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Experimental research of the thermal characteristics of a multi-storey naturally ventilated double skin façade

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ABSTRACT

This study presents the results of the actual thermal behaviour of a multi-storey naturally ventilated double skin facade. Governed by lack of experimentally measured data, a field of detailed measurements were performed during the 2013/2014 season in the office building located in Belgrade, Serbia. The uniqueness of this building is that the first facade layer is made in the tradition manner. Apart from studying classical environmentally influenced air cavity behaviour, the methodology incorporates a detailed analysis of the air cavity enthalpy flow. The main purpose of this research is to examine the current state of the building facade and how it affects energy performance. To this effect, measurement data was used in order to analyse transmission losses and gains and to quantify enthalpy change of the cavity air linked to the airflow established within the facade. Analyse of the transmission losses and gains were described by a series of diagrams of vertical and horizontal temperatures trends for selected typical days in each regime. For investigation of the natural ventilation potential, an adequate indicator based on the enthalpy change was established. Overall, the experiment results highlight that the use of a double skin facade does not necessarily reduce energy consumption.

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1. Introduction

The envelope (facade) is the part of the building which forms the primary thermal barrier with its environment. It represents the most important factor in determining the level of thermal comfort, natural lighting and ventilation ability, and finally how much energy is needed for heating and air-conditioning. New stricter building codes, regulation and roadmaps [1], focus on emergency of the use of highly energy efficient technologies and equipment, as well as new adaptive facade solution [2]. The idea of a“zero energy” or“green” building has been very popular recently. The usage of renewable sources to reduce the need for conventional energy becomes a greater challenge for the engineers. The question is which building construction can utilize this in order to supply all the needs of the building?

Naturally ventilated double skin facades (NVDSF) represent one of the most innovative types of adaptive building envelope solution. Generally, a double skin facade (DSF) system consists of an external screen, a (naturally or mechanically) ventilated cavity and an inner screen [3]. Solar shading can be placed in the ventilated cavity. Oesterle [4] gave the most cited definition of DSF. For the author, a double skin facade consists of a multi-layered facade envelope, which has an external and internal layer that contains a buffer space used for controlled ventilation and solar protection. This type of facade is able to utilize external environment to maintain indoor comfort. According to this, Selkowitz [5], gave one of the most comprehensive definitions where the facade becomes a building's energy supplier and energy manager.

Beside the energy point of view, there are many other considerations (natural lighting and ventilation, noise and wind protection...) in the process of designing a DSF which lead to a very comprehensive engineering approach. This other consideration could significantly improve indoor comfort, providing a major contribution to “non-energy” benefits, such as the health and medical expenses of the occupants. Through its design, DSF enables natural ventilation without jeopardizing the safety, security and noise requirements of the building. This ability provides better room air quality and more comfortable thermal conditions, especially in urban areas. An excellent example illustrating this is the recently finished “One Angel Square” building (2013) in

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Nomenclature

BREEAM	building research establishment environmental assessment methodology
NVDSF	naturally ventilated double skin facade
DSF	double skin facade
WWR	window to wall ratio
HVAC	heating, ventilating and air-conditioning system
BMS	building management system
VBA	visual basic for applications
IR	infrared
NE	north-east
NW	north-west
SE	south-east
SW	south-west
W	west
S	south
E	east
N	north
U	overall heat transfer coefficient
g	solar transmittance

Manchester, UK. This building with DSF envelope is today the most sustainable large building in Europe and only one built to a BREEAM “Outstanding” rating.

The DSF concept, with proper design and control strategies, could positively affect the overall energy consumption of the building [6,7,8,9,10,11,12]. But, as well as positive impact, there are studies whose results show negative effects and increased energy consumption, especially due to summer overheating [13,14].

