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The role of areal heat capacity and decrement factor in case of hyper insulated buildings: An experimental study

F. Stazi [a,*], G. Ulpiani [b], M. Pergolini [a], C. Di Perna [b]

[a] Department of Department of Materials, Environmental Sciences and Urban Planning (SIMAU), Polytechnic University of Marche, Ancona, Italy
[b] Department of Industrial Engineering and Mathematical Sciences (DIISM), Polytechnic University of Marche, Ancona, Italy

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ABSTRACT

Extensive simulation-based researches have highlighted the importance of placing a massive layer in the inner side of hyper insulated CLT buildings in the interest of optimize their thermal performance on an annual basis. The purpose of the present research is to experimentally evaluate the thermal responsiveness of multi layered and highly insulated CLT building envelopes characterized by different combination of two dynamic parameters, namely the internal areal heat capacity κ_1 and the decrement factor *f*.

An on-site monitoring campaign was extensively performed, during summer and winter seasons, on an unoccupied and windowless test room in Central Italy. Four internal linings were simultaneously tested on the south facing wall: plasterboard (as a baseline reference), two dry clay panels with different thickness and a combination of brick and an additional internal insulation layer. Over the year, the indoor microclimate was exposed to three different occupancy/solar gains profiles, identified with Test 1–3 and supplied to the room by three electric radiators.

During Test 1 and Test 2 (summer and autumn, respectively), the results have shown the limits of the adoption of lightweight and hyper-insulated external walls with high internal areal heat capacity and very low decrement factor in the Mediterranean area. In fact, such typology exhibits the highest surface temperatures, with daily maximum around 28 °C and nocturnal minimum approximately 1.5 °C lower. Moreover, increasing the thermal resistance of a wall by adding an insulated lining partially inhibits the proper storage ability on the inner side, causing the release of more heat inside the test room.

Conversely in winter (Test 3), such configuration was found to have a positive response in terms of stored heat quota, with respect to the released one.

The solution that guaranteed the best thermal performance on annual basis under different indoor boundary conditions was the wall envelope characterized by average inertial properties, notably κ_1 equal to 33 kJ/(m^{2}K) and a decrement factor of 0.072.

1. Introduction

It is well acknowledged that the reduction of the energy consumption throughout the building stock is a priority in the European roadmap to contain the greenhouse gas emissions [1]. The NZEB paradigm, prospected by the European Directive 2010/31/CE, has established high performance targets for new buildings that entail optimized design of the single components, as well as of the building as a whole system framed in its specific climatic context [2].

Against such backdrop, the envelope's role is pivotal, since it governs the amount of energy necessary to maintain adequate indoor comfort levels, by arbitrating the perturbing action of the weather outside and occupancy patterns inside [3].

In winter, as apparent from previous studies [4–8], a proper design allows to retain the heat, that is stored inside because of the free gains given by internal and external sources, thus limiting the heating system workload. Conversely, in the warm seasons and especially in cooling-dominated climates, the goal is to dissipate the potential overheat or at least to shave/shift its peak so that less heat stays entrapped: by misaligning the hours of maximum outdoor temperature and solar radiation and the time by which the heat is released, the benefits in summertime and those in wintertime get harmonized [9–11].

Indeed, envelopes with a great amount of thermal mass, phase out and flatten out the heat flow triggered by external ambient temperature fluctuations (Fig. 1) and display a reduced and delayed reaction to the perturbing excitation; this transient effect is

* Corresponding author.
E-mail addresses: f.stazi@univpm.it (F. Stazi), g.ulpiani@pm.univpm.it (G. Ulpiani), m.pergolini@pm.univpm.it (M. Pergolini), c.diperna@univpm.it (C. Di Perna).

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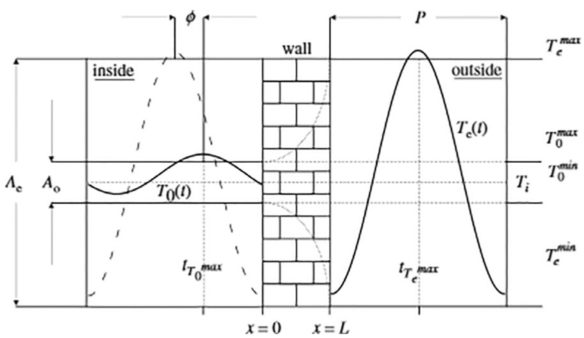

Fig. 1. Schematic representation of the outdoor heat wave propagating through the wall [12].

referred to as the thermal inertia of the building and stands for the resistance to temperature change of the components interacting dynamically with the outdoors, during a full heating/cooling cycle (24 hours).As a consequence, a thermal flywheel behavior is established and, when probably tweaked, this might assist in creating favorable indoor thermal comfort conditions without the need for active cooling and heating, especially in climates with high diurnal temperature variations [13].

