A new test rig for the assessment of building envelope components integrating solar active systems

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Abstract

In the last few years, the interest in building envelope components integrating active solar systems has been increasingly spreading. Starting off from the concept of the hot-box, and according to the standards UNI 8990 [1] and UNI ISO 12567-1 [2], EURAC designed a novel test rig for the assessment of advanced building envelope systems, in order to measure the actual performance of both passive and active elements. At the writing of this paper, the laboratory is in the realization phase and it will be fully operative in late autumn 2010. The main objective of the test rig is to investigate to give support for the development of multi-functional building components. This is achieved in sight of so called "Net Zero Energy Building". The test rig will allow development of components having better passive and active control of energy fluxes. Hence, such developments will increase energy efficiency of the envelope and, therefore, the whole building. The development of the test rig comprise many challenges discussed in this paper as well as technical challenges for defining arrangements for both standard and research experimental campaigns, in steady-state and dynamic conditions.

1. Introduction

The 2010/31/EU [3] directive on the energy performance of buildings officially introduces the concept of energy balance towards nearly zero-energy buildings. To achieve such a goal, it is necessary to decrease the energy demand of the buildings as well as to improve the efficiency of the energy systems also integrating RES – Renewable Energy Sources - in the envelope.

Complex and high-performance building envelope components are being developed to answer the new requirements. Multifunctional envelopes and building components integrating active solar systems are now the object of several studies from an architectural as well as a physical-technical point of view. International and local R&D projects such as IEA ECBCS Annex 50 [4], TES Energy Façade [5], Multifunctional Plug&Play Façade [6] and FP7 Cost-Effective [7], pursue such aim conceiving and developing solutions both for existing and new buildings. From the building physic's point of view, experimentation of building quality implies the study of the thermal and energy performances of envelope components in order to very well know the heat, light, moisture etc. interaction between the indoor and outdoor space. Moreover the European legislation requires to quantify these properties. Therefore, there is a growing need for suitable advanced experimental arrangements to analyze these advanced building components.

In the last thirty years, the main European research institutes have been setting-up laboratories and test facilities able to carry out tests to measure the thermal properties of building components. In Italy, ITC-CNR (Construction technologies Institute of the National Research Council) carries out several and different analyses on building elements and materials, e.g. tests for the thermal transmittance evaluation using a standard guarded hot-box. In Europe, there are other institutes equipped with a hot-box unit such as research institutes Fraunhofer ISE in Freiburg and EMPA - Building Technologies Laboratory in Switzerland or certification institutes as IFT in Rosenheim (D) . IFT is equipped with several hot-box and carries out test for the certification of products for manufacturers of windows, curtain walls, glass, industrial and commercial doors and accessories. The last test facility was set-up in 2008 by the Construction Quality Control Laboratory of the Basque Government in Spain [8, 9] The interest of these research institutes in developing innovative technologies in the building field is growing, especially towards a research activity aimed at the development of components integrating solar elements [10].

There is a need to go one step further in developing a new approach for laboratories analysis, also coupling theoretical models and simulations, in order to experiment innovative building elements. The availability of simulation tools (numerical software) that day by day increase their accuracy and robustness, allows to analyse the theoretical behaviour of building façade components and to better understand the physics of the problem [11], even if there is still a lack of test rig for the direct performances assessment.

Starting off from the classic hot-box concept, and according to the in-force standards UNI 8990 and UNI ISO 12567-1, EURAC designed a new kind of test bench for the assessment of complex building envelopes and novel emerging products which on the one hand decrease building energy demands and on the other hand increase the energy production by using more efficient solar technologies.

2. Methodology approach of the design phase

From the original idea through the executive design of the test facility and to its realization, the work lasted for about a year. During this period, we studied the methods from the European [1], [2] and American [12] standards that describe equipments and procedures to evaluate the thermal properties of windows and opaque walls in steady-state conditions, using the calibrated or guarded hotbox. On the base of standards, a pre-dimensioning of the hot-box was done to understand the thermal and energy balance among chambers. The outwards thermal losses (those from the metering chamber to the cold one and losses through the edges) were analysed in correspondence to the material and geometric discontinuity, as well as the insulation properties and internal air flows. In addition methodological approaches coupling simulation on theoretical models to experimental tests have been investigated as references [8, 9]. Furthermore, the test methods for solar thermal collector assessment [13] and the requirements for solar simulator [14] were studied.

