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Multi-objective optimization analysis for high efficiency external walls of zero energy buildings (ZEB) in the Mediterranean climate

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ABSTRACT

ZEBs in Europe adopt a technology of light multi-layered walls by using structural materials with low density, thermal isolation, wide thickness, low specific weight, low mass accumulation, to achieve very low steady thermal transmittance. These techniques work toward bringing down winter heating costs.

In the Mediterranean area, the thermal overload is irreversible when radiation is not controlled and the free supply of heat indoors is mismanaged. The characteristics of multi-layered walls do not yield typical passive heating system benefits because there are not large surfaces with thermal accumulation mass that are capable of storing heat when necessary, and discharge it once the effect of solar radiation is exhausted.

A multi-objective analysis is key to obtaining several types of high energetic efficiency external walls for ZEBs in the Mediterranean climate, through the combination of various materials. The analysis is carried out in terms of steady thermal transmittance, periodic thermal transmittance, decrement factor, time shift, areal heat capacity, thermal admittance, surface mass, thickness.

The results show that the superficial mass of the external wall has important to obtain the best performance in the warm climate. It is possible to reach high performance in the summertime also by lighter and thinner walls.

1. Introduction

The environment is increasingly affected by the construction sector. Castro-Lacouture et al. [1] and Wang et al. [2] explain how that sector uses around 40% of natural resources extracted in industrialized countries, consumes almost 70% of electricity and 12% of potable water. Recent studies around the world about environmental and energy issues show a tendency to reduce emissions from energy consumption and greenhouse gas emissions in the building industry, through insulation and energy system improvements. Besides, Venkatarama Reddy et al. underline [3] that the whole construction process is responsible for a large amount of toxic emissions, accounting for 30% of greenhouse gases and a further 18% indirectly caused by material abuse and transportation.

Voss et al. [4] and Evola et al. [5] report that over the last 20 years several buildings (over 350), designed in order to obtain a zero energy balance, have been built in all parts of the world. Most of them are placed in northern European countries, the USA and Canada, characterized by extremely cold climate. On the other hand, the bibliography regarding ZEBs built in Mediterranean area is not completely satisfactory. The design approach of a ZEB has to be significantly different varying the climate zone, focusing the attention on the thermal mass and the thermal inertia of the envelope in a temperate climate.

Yu et al. [6] explain how the building envelopes are the interface between indoor and outdoor environment which affect the indoor heat gain and heat loss in the design of sustainable buildings. In particular, they identify the most important design parameters in order to develop more efficiently alternative design solutions.

This paper is concerned with defining a method for the construction of new low-rise residential buildings in the Mediterranean climate. The final aim is to determine not a single optimal solution but a set of possible external wall configurations among which the designer can choose the proper solution for his application, according to the Pareto front of the multi-objective problem.

1.1. EPBD 31/2010

The European Directive 31/2010 [7] upholds the concept of zero or nearly zero-energy constructions which are increasingly becoming more common throughout Europe. Member States shall draw

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Nomenclature

A	area (m^2)
C	heat capacity (J/K)
L_{mn}	periodic thermal conductance (W/K)
R	thermal resistance (m^2 K/W)
T	period of the variations (s)
U	thermal transmittance under steady state boundary conditions (W/m^2 K)
Y_{mm}	thermal admittance (W/m^2 K)
Y_{mn}	periodic thermal transmittance (W/m^2 K)
Z	heat transfer matrix environment to environment
Z_{mn}	element of the heat transfer matrix
a	thermal diffusivity (m^2/s)
c	specific heat capacity (J/kg K)
d	thickness of a layer (m)
fd	decrement factor
j	unit on the imaginary axis for a complex number
q	density of heat flow rate (W/m^2)
t	time (s or h)
x	distance through the component (m)
Δt	time shift: time lead (if positive), or time lag (if negative) (s or h)
M_s	total surface mass (excluding coats) (kg/m^2)

Greek letters

δ	periodic penetration depth of a heat wave in a material (m)
Φ	heat flow rate (W)
ξ	ratio of the thickness of the layer to the penetration depth
κ	areal heat capacity (J/m^2 K)
λ	design thermal conductivity(W/m K)
ρ	density (kg/m^3)
θ	temperature (°C)
ω	angular frequency (rad/s)
ψ	phase differences (rad)

Subscripts

m,n	for the thermal zones
a	air layer
1	internal
2	external
s	related to surface
22	from environment to environment

Symbols

ˆ	complex amplitude
-	mean value
| |	modulus of a complex number
arg	argument of a complex number

up national plans for increasing the number of nearly zero-energy buildings; in particular, by the end of the 2018, for the new buildings occupied and owned by public authorities, by the end of the 2020 for all new buildings. Actually, there is not a shared definition for ZEBs.

The European Directive asserts the concept of a building with nearly zero or very low amount of energy required that should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

In literature, Atanasiu et al. [8] propose possible explanations of ZEBs such as building that use "*nearly zero or a very low amount of energy*", or employ "*renewable energy sources*" on-site or nearby.

Torcellini et al. [9] show that a zero energy building can have several definitions, depending on the boundaries and the metrics, but also on the project goals and the values of the design team and the building's owner. If, on one hand building owners typically care about energy costs, on the other organizations such as DOE (Department of Energy, Washington, DC) are concerned with national energy figures, and are typically interested in primary or source energy. A building designer, instead, will be concerned with site energy use for energy code requirements. Finally, those whose main goal is to avoid pollution from power plants and the burning of fossil fuels will be interested in reducing emissions. Four commonly used definitions are: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. Each definition uses the grid for net use accounting and involves different applicable renewable energy sources.

Sartori et al. [10] underlines that the term n-ZEB, indicates a building connected to the energy grids. It is recognized that different definitions are possible, in accordance with a country's political targets and specific conditions. The balance concept is central in the definition framework and two major types of balance are identified, namely the import/export balance and the load/generation balance.

1.2. Cold and warm climates

Al-Sanea et al. [11] show that high energy efficiency buildings in North Europe adopt the technology of multi – layered walls. Structural materials of low density and thermal isolation are used to achieve very low steady thermal transmittance. The fundamental characteristic is the insulation's wide thickness and low specific weight. These highly insulating techniques are indicated for heating costs in cold winters, which prevail over summer cooling costs, because the main requirement in winter is the accumulation and preservation of internal heat. During the summer, at night, it is strategic to let off the thermal overload accumulated during the day through solar radiation and internal loads.

For many years the guarantee for a good thermal performance was to keep the values of steady thermal transmittance as low as possible. To obtain the best results low energy buildings or passive houses had to have high insulation levels.

Congedo et al. [12] show how a hyper-isolating envelope does not allow the discharge of accumulated heat at night because of low thermal mass and low thermal inertia, thus different solutions have to be carried out in warm climates. In temperate climatic zones, like the Mediterranean area, the thermal overload is often irreversible if there is not a perfect control of radiation in the building and a correct management of the free supply at heat inside the building; this hyper-isolating envelope does not entail the benefits produced by a passive heating system because there is not enough thermal accumulation mass able to store heat when solar radiation is available, and discharge it inside when solar contribution is absent.

As regards passive cooling the thermal accumulation mass can be used as thermal reserve. This work suggests the solution of adopting structural elements with thermal accumulation mass or the use of high density or high specific heat materials for external walls. Experimental and parametric studies have shown that, for buildings in warm climates, it is fundamental to have a high areal heat capacity and high admittance as to not activate overheating, thus producing summer discomfort. This solution lowers condensation risks.

Fang et al. [13] demonstrate that use of an external wall insulation system can improve building energy efficiency in summertime.