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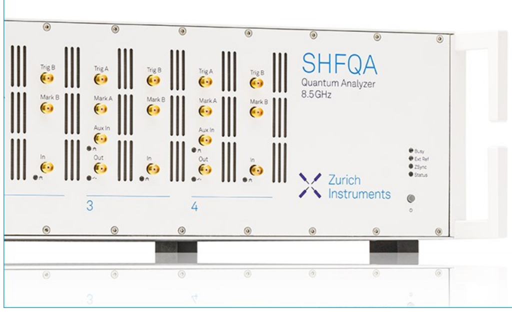

Maison CBET – A Comprehensive Full Scale Test Bench for Comfort and Energy Analysis of Buildings

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Abstract. An innovative test bench has been developed in