The achieved background of knowledge helped in planning and designing the test facility, however it has been quite a challenging work, as it represents an integration of different standards and laboratory experiences of several research teams. The overall laboratory includes the guarded hot-box, a hydraulic circuit to manage assessing and supplying of thermal active components and a sun simulator. If the tested specimen integrates solar thermal collectors, their performances can be evaluated using together the sun simulator and the hydraulic circuit. The latter allows also to supply hot water to heating units such as possible radiant panels integrated within an envelope component.

The test rig has been designed also to carry out dynamic analyses able to assess the dynamic parameters foreseen in the energy legislation and in the standard UNI EN ISO13786: 2008 [17].

A section of the guarded hot box is shown in ‘Fig.1’.

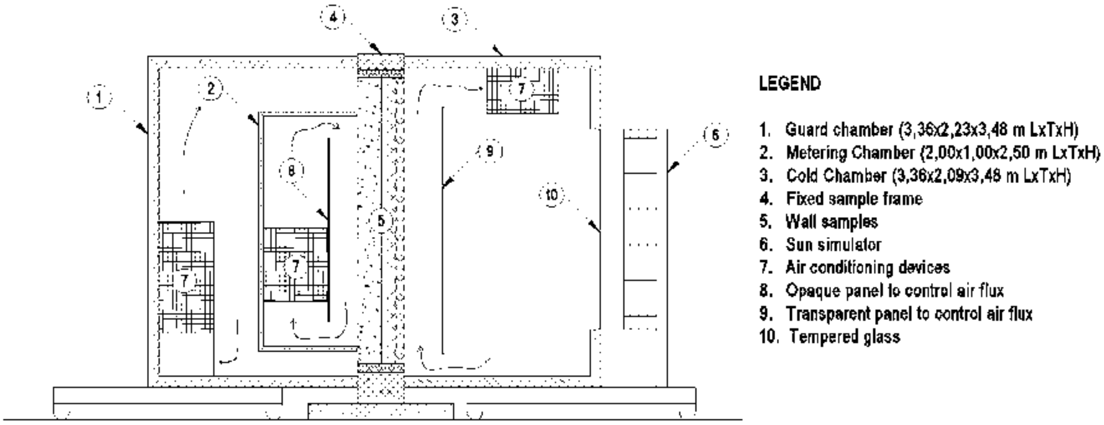

Fig. 1. Section of the guard hotbox .

3. The guarded hot-box

The guarded hot-box consists of three climatic chambers: the cold chamber emulates the outdoor environment, while the metering one emulates the indoor environment. The metering chamber is surrounded by a guard chamber held at a the same temperature of the metering one with a maximum difference of ±0.2°C in order to minimize the thermal flux between them. The temperature within the metering chamber is controlled by a refined power regulator. The cold chamber covers a temperature range of -20 °C to 40 °C, while the metering chamber covers a temperature range of 18°C to 40°C, with a temperature fluctuation in time less than ±0.1 °C. The chamber also allows to simulate the ventilation occurring on the surface of the tested assembly by means of controlled fans. The forced-air ventilation is vertical, from the roof to the floor in the metering chamber and from the floor to the roof in the cold chamber, along the surface of the specimen on both sides, with a speed range of 0.1 – 10 m/s in the cold chamber and less than 0.3 m/s in the metering one. The velocity fluctuation in time is less than ±0.025 m/s. The guarded hot-box is also provided with a humidity-control system in order to avoid condensation and moisture transport within porous samples that could strongly affect the evaluation of its energy performances. For the cold chamber, the relative humidity range is of 40-80%, while in the metering chamber a dehumidifier is in charge of keeping the percentage under 15%.

The guarded hot-box is able to test several kinds of samples both opaque and complex components. The samples can have a maximum dimension of 3 m x 3 m and a thickness until 50 cm, however the measurements will always be done over an area of 2.42 m x 1.92 m that corresponds to the aperture of the metering chamber.

Inside the cold and the metering chambers, there are foreseen thermocouples type T which measure the temperature of the air and of the specimen surfaces in order to evaluate the thermal performances of the studied wall assembly. Each of these two chambers is also provided with a relative-humidity sensor and an anemometer to control their climatic conditions.

4. The hydraulic circuit and the sun simulator

A hydraulic close test loop together with the artificial sun allow to evaluate the energy efficiency of active solar systems integrated into the envelope and therefore the thermal behaviour of the overall construction component. In this sense, it will be possible to investigate as well as to better understand the interaction between the building passive and active components under steady-state and dynamic conditions both for winter and summer cases. The positive and negative effect on the performances of the different elements (e.g. thermal bridge as well as temperature increasing of the solar cells due to the PV integration) could be studied.

