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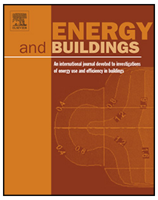

Preventing overheating in offices through thermal inertial properties of compressed earth bricks: A study on a real scale prototype

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ABSTRACT

Buildings are increasingly required to be efficient not just in their operation, but from construction to demolition. Thus, interest in natural construction materials with low embodied environmental impacts has increased, (re)inventing materials and components from vernacular architecture. Compressed Earth Bricks (CEBs) are an example of this kind of component. They are flexible in a wide range of applications and their natural features favour their usage as thermally massive elements to increase a building's thermal inertia (TI). The ability to store heat during the day and release it later helps buildings in dampening thermal swings, making TI a good strategy for preventing overheating in offices usually characterized by critical internal loads.

Previous studies highlighted the difference between the thermal behaviour results obtained with tests on the materials, like experiments in controlled climatic chambers and real-world applications. In this study, an application of CEBs is taken as a case-study to analyse the thermal behaviour of an earthen wall and the potential of coupling night ventilation to stabilize temperatures and increase indoor comfort. Comparing the results obtained in two different rooms, representative of lightweight and heavyweight earthen construction, it was possible to quantify the contribution of CEBs walls to the passive cooling strategy in office buildings, according to different ventilation profiles/scenarios.

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1. Introduction

The constant growth of world population [1] means more buildings and infrastructure, which will further increase the green-house gas emissions, energy demand and waste production from the construction sector. This industry already accounts for up to 40% of the primary energy used in Europe [2] and almost one third of the energy consumption in the world [3]. The impacts of energy use in buildings has been tackled by the EU with a specific Directive [4], which introduces the concept of Nearly Zero Energy Buildings [5]. However, cooling demand in the commercial sector has increased dramatically in the last decades [6] due to higher internal gains, higher comfort expectations, and warmer summertime conditions [7]. Moreover, lightweight and over-insulated constructions are unable to dissipate the high internal heat gains, resulting in the accumulation of heat and overheating during the day [8]. This is typically the situation of office, characterized by high-internal-load, which concur with the low capacity of heat dissipation in increasing the indoor temperatures.

Thermal inertia (TI) has been studied as an effective method to reduce cooling loads in the summertime [9,10] and preventing overheating, thanks to its capacity to store the internal heat during the day and release it during un-occupied hours [8]. It modifies the way a building responds to changes in external and internal conditions, especially in buildings with a recurrent use pattern [11].

The effectiveness of TI is enhanced if coupled with night ventilation, which improves the cooling potential by dissipating during

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the un-occupied hours the heat stored in the building fabric during the day [12–15]. However, due to the dynamic interactions between TI, the context, and the building [16], the cooling potential may significantly vary from case to case and the magnitude of its effects become difficult to predict [17]. The strong dependency on the interactions between several parameters [18] and the difficulties in describing them properly introduce a gap between thermal simulations and reality [19,20], often overestimating TI effects [21]. For this reason, real scale experiments are necessary to define the specific potential of TI. From the literature review, a great potential lies in TI application, especially when coupled with optimal ventilation strategies [22]. The specificity of TI effects to each case makes important to contextualize and understand its potential during the early design phase to understand the possible benefits on the building's performance.

This paper aims to quantify by real scale experiment the cooling potential of TI in the framework of the smart living building research project [23], towards the definition of design solutions for a future low-carbon building. The research project goal is the definition of design guidelines useful for the future architectural competition aimed at the design of an innovative building with outstanding energy and environmental performances, placed in Fribourg (Switzerland). In this framework, TI becomes essential as passive strategy to have a better indoor control without mechanical cooling system, avoiding indoor temperature peaks. The objective of the presented case study is to analyse the effects of TI applied to the specific case of an office building, through the comparison of the indoor temperatures achieved by two different rooms characterized by different TI levels. For this, an experimental campaign to compare a lightweight and a massive construction was carried out on a 1:1 scale prototype, due to the necessity of defining TI contribution to heat-peaks reduction in the specific case of smart living building.

