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Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate

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A B S T R A C T

Given the recent worldwide environmental issues, there is a need to reduce the energy consumption and the greenhouse gas emissions of the building sector, keeping in mind the whole life cycle assessment of construction materials. Determining the sustainability of the products is complex, and the presence of one or more “eco” features does not necessarily make it “eco” in its entirety. The ITACA Protocol for environmental sustainability promotes the use of recycled, renewable and locally sourced materials.

A multi-criteria analysis has been carried out in order to identify high energy efficiency external walls for ZEBs in the Mediterranean climate, privileging eco-friendly building materials. The modeFRONTIER optimization tool, by the use of calculation procedures developed in Matlab, was used to evaluate the dynamic performance of building components. The optimization was performed in terms of steady thermal transmittance, periodic thermal transmittance, decrement factor, time shift, areal heat capacity, thermal admittance, surface mass, thickness and ITACA score.

A method for the design of new low-cost residential buildings will be defined; in particular, 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-criteria problem. The results underline that, in a warm climate, the best sequences of layers are with high surface mass for the first layer (internal side), followed by common insulating materials for the middle layer and eco-friendly insulating materials for the outer layer.

1. Introduction

The construction sector has a huge impact on the environment [1], as it uses around 40% of the natural resources extracted in industrialized countries and consumes almost 70% of electricity and 12% of potable water [2]. Worldwide, about environmental and energy issues, there is a tendency to reduce energy consumption and greenhouse gas emissions in the building industry. The whole construction process is responsible for a large amount of toxic emissions, accounting for 30% of greenhouse gases, because of their operation, and a further 18% indirectly caused by material abuse and transportation [3].

All the phases of a building's life cycle (construction, fit-out, operation and ultimate demolition) have a significant impact on human life and the environment both directly (through material and energy consumption and the consequent pollution and waste) and indirectly (through the inefficient infrastructure). In response to these impacts, there is a growing propensity among organizations, involved in environmental performance targets, to make construction activities more sustainable with appropriate strategies and actions [4]. Bribian et al. [5] show that the impact of the construction process can be significantly reduced by promoting the use of the best eco-innovation techniques available on production processes, preferably locally produced.

The building materials selection plays a key role in the achievement of the ‘Green Buildings’ target [6] and is performed both in the early stage of the design process, when the strategic choices concerning the building are made, and in the working plan, when the materials available on the market are selected. Both aspects are equally important for the actual fulfillment of ‘greenness’ requirements, but architects and engineers, responsible of this choice, often lack evaluation tools supporting them during the selection of materials.

Flores et al. [7] propose a material selection optimization model that considers objective and subjective factors. A correct choice of materials can help to reduce the energy use in a building, carbon dioxide emissions, energy use in materials production processes,

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environmental impact over the life cycle, among others and air quality discomfort. Jeanjean et al. [8] studied a tool for determination and comparison of building material and their thermal mass.

The selection of construction materials is considered as a multi-criteria decision problem. Ideally, sustainable assessment would integrate social, technical, environmental and economic considerations at every step in the decision-making process. It is essential to have an accurate and supportable material selection method to classify appropriate criteria and to evaluate trade-offs between ecological, financial, social and technological aspects [4]. Different authors [6,7] prove that the selection of eco-friendly materials and products is by far the most controversial task in sustainable construction, and the high performance green building projects represent a laborious and difficult assignment facing the project team [9].

In the European Union, according to Directive 2010/31/EU [10], energy policies cover both new buildings and existing buildings. These basic points concerning the overall European energy framework include: the use of renewable energy, the estimate of overall consumption, and the elaboration of a comparative methodology framework for assessing the optimum economic and minimum energy performance requirements. The reduction of energy consumption and an increasing use of energy from renewable sources can promote the security of energy supply, foster technological developments, and create opportunities for employment and regional development.

Member States have the responsibility to set minimum requirements for the energy performance regarding buildings and building elements. Those requirements should be set with the assumption of achieving the cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building.

A multi-criteria analysis was carried out in order to identify high energy efficiency external walls for ZEBs in the Mediterranean climate, privileging eco-friendly building materials. For such a reason the analysis is focused on the summertime.