It is well proven though that, when it comes to very hot areas, other cooling strategies need to be in place to counteract the discomfort events that are likely to occur given the overabundance of heat gains and the recent escalation of extreme climate events such as tropical nights [14].

Extensive literature exists on the topic, notably to define the design criteria for optimized walls composition. Even though the ingredients for designing a high performance envelope are pretty much disclosed, designers are still faced with a challenging task since the best wall composition comes out of a tradeoff between the simultaneous optimization of diverse parameters: the steady state thermal transmittance U should be advantageously minimized to optimize the winter performance, while in summer, high time lags Δt (for example close to 10–12 h) and internal areal heat capacity κ_1 alongside with low decrement factors f are postulated to reduce the fluctuations of the indoor air temperature and avert the cumulative effect of multiple simultaneous heat fluxes [14].

Several studies advocate that a general practice suitable to maximize both energy savings and thermal comfort for most buildings and climates is to locate higher amounts of thermal mass at the inner side of the thermal insulation: [8,13,15–19].

Bearing this in mind, recently developed solutions turned out to be inefficient. For instance, light and hyper-insulated building configurations, adopted in the last decades, not only in the North–European region, but also in the Mediterranean area, currently achieve very low thermal transmittance U, with external thick insulation layers that act as thermal barriers blocking the ingoing and outgoing heat flows, hence limiting the heat transmission through the external wall [20,21].

Yet, such envelope setting, especially when unshaded, is way far from attaining an optimal performance in summer time, when the heat barrier effect backfires, turning into a detrimental “oven” effect: overheating frequently occurs and impinges on cooling consumptions. Latest researches have demonstrated that for this type of envelopes, the adoption of an internal finishing layer with appropriate thermo-physical properties can reduce the discomfort [22,23]. In these studies the effect of various combination of κ_1 and f are announced but they are preponderantly simulation-based without any experimental double-check on this particular feature.

Moreover, the exact energy saving potential and comfort benefit bound to thermal inertia is hard to ascertain, not just for the plethora of parameters at stake (which contribution is rather challenging to isolate), but also for the lack of proper metrics, experimental procedures and standards to thoroughly describe the effect [13].This mirrors in the extensive variability of results in literature: the reported energy saving, for instance, scatters from + 10% [24] to - 80%[4]. Such variability stems from the time varying nature of the heat flows, first in line the daily swing of outdoor air temperature and solar radiation.

Our research group in 2009, realized a study focused on the energy performance of buildings envelopes with different levels of internal areal heat capacity [14]. In the previous research, traditional highly insulated and massive envelopes typologies were considered but the comparisons between different wall typologies were mainly based on numerical analysis.

The aim of the present experimental work is to simultaneously evaluate the thermal performance of multi layered external walls in highly insulated CLT buildings, characterized by the same wall composition but with different internal linings, featuring different levels of internal areal heat capacity κ_1 and decrement factor f. In order to achieve this target, a highly insulated test room was provided with four different internal linings placed on the south oriented wall. The innermost layers were monitored yearly with the purpose of assessing their thermal behavior, under the same outdoor and indoor environmental conditions.

2. Phases and materials

The present research consisted of the following steps:

- preliminary study of the thermo-physical properties and transient parameters of a fictitious building material to identify the features that affect κ_1 and f values. Consequent selection of internal linings to represent increasing levels of thermal capacity and decreasing ones of decrement factor;
- panels installation and monitoring. The panels (60 cm x 200 cm each) were installed on the south wall of a hyper-insulated and lightweight test room and the internal surface conditions of the envelopes were monitored yearly;
- data collection and interpretation of the results. The heat transfer through each portion of the south wall was assessed under different internal heat loads and throughout the seasons. The comparison was conducted in terms of flywheel effect (heat flowing), responsiveness (time trends) and expected operative indoor conditions (surface temperature).

2.1. Materials

The internal areal heat capacity κ_1 of a wall envelope depends on the inner lining material thermo-physical properties, namely on its thickness t, thermal conductivity λ, specific heat capacity c and density ρ. Therefore, the material chosen for the internal finishing of a building envelope is a crucial matter since it will impact directly on its thermal inertia and storage capacity.

In order to deeply understand the relation between such properties and the transient thermal parameters, a fictitious material was considered for the internal panel. The fictitious material is characterized by a thickness of 20 mm, a thermal conductivity λ of 0.3 W/(mK), a specific heat capacity c of 1000 Jkg/(K) and a density ρ of 1200 kg/(m^3). These values were varied (one at a time within specific thresholds based on UNI 10351:2015 [25]) to verify their incidence on κ_1 and f parameters. The decrement factor and internal areal heat capacity were calculated according to UNI EN ISO 13786. The decrement factor f is the ratio between the modulus of the dynamic thermal transmittance Y_{12} to the steady state thermal transmittance U and it can be expressed by the following equation:

$$f = \frac{|Y_{12}|}{U} \quad (1)$$