The sun simulator will be set up outside the cold chamber and its irradiation beam will reach the target passing through a transparent aperture on the back side of the cold chamber. This aperture will be open only when the sun simulator will be used, otherwise it will remain closed. he sun simulator allow to irradiate a 3 m² area (1.5x2.0 m) with a maximum irradiance of 1000W/m², that can be dimmed to its 70%.

5. Typology of specimens to test

In the current research, the focus is on the envelope which has high contribution in both reducing energy demand and producing and storing energy. Indeed, the envelope contains firstly passive components (insulation, cladding and shadowing systems) and secondly active components (such as solar thermal collectors, photovoltaic panels, etc.).

One of the next building sector trends will be the development of new materials (PCM,VIP, thin and dynamic insulation, etc.), new technologies (ventilation and energy delivering devices in the façades) and multifunctional and innovative components for the envelope [15, 16]. The thermal and energy evaluation of these components plays a fundamental role in the definition of usable, high quality and competitive products.

The test rig so conceived answer this need. It enables the measurement of the dynamic thermal properties of specimens of conventional building envelope components as walls, windows and doors. Moreover, it allows to carry out tests on ventilated façades, innovative façades integrating active solar systems either thermal (BIST) or photovoltaic (BIPV) and in general on solar technologies for the whole envelope. Envelope components including heating system (dynamic insulation) or mass activation system could also be tested. The measurement equipment will allow to assess all the thermal performance indicators as the g-value and the U-value of the specimen.

According to the standard UNI EN ISO13786: 2008 [17], thermal behaviour of the specimen can be experimented when it is subjected to variable boundary conditions (variable heat flow rate or temperatures). Furthermore, the combined work of the guarded hot-box, the hydraulic circuit and the artificial sun will also allow to evaluate the energy performance of solar thermal collectors when integrated into the envelope. Regarding photovoltaic devices, tests will provide a measure of the temperatures in actual working conditions when integrated in an envelope component. This can later be used to determine the performance of the panel in dedicated test facility (flasher sun simulator), measured in particular temperature conditions and heat exchange.

In the methodology approach foreseen for a complete analysis on the samples, two main aspects will be taken into account: the experimental and the numerical one. The experimental analysis, carried out with the support of the test rig, gives real information about the thermal behaviour of the specimen. Furthermore, the validation of a numerical model of the test rig can be useful in generalizing the results and to have a complete analysis of the sample. In this way, it will be possible to foresee the behaviour of the element considering different dynamic variables and under different weather conditions with varying the equipment parameters (beam irradiation from the artificial sun, temperatures and humidity of the two chambers).

The approach foresees the following steps:

- definition of a numerical model of the test rig with CFD software;
- input of the sample features in the model and simulations;
- definition of the monitoring system and of the boundary conditions under which the test will be carried out;
- carrying out of the tests;
- data post processing and comparison with the model.

This test rig has been conceived as part of wider concept of laboratory, able to answer to many needs and requirements. In fact strong interactions among other test rigs in EURAC are foreseen concerning both passive and active solutions for Net Zero Energy Buildings. The aim is to have an overall methodological approach allowing the technological development of building products and the assessment of their performance both numerically and with physical experiments, both under controlled and real working conditions.

6. Conclusion

The new 2010/31/EU directive on the energy performance of buildings is promoting buildings with a good balance between energy consumed and produced. To achieve such goals, multifunctional and high-performance building envelopes as well as building components integrating active solar systems are being developed. High quality and performance are important key-words in the design phase of a building product. Experiment approaches allow to evaluate the actual thermal and energy performances of such products, both in steady-state and dynamic conditions.

Starting from the hot-box concept, EURAC designed a novel test rig for the assessment of advanced building envelope systems. It represents a technical challenge in test facility field, as it combines different experimental procedures and a new experimental arrangement is defined both for standard and research experimental campaigns. The test rig, consisting in a guarded hot-box, a hydraulic circuit and an artificial sun, is able to measure the actual performance both of passive and active elements. The adopted methodology approach foresees that the experimental analysis on the sample is coupled with a numerical analysis. Once a numerical test rig model is defined, it will be possible to get a complete evaluation of samples and to foresee their behaviours under different climate conditions.

The main objective of this laboratory is to investigate and therefore to give support for the development of multi-functional building components, allowing to increase the envelope and whole building energy efficiency, through a better passive and active control of energy fluxes, towards the so-called "Net Zero Energy Building".

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