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Outdoor test cells for building envelope experimental characterisation – A literature review

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ABSTRACT

In the past decades the construction sector experienced the diffusion of a wide variety of complex building envelope components and passive elements and strategies, characterized by a dynamic response to the climatic parameters. Many of these components have been claimed to contribute to reducing building energy use and improving occupants' comfort. These kind of envelope elements need nevertheless to be tested under laboratory and real dynamic weather conditions in order to characterise, and possibly to model, their behaviour and their effectiveness both in terms of energy saving and indoor environmental quality. Both indoor laboratories and outdoor test cells have been developed in order to tackle the challenging issue of experimentally characterising innovative envelope elements. However, not always the experimental methodologies are fully and explicitly described in the available literature, and they are rarely compared to other types of experimental procedures. The aim of the present paper is to describe and review recent state of the art technologies for outdoor test cells. The paper starts with a short introduction on potentialities and limitations of outdoor facilities with respect to indoor laboratories and real buildings field tests, and it continues with a detailed classification and description of the most relevant outdoor test cells developed in recent years.

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1. Introduction

The market of building construction is in rapid evolution, driven by increasing requirements in terms of low-energy need and high levels of Indoor Environmental Quality [1,2]. Transparent components are particularly challenging, being, as remarked by Clarke et al. [3], the “weakest and strongest elements” from an energy point of view: from one side they present risks of thermal discomfort (e.g. radiant temperature asymmetry and down draughts) and visual discomfort (disability and discomfort glare), on the other side they allow the building and occupants to benefit of solar heat gains, daylight and the (hopefully pleasant) view on the outside. Also opaque building elements are undergoing a continuous optimisation process, in particular to address the market of energy efficient refurbishments. This market is increasingly asking for insulated, airtight prefabricated modules that allow to drastically reduce the installation time and the disturbance of building occupants and neighbourhood in the case of retrofit of existing buildings [4], while offering high hygrothermal performance and long durability. Highly increased airtightness in new buildings and energy efficient retrofits requires in turn the introduction of controlled ventilation, sometimes decentralised and included in envelope elements.

Façade elements thus become multi-functional, providing not only the thermal insulation of the building, but also (pre-heated) fresh air to the indoor space, the control of solar gains and incoming daylight, the control of surface condensation risk and so on. The assessment of the effectiveness by which the innovative building elements perform one or more of these functions is a complex task. Researchers and standardisation bodies are trying to identify the most appropriate procedures to correctly estimate the actual behaviour of building components in a simple and cost-effective way.

The assessment procedure may be performed by means of three main facility categories: outdoor real-scale facilities (whole buildings, possibly with occupants), laboratory indoor facilities, and outdoor test cells [5]. The first corresponding to in-field measurements with boundary conditions determined by weather and sometimes occupants behaviour, the second and the third to measurements under laboratory controlled boundary conditions, although in the case of test cells not all of them are under control of the research team.

It might be argued that field measurements give the most “lifelike” results, however they suffer from several constraints. First of all they are influenced both by external weather conditions and by indoor conditions, the latter depending on the characteristics of the building and the heating/cooling system and on the occupants' behaviour. It is therefore difficult to isolate a single variable, since external and internal factors simultaneously act during the measurements [6].

Secondly, obtained data may be hardly comparable with other available datasets, due to the peculiar architectural features of each real-scale building, such as surface to volume ratio, stratigraphy of walls, transparent to opaque surface ratio etc. Thirdly, it is usually difficult to obtain the high levels of instrumentation and control necessary for accurate determination of performance, due to several reasons such as the costs of the instrumentation, the presence of occupants, the characteristics of the heating/cooling system etc. [5].

Tests made in a controlled laboratory give the chance to accurately control all the most influential parameters, such as ambient temperature, relative humidity and air velocity. Examples of laboratory facilities used for testing building components are hot-box facilities for measuring thermal transmittance (in particular, with reference to standards ISO 8990:1994 [7] and ISO 12567-1:2010 [8]), spectrophotometric testing for optical properties of glazed elements, solar simulators and climatic chambers for testing the output from photovoltaic modules [9]. Laboratory experiments usually set steady-state boundary conditions, or, if at all, pre-defined test sequences. Effects of one or more outdoor weather conditions are sometimes mimicked by means of dynamic schedules (e.g. air temperature, wind speed, solar radiation or driving rain), but never fully reproducing the complex interactions of pure stochastic processes typical of real climate. Furthermore some outdoor conditions are difficult to mimic, such as radiation diffused by the sky and the ground. The control over boundary conditions on both sides of the component may be an advantage when the aim is comparing different components under very similar steady-state or cycling boundary conditions.

Test cells may fill the gap between laboratories and full-scale buildings, since they allow to keep all the necessary indoor conditions under control, while letting outdoor conditions vary as in the real environment. In particular, the interest of this type of experiments is on the interplay of external driving forces, such as external temperature, wind speed and direction, solar direct radiation, radiation diffused by the sky and the ground, external humidity and so on. Occupancy interaction (e.g. window and curtain adjustments, activation of uncontrolled internal heat sources) is excluded, and the HVAC system is fine-tuned in order to control as much as possible the indoor environmental conditions. In particular, it is fundamental to get as close as possible to the hypothesis of perfect air mixing which underpins the models commonly used for the energy balance of the test cell.

Indoor laboratories and test cells are complementary and not antagonist facilities. Although testing under laboratory conditions offers the advantage of being replicable under close-to-identical conditions, the latter ones provide several advantages, such as the possibility to test a component under dynamic, real climatic conditions and in an indoor environment that is rather similar to an actual office space in terms of visual, acoustic and thermo-physical properties and air flow patterns [10]. In addition, test cell experiments can be used to assess the representativeness of laboratory results [11] and to empirically validate modules of building energy simulation tools [12].

Compared to field measurements in real-scale buildings, test cell experiments ensure a higher quality of instrumentation and acquisition systems, and more homogeneous indoor environmental conditions. All the most influencing variables are thus controlled, while climatic conditions are continuously monitored. In addition, the control unit allows to implement specified dynamic test sequences by controlled variations of the indoor environment (e.g. [13,14]). Results obtained through test cell experiments can be beneficial to many target groups, such as designers and manufacturers (to optimise the design and realisation of their products), researchers (to analyse and model the heat transfer phenomena and other physical phenomena occurring under measured boundary conditions) and end-users, who benefit from the optimised performances of products made possible by the tests [13].