A previous analysis [24] investigated the role of TI in reducing heating demand, highlighting the importance of using natural materials for an environmentally efficient design solution. The results demonstrated that TI has slight benefits on heating energy demand consumption, yet negligible due to the low percentage of reduction, which is less than 6% for very heavy constructions. Rather, another interesting conclusion was found: TI is an interesting strategy on life cycle optimization only when low-carbon materials are used to increase the building's thermal behaviour: concrete, fired bricks and concrete-based materials have higher embodied impacts that can't be balance by the savings induced on the operative energy use [24]. New innovative building standards are pushing the industry towards the concept of zero operational energy, reducing the impacts related to the operative life and, consequently, increasing the role of construction materials in the building's overall environmental performance [25–27]. Choosing appropriate materials can reduce the building's energy use up to 17% [28] and cut almost 30% of the carbon emissions [29]. For this reason, we have witnessed an upsurge in interest in natural or new materials [30] that promise a lower embodied energy demand [31]. One such material is earth, or soil, a vernacular solution re-discovered as an answer to the new challenge of finding low-carbon resources for sustainable architecture. In the analysis presented unfired earth bricks are used to implement TI. Smart living building research frames the analysis towards the optimization of the envelope performances on a life cycle perspectives, introducing a strict requirement to the materials choice: natural materials for TI have benefits on LCA due to their low embodied impacts and, therefore, they could play a key-role in the whole building life cycle performances.

1.1. Earth products and compressed earth bricks

Earth materials are, in many situations, good alternatives to the traditional ones used in constructions [32,33]. They are often cheaper [34,35] and using earth reduces the energy required for construction and operation [36,37]. In addition, the embodied impacts related to earth construction are almost half of a traditional Portland cement building [38], mainly due to the material-extraction process [32] that allows the extensive re-use of waste soil [39], and the abundance of suitable soil. Environmental benefits are not the only positive effects of earthen materials. Studies have highlighted the pleasant indoor environment achieved in rammed earth buildings, especially because of the hygrothermal comfort [40–44] and the relative absence of toxic substances [45]. In the case study TI effects are implemented through Compressed Earth Bricks (CEBs), selected among all the possible earthen products available on the market [32]. The choice was driven by two factors: the thermal characteristic of the bricks and the easy implementation in the scale 1:1 prototype. CEBs thermal properties are particularly indicated for implementing TI, as they have high specific heat capacity (approx. 1.1 kJ/kgK), which determines the capacity of the materials to store heat, and relatively high thermal conductivity (approx. 0.79 W/mK), which indicates how rapidly the heat stored will move inside the material allowing for higher storage. Great heat capacity and appreciable heat conductivity are two essential properties for a material that must be used to increase TI [46]. High conductivity without sufficient heat capacity defines a material that cannot store enough heat; on the contrary, a material with high heat capacity and low conductivity might have a slower store-and-release heat cycle, with negative impacts on the indoor environment. In fact, slow thermal cycles can mean that the heat is released during the following day, resulting in additional heat load for the building during the heat-peaks. Instead, CEBs are characterized by the optimal mix between these two parameters. Moreover, the system used in the analysis is a complete dry system: the blocks are pre-formed with a special male-female joint visible in Fig. 5 and don't need the use of mortar. This feature results in less time for the implementation in the prototype and the possibility to demount the additional walls without compromising the material.

The CEB technique is a perfect example of innovation from architectural tradition: CEB system is the evolution of the ancient adobe bricks technique, usually used in vernacular architecture. In this process, blocks of soil are manually or mechanically compressed inside a mold to obtain heavy and resistant blocks, enhancing their structural properties [32]. Recent studies on earth buildings have focused mostly on the seismic and structural issue [32] or on the moisture buffering potential of earth as porous material [46–49,53]. However, the contribution of CEBs to building TI has not been extensively researched [50,46,52], even though their high thermal capacity makes CEB a perfect material for TI purpose. Studies are often conducted either in a steady-state condition [46] overlooking the dynamic response of thermal inertia or on bricks as singular product [53].

The lack of information about CEB potential in thermal inertia application [21,46,51], the necessity of transient analysis [16,17], the difficulties encountered by virtual simulations in describing TI phenomenon [19,20] and the relevance of these issue in the smart living lab framework [23,24] contribute to highlight the relevance of an in-situ experimental campaign aimed at the quantification of the potential of CEB, TI and ventilation as low-carbon cooling strategy in continental climate.