with simulation values;
- dynamic simulations and model calibration through comparison with measured values; and
- parametric analysis on the virtual model to extend the study for different seasons and to assess the comfort levels and energy saving potential of different retrofit scenarios.

2.2. The case study

The case study (Fig. 1) is a single-family house located in the central Italy near the Adriatic coast (latitude 43°27′, longitude 13°37′), characterized by 1647 degree-days. The building is a typical example of traditional rural architecture. It was built up at the beginning of 1900 and the first floor had been completed in the subsequent years (around 1920) with a different constructive technology. It consists in a volume of two storeys above ground level