The wintertime is not critic in such an areas but obtaining high performance on summertime does not guarantee compliance with the limits imposed by the Italian Law on the wintertime; therefore, also the check of the steady thermal transmittance and the hygrothermal performance test (Glaser) have been carried out for the best solutions.

The Hygrothermal performance test (Glaser) has been performed considering the temperature data of Lecce (Italy) where the critical months are January–February on the wintertime. In Fig. 1 the annual oscillation of ambient temperature in Lecce – Italy is shown.

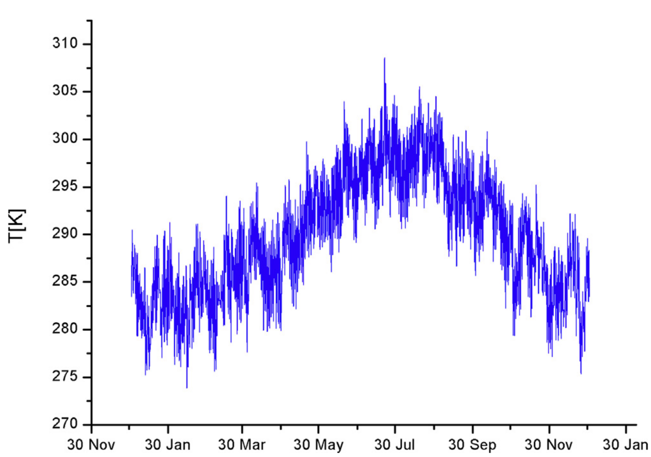

Fig. 1. The ambient temperature annual oscillation in Lecce – Italy.

The modeFRONTIER optimization tool rel.4.3.0, by the use of calculation procedures developed in Matlab, was used to evaluate the dynamic performance of building components. The optimization was performed in terms of steady thermal transmittance, periodic thermal transmittance, decrement factor, time shift, areal heat capacity, thermal admittance, surface mass, thickness. The combination of several eco-friendly and locally sourced materials allows to maximize performance in agreement with the ITACA Protocol (Institute for Innovation and Transparency of Contracts and Environmental Sustainability). The results of the work show several high energy efficiency external wall configurations in terms of dynamic thermal performance and weight.

2. Sustainability evaluation

In agreement with the Organization for Economic Co-operation and Development (OECD) [11], eco-friendly buildings can be identified as those buildings whose structures have a minimum negative impacts on human health and on the environment. The OECD project identifies several objectives for sustainable buildings [12]: resource and energy efficiency, pollution prevention in terms of indoor air quality and noise abatement, environment harmonization, integrated and systematic methods, etc.. The topic of sustainability applied to buildings may be examined from two different standpoints. First of all, it is possible to estimate the impact that construction and day-to-day running will have on the environment as a whole; furthermore, it is also possible to assess, in details, the impact that every single technology employed, each component and each material being used, will have on the environment.

All the protocols currently available assessing sustainability, allow to define the standard of sustainability of a building as a whole, but they show limitations when it comes to evaluating the impact of single materials on the environment. That is due to the fact that determining a product's sustainability is complex, and the presence of one or more “eco” features do not necessarily make it “eco” in its entirety. It can become even more complex when the sustainability assessment of a product must take into account its whole life cycle, from raw materials to final disposal, whereby each phase has a corresponding environmental impact. The first issue to face is the definition of “sustainable”, thus setting a criterion, or a threshold of values, that would allow to univocally estimate that product's impact on the environment.

The factors involved in the production of different types of materials are many and of different nature, sometimes even in the same family of materials, therefore the equation “natural equals sustainable” is simplistic and incorrect [13]. The environmental sustainability certificate is the tool that allows to state the performance and the environmental impacts of a building on a specific area. In a world which grows increasingly “green market-oriented ”, the problem is to give objectivity to the concepts of sustainability. In the world there are numerous assessment systems and sustainability certifications have been developed worldwide.

There are two ways to assess the sustainability of a building: qualitative and quantitative. The qualitative method is based on requirements which correspond to specific weights and scores, the sum of which indicates the global level of energy and environmental sustainability of the building. The quantitative method is a detailed method, referring to Life Cycle Assessment (LCA analysis), quantifying the energy incorporated from the building during the entire life cycle. It is, therefore, a rigorous environmental balance of the entire process, including building management and the end of the building life.