Differing opinions and experiences have produced problems and doubts among engineers and practitioners. Although current practice has proved great potential of the DSF, designers cannot utilize this concept with confidence. Main reasons for that are:

- Lack of standards, a unique methodology and guidelines on how to design and estimate performance of the DSF,
- Low level of knowledge and experience in design and operation phase,
- For each climate, only a couple of monitored and experimentally tested real building with DSF exist (most results comes from laboratory test cells),
- There is no systematically organized documentation of the energy and environmental performance of existing DSFs.

A recently finished EU project [15] and research studies [6,7,16] have contributed greatly to the positive promotion and development of the guidelines for design, operation and energy estimation of the DSF.

The majority of current research covers only energy performance indicators based on material properties (U or g-value). Few studies investigate the enthalpy change of the cavity air [13]. The deficiency of each of the studies mentioned is that facade effectiveness appraisal and the process of selecting a proper control strategy are based only on air temperature. This logic is not completely correct, especially in the case of multi-storey facades where, due to the vertical thermal gradient, the values of relative air humidity vary. For calculation of the transmission losses and gains it is enough to use temperature control. But in case of ventilation or air-conditioning assessment, estimation of the enthalpy change of the cavity air is required. After all, the balance and correlation between enthalpy data (outside, cavity and room conditions) gives a clear picture of facade energy potential.

Experiment results and development of a new, more comprehensive methodology for DSF assessment are the main contribution of this research.

The current state of Serbian building stock can be found in following three studies, written by Todorović, M. and Todorović, B. [17,18,19]. Regarding the worldwide distribution of buildings with DSF, the majority are located in the continental and northern European countries (over 50% of the total number). Japan also accounts for a large percentage (about 13%). In these countries, the climatic conditions are suitable for the proper adaptation and application of DSF. Germany has the highest percentage of these buildings (about 20%). The dominant presence of DSF in Germany can be connected to the fact that Germany was one of the first countries that started to develop this concept. On the other hand, a very small number of buildings with DSF have been identified in Canada, USA, Australia and other parts of the world.

This concept of building envelope is not well-known in Serbia, despite its suitability to the climatic conditions. The reasons for this are mainly the economic condition of the country and the undeveloped building industry. There is also a low level of knowledge concerning the typology, performance and design of DSF among the majority of research institutions, big companies and target groups engineers, architects, developers, facade suppliers and relevant governmental bodies. In addition, there is lack of planning policy, lack of legal standardized schemes among architects, engineers, clients and no awareness of any specific legislation on DSF among target groups. The concept promotion in Serbia is inadequate, which is illustrated by two conflicting methodologies for the calculation of gross building area [20,21]. The recently declared regulation [20] is in contrast with [21], and it promotes the calculation of gross building area without taking into count the DSF part. Problems arise in practice when some local municipalities use the previous standard [21], which can lead to an increased amount of taxes. In contrast to this, Todorović made a very good and the unique research development in this area [22,23,24].

2. Methodology and research goals

From a methodological point of view, the analysis of the measurement begins by observing the current weather conditions and how changes affect the behaviour of DSF. In this way, diagrams of the relation between air cavity temperature, outside temperature and global solar radiation intensity are created. The analysis goes on by presenting wind and solar contribution and influence on the mean cavity air velocity (in case of very strong winds). The methodology involves the formation of diagrams of vertical temperature gradient and horizontal temperature trend for typical days. This part of the thermal investigation contributes to the analysis of transmission losses and gains of the target facade. When air passes through the cavity it causes enthalpy transport. In order to have a wider and more detailed picture of thermal performances of the DSF it is necessary to take into account the enthalpy change of the cavity air. This relates to the ability of the DSF to contribute to ventilation, and the possibility of integration with the HVAC system.

Calculation of hourly values for absolute air humidity and enthalpy was done by writing a code in Excel using Visual Basic for Applications (VBA). The detailed calculation procedure is described in [25,26].

Measurements accuracy (beside standard equipment calibration and onsite manual measurement testing) is checked by comparative analysis of calculated values of absolute air humidity in the lower and upper zone of the DSF. These values are calculated (Eq. (1)) based on the measured data of temperature, relative humidity and barometric air pressure in the DSF. Considering both

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