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Conception of a new test cell facility for characterizing building envelope components

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Abstract

Outdoor test cells have been extensively used for analyzing the thermo-physical properties of building envelope components under real climate conditions. The paper presents a new test cell facility, under development at the Ecole Spéciale des Travaux Publics, du Bâtiment et de l'Industrie (ESTP Paris) within the framework of a collaboration between the end-use Efficiency Research Group of Politecnico di Milano and ESTP. The facility will allow to obtain reliable estimates of thermal performance indicators of transparent and opaque building elements. A particular care has been taken in the design phase in order to minimize or to accurately evaluate all sources of uncertainty, such as (i) conductive heat losses through the test cell envelope, (ii) time lag of response to transient solar conditions, (iii) levels of airtightness and of resistance to vapour or water penetration..

Key words: test cell, building envelope, experimental test, outdoor facility, guarded hot box

Main subthemes (Tick one item):

☐ Advances in Modeling of Structures (AMS)

☐ Materials for Construction (MFC)

X Innovative Design and Methods in Construction (IDM)

☐ Geotechnics for Environment and Energy (GEE)

1. Introduction

A broad variety of complex building envelope components have entered the building construction market during the last decades [1]. These elements are often characterized by a dynamic response to the outdoor climate and by features which can be adapted to the local climate, to the building use and to the desired architectural aesthetics. Many of these components have been claimed to present high thermal performance while improving occupants' comfort conditions. In this scenario, it is of crucial importance to test and characterize correctly these elements under real dynamic weather conditions, in order to analyse their behaviour and evaluate their effectiveness in improving building performance, by means of existing or ad-hoc performance indicators. Both indoor laboratory and outdoor test cells can be used for the purpose, presenting peculiar differences that make them complementary facilities. The present paper highlights the main features of the test cell under construction at the Ecole Spéciale des Travaux Publics, du Bâtiment et de l'Industrie (ESTP Paris) within the framework of a collaboration between the end-use Efficiency Research Group of Politecnico di Milano and ESTP.

Figure 1. A 3D perspective of the new test cell facility under construction at ESTP (Paris)

2. The Box Office facility

A detailed physical analysis and design activity has been performed by the research team in order to minimize or to accurately evaluate all sources of uncertainty, The design choices have been based on a wide literature review, on interviews to experts in IEA ECBCS Annex 58 (Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements) and

DYNASTEE network and on an intense information exchange with constructors of calorimeters and suppliers of data acquisition systems.

The first issue to address has concerned the control of heat flows through the test cell envelope. Various design approaches have been proposed so far, including:

- Local measurement of heat exchanges: test cells can be provided with a grid of large-area heat-flow meters applied to the internal surfaces of the walls; they enable to measure the heat flows passing through the envelope. This solution has been extensively developed within PASLINK project [2], and has been recently upgraded for the test cell built in Florence and described by Alcamo [3].
- Other test cells - such as the EMPA outdoor facility described by Manz et al. [4]- are surrounded by a thermally-controlled (guard) zone. The air temperature difference between the metering zone and the guard zone must be kept as small as possible in order to minimize heat exchanges between those two zones.

The decision of adopting a guard zone for the test cell at ESTP has been based on the following considerations:

- Guard zones allow to minimize heat losses down to values that cannot be obtained by means of thick insulation layers. This is of particular interest in tests for determining the thermal transmission (U-value) of building components.
- The first method (grid of large-area heat flow meters) presents some potentially critical issues, such as (i) the necessity to periodically calibrate a large number of sensors (ii) the additional complexity introduced by the high number of sensors used (PASLINK test cells use about 240 Heat Flux Sensitive Tiles), which entails the risks of sensors' malfunctioning/failures and a greater amount of data needed to calculate the heat balance of the test cell.

Looking at the traditional guarded test cell, with internal dimensions of the metering zone (usually called *test room*) typical of a real office space (e.g. LxWxH = 5m x 3m x 3m) at least two potential problems can be detected:

- The test room presents a high thermal inertia: this has a negative effect on the responsiveness of the system during transient conditions. Before the cooling unit can remove the incoming solar gains, these must heat up the internal surfaces, be transferred to the indoor air by convection, and finally reach the cooling coil;
- The test room presents a large surface area of the envelope compared to the surface area of the test sample. In case of a non-optimal control over the guard zone, the heat losses through the

test room envelope can become non-negligible with respect to the heat losses through the test element;

- It may be difficult to reach a full mixing in the guard zone, and this can result in a non-uniform surface temperature distribution on the external side of the metering zone envelope. Even when the thermostat in the guard zone detects a temperature equal to that of the test room, there may be actually local heat fluxes crossing the two zones, due to local temperature differences into the guarded zone;

The choice of the internal dimensions of the test room is justifiable just in view of having an indoor space that is representative of a real office, but it is not optimal for a calorimetric approach.

