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Life cycle assessment approach for the optimization of sustainable building envelopes: An application on solar wall systems

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A B S T R A C T

Design of sustainable building envelopes requires the analysis of environmental performances in every stage of their life cycle. As a matter of fact, the production phase of building materials and components can significantly contribute to the total energy consumption and environmental loads of buildings. However, façade systems such as passive solar systems, ventilated walls and double skins, are usually not designed considering aspects related to their life cycle. Furthermore, there are still few studies concerning the optimization and the combined effect of different design features of complex façades on environmental and energy performances.

This paper introduces an integrated approach for the optimization of energy and environmental performances of complex building envelopes that combines life cycle assessment, energy simulation and optimization analysis with factorial plan technique. The environmental performance was calculated in terms of energy demand and CO_2 emissions in the production phase and operational phase. The methodology was applied to an exemplary case study with solar wall systems.

The results showed that solar walls have high environmental impact both in the production and operational phases. Results of the optimization analysis demonstrated that it is possible to reduce the CO_2 emissions and cumulative energy demand of solar walls for both the production and use phases up to −55% in comparison with a traditional design. This methodology may be generally applied to the sustainability analysis, design and optimization of efficient façade systems.

1. Introduction

In the European Union 40% of total energy consumption is due to the building sector [1]. Even if the top cause of energy consumption in residential buildings is heating, the building materials can represent more than 60% of the heating consumption [2]. However, energy certification of buildings in the European Member States does not usually consider aspects related to the life cycle. As a consequence, the design of building envelope systems rarely focuses on environmental impacts during their life cycle. In order to reduce both energy consumption and greenhouse gases emissions related to buildings, it is fundamental to introduce a design approach based on sustainability and taking into consideration every stage of their life.

Life cycle assessment (LCA) is a technique used to assess potential environmental impacts of products throughout their life cycle. This technique has been widely applied to building components and entire buildings [2–4]. A review of the tools for the environmental analysis of buildings can be found in [5]. The relevance of simplifications on LCA analysis of several building components, including walls and roofs, was analyzed in [6]. It was shown that transports and ancillary materials should not be neglected while the building process and the cutting-waste have low relevance. Comparative life cycle analysis was used by several studies to compare different solution for façade components, including glazed façades [7–9]. However, for complex façade components, such as passive solar systems, ventilated walls and double skins, the design process must take into consideration the interaction between the different elements of the system in reaching high energy and environmental performances, at every stage of their life cycle. Furthermore an optimization process concerning all the elements of the envelope is needed.

This paper introduces an integrated approach generally applicable to optimize energy and environmental performances of building envelope systems considering their life cycle. The methodology combines LCA, energy simulation in dynamic state and optimization process using factorial plan technique. The environmental performance was calculated in terms of CO_2 emissions and energy demand in the production phase and operational phase.

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The methodology was applied to an exemplary case study with solar wall systems.

2. Literature review about solar walls

The interest in passive solar systems is increasing in the last decade due to the need of high energy performances of building envelopes required to reduce energy consumptions of buildings. Their use is encouraged by European Directive [1] and national regulations of the Member States. However there are still open problems regarding the design of passive solar systems as well as many uncertainties about their real performances and environmental impacts, in particular for solar walls.

Solar wall is a passive solar system able to catch solar radiation exploiting greenhouse effect created in a glazed cavity, to absorb and store heat using a massive wall and finally to exchange it with the indoor environment by transmission through the wall. It is usually made up of a south-facing masonry or concrete wall, an air layer and glazing on the exterior. A particular type of solar wall is Trombe wall that is equipped with vents at the top and at the bottom of the wall for the air thermo-circulation between the air gap and the indoor environment. Heat exchange of Trombe walls with the indoor environment is partly by transmission through the wall and partly by ventilation through the vents.

Large part of the research about solar walls focuses on the optimization of winter and summer energy performances and indoor thermal comfort conditions.

