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A High Performance Controlled Temperature Building Shell for the Sustainable Upgrading of Buildings

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Abstract

The energy and environmental upgrading of the built sector is a burning topic that has urged scientific communities worldwide to keep searching for innovative high performance sustainable building products, systems, designs, and practices. The synergy among several approaches and methodologies has been widely accepted and established as the key in achieving the most sustainable constructions. The aim of this paper is to present a novel high performance building element that establishes a building's thermal comfort and effective cooling, while at the same time it has negligible energy requirements. The operation of this innovative solution is based on an active controlled temperature building shell that employs airflow patterns for the stabilization of the building's temperatures. This work investigates the energy performance of the controlled temperature building shell through the employment of numerical simulation tools, while life cycle methodology is also implemented for the assessment of the environmental impact of the novel element. The results and conclusions of the analysis will establish the overall level of performance of the proposed solution, and demonstrate the significance of integrating several methodologies for the promotion of the sustainable upgrading of the building sector.

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Keywords: Building element; thermal comfort; numerical simulation; Life Cycle Assessment; double skin facade

1. Introduction

The European Union is aiming for a 20% cut in Europe's annual primary energy consumption by 2020. Several measures have been proposed to increase efficiency at all stages of the energy chain [0]. The measures focus mainly on the building and transport sectors, where the potential for savings is greatest. Building operation causes many forms

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of environmental degradation that place an increasing burden on Europe's resources and jeopardize the future of the building industry and societal health and welfare [0]. It is expected that cutting-edge building materials and elements will play a major role in the fulfillment of the European energy targets. Accordingly, the improvement of the thermal properties of the building envelope represents one major strategy towards promotion of energy efficiency and energy conservation in the building sector. Among the established solutions, double skin facades (DSF) have been proven to have added advantages in improving thermal insulation performance of the building envelope [0]. For that reason the employment of DSF has gained significant popularity within the building sector, while the fundamentals of their operation could potentially form the basis for the development of new innovative building elements.

The key objective of this study is to introduce and validate the performance of a novel concept, the Controlled Temperature Building Shell. The operation principle of the Controlled Temperature Building Shell is based on the continuous induction of controlled-temperature air within the building envelope, conditioned with the use of a heat pump, resulting to a steady building shell temperature. The introduced concept is validated both with the use of finite element analysis (Comsol Multiphysics) [0], as well as with the implementation of a comprehensive life cycle assessment, (EcoHestia Database) [0] . In this study a brief review of the current DSF technologies is implemented. The methodology of the study and information regarding the parameters and conditions of the numerical simulation tools is also provided. This study constitutes a "proof-of-concept" validation of the Controlled Temperature Building Shell. The basic principles of this concept are reported, the technology concept is formulated and its numerical critical functions are described. The Controlled Temperature Building Shell is set into an appropriate context and a numerically-based study to validate its analytical prediction is implemented. The results of the analysis and the lessons learnt are presented in Section 4.

2. Theoretical Background

2.1. Double- skin ventilated facades

DSFs are multiple layer skins constructions, which are typically comprised of an external skin, an intermediate space and an internal skin, such as a cavity is formed where air is flowing [0 0]. Within this context, DSFs can collect or discard heat, and can also be operated under different ventilation modes, depending on the building energy requirements and the climatic conditions. The Trombe wall concept can also be considered as a DSF application [0]. According to Zhou and Chen [0] and Wong et al. [0] most of the studies about DSFs performance have been carried out in colder and temperate climate conditions, including Europe, North America, and Japan, while recently DSF have also appeared in the hot-summer and cold-winter zones. With regard to their design features, DSFs offer a number of benefits. The air channel can significantly reduce the heating and cooling energy demands [0 0 0] and also improve the building's thermal comfort [0]. Additionally, the external layer provides protection against the weather and improved acoustic insulation [0]. Despite the reduction of the heating and cooling demands during their operational phase, DSFs are building elements that require additional building and insulation materials that suggests higher energy consumption and additional environmental burden during their manufacturing and installation phase [0]. Life Cycle Assessment (LCA) studies of DSF take into consideration the material and energy consumption throughout their life cycle, including the raw materials extraction, production, maintaining and waste management phases. DSF LCA studies consider the embodied energy versus the energy savings achieved during their operational stage, extracting relevant KPIs. Documented LCA results indicate that the use of a ventilated façade with PCM in its air chamber reduces by 7.7% the overall environmental impact of the building, by considering a 50- year lifetime [0]. Additionally, the parametric analysis of 128 DSF configurations, undertaken in the work of [0] revealed that DSFs are more energy-efficient than single-skin in 98% of the cases, and more carbon-efficient in 85% of the cases.

2.2. Controlled Temperature Building Shell description

The operation principle of the Controlled Temperature Building Shell is based on the continuous induction of controlled-temperature air within the building envelope resulting to a steady building shell temperature. The Controlled Temperature Building Shell element shares similar structural characteristics with DSFs, incorporating an external façade, an intermediate space and an internal façade, such as air can flow within the intermediate space, and thus creating an air cavity in between the two facades. The single active cavity inside the building shell is 5cm thick, in which air of controlled temperature is circulated. The air circulating into the cavity comes from an air storage of

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