In order to address these issues, the first step in the design process of the Box Office facility has been the decoupling of Indoor Environmental Quality (IEQ) tests from calorimetric tests.
This has led to a configuration by which the calorimetric tests are carried out in a dedicated metering box, while the IEQ tests are carried out in a room. A scheme of both configurations for the operation of the test cell is presented in Figure 2.

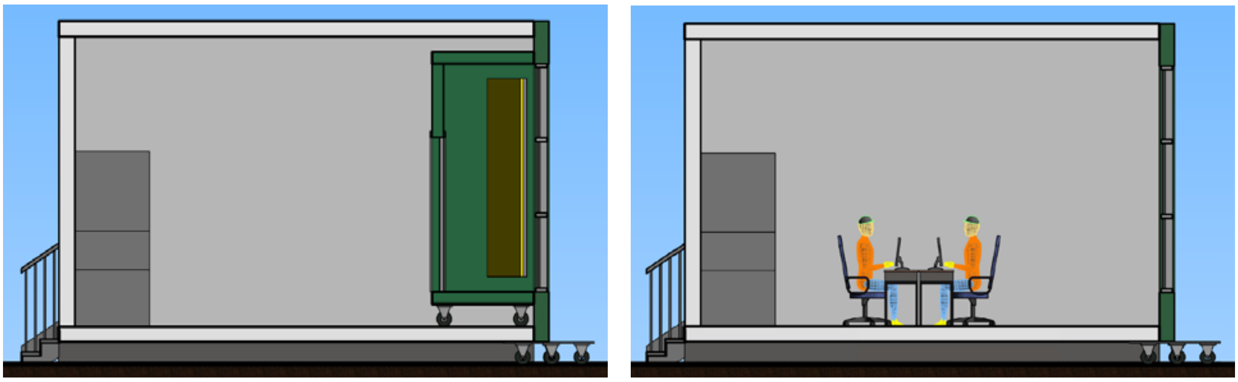

Figure 2. On the left: configuration used for the calorimetric tests: the test sample is applied on the aperture of the metering box, while the guard zone closely follows the air temperature in the box. On the right: configuration adopted for Indoor Environmental Quality tests, having removed the metering box.

Compared to the traditional guarded test cell, the suggested solution presents the following advantages:

1) Response time – the small volume of air and the small surface area (and mass) of the box walls allows to rapidly control the internal temperature of the box in order to keep the set-point. In addition, a solar absorber has been designed for the purpose. As already mentioned, the response time of the metering zone is a very important feature when the aim is analyzing the solar factor at varying solar incidence angles.

2) Heat loss minimized - Unwanted heat losses are further reduced because the surface ratio between test component (3m x 3m) and the rest of the envelope of the metering zone passes from 20% to 40% (as the depth of the metering zone passes from 500 to 120cm). The reduction of surface area causes a (less than) proportional reduction of potential conductive heat losses (thermal bridges become proportionally more influent).
3) Temperature uniformity on the external sides of the metering box- The guard zone can be easily well-mixed, reducing the risk of surface temperature non-uniformity on the external side of the metering box;
4) airtightness **–** the small dimensions of the metering box and the possibility to move the box on wheels when fixing it to the test component give additional guarantees on the airtightness of the system. A tracer gas test before each experimental campaign will determine the airtightness level achieved.

In addition, the possibility to remove the metering box allows to perform tests in the guard zone on thermal and visual comfort and (under certain configurations) ventilation effectiveness. The guard zone presents internal dimensions rather representative of an office room and still offers a good control over environmental conditions (temperature stability will be in a range of ±0,5°C). A photoacoustic gas analyzer can be used to perform tests on contaminant distribution. This type of test can be conducted, for example, when characterizing prefabricated elements including a decentralized ventilation system. The guard zone will be equipped with air and surface temperature sensors according to the methodology proposed by PASLINK [5] and COMPASS projects [6].
In this case, the guard zone will *not* be used following a calorimetric approach.

3. Future steps

The test cell is now under development and will be installed and calibrated at ESTP by autumn 2015. Candidate technologies for the next experimental campaigns include pre-fabricated façade elements for new buildings and retrofits, integrating for example active elements (such as photovoltaic and concentration photovoltaics modules or solar thermal collectors) or decentralized mechanical ventilation systems with heat recovery. Other likely candidates are advanced glazing systems presenting thermochromic, thermotropic or electrochromic properties and highly insulating layers such as aerogels and Vacuum Insulated Panels. The dynamic behaviour of materials such as air-permeable concrete and organic/inorganic Phase Change Materials, and the cooling properties of highly reflective coatings could also be tested under real solar radiation and wind conditions.

The output of test cell experiments will be beneficial to various target groups, such as designers and manufacturers (to boost the research and development of new products), research centres (to fully understand and model the physical phenomena occurring in a controlled space facing real outdoor conditions) and potential clients, who ask for relatively inexpensive solutions guaranteeing high levels of Indoor Environmental Quality.

4. References

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