In winter, drawbacks related to Trombe walls concern low thermal resistance, uncertainty of ventilation exchanges and inverse thermo-siphon phenomena which can determine high heat losses [10]. Some actions are suggested to enhance winter performances of Trombe walls: using a more complex design such as composite Trombe wall [11,12], insulating external glazing [13], deactivation of ventilation [13], proper management [14].

In summer overheating drawbacks can occur due to high heat gains of Trombe walls. Such problems can be solved or reduced by several actions: insulation of Trombe wall [15]; use of solar shading [16,17]; ventilation of Trombe walls [15,16]. Previous studies demonstrated that solar walls are convenient systems in Mediterranean climates in terms of energy performances and thermal comfort provided all the year round [13].

Despite the large number of studies about Trombe walls, there are few researches about their life cycle. The optimization of life cycle cost of Trombe and the amount of CO_2 emissions during the use phase was investigated by a recent study [18]. However solar walls are often made up of materials and components, such as concrete and aluminum framing, characterized by relatively high environmental impacts in the production phase. There are not studies in literature concerning both the pre-use and use phase of Trombe walls.

This study investigates the impact of different design features, identified in literature, both in the pre-use and use phase.

3. Methodology

The methodology applied in this study envisages an integrated approach based on energy analysis of buildings, LCA and optimization process. The methodology includes the following steps:

- Goal and scope definition;
- Life cycle inventory analysis;
- Life cycle impact assessment;
- Parametric analysis and optimization analysis.

LCA was performed according to the standard ISO 14040 [19]. Energy analysis was carried out with simulation in dynamic regime.

3.1. Goal and scope definition

3.1.1. Goal definition

The goal of this study is to develop a methodology to optimize energy and environmental performances of complex building envelope components and to test the methodology on a case study with solar wall systems. Optimization regards the minimization of the energy needs and environmental impacts due to the façade system in its life cycle by testing several setups. Results of this study may also be used as recommendations for the proper design of solar walls.

3.1.2. Scope definition

The system to be studied is a classical Trombe wall. The function of Trombe wall considered in this analysis is the attitude to use solar energy in order to reduce building energy needs for heating and cooling.

A Trombe wall in a solar residential building prototype in Ancona (central Italy) was assumed as case study. The system (Fig. 1) is made up of a 40 cm concrete with plaster on the inner face

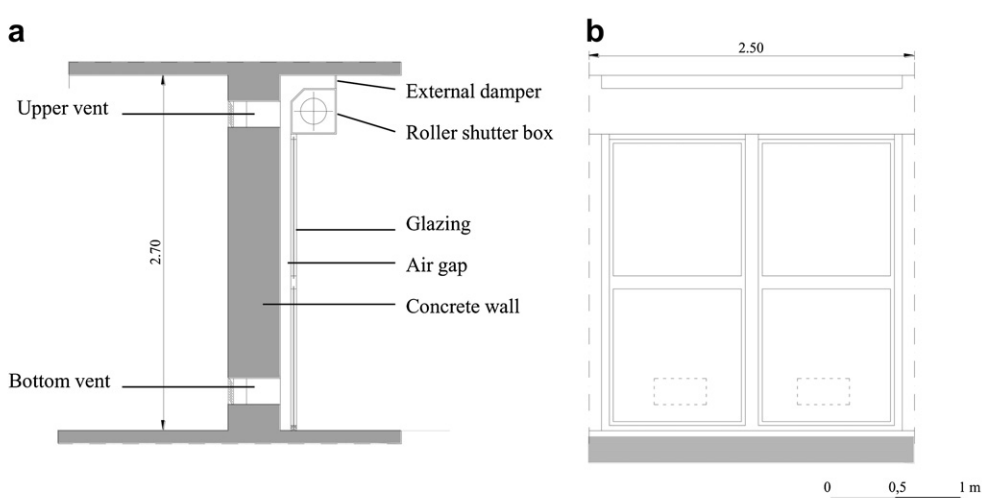

Fig. 1. Cross section (a) and front view (b) of the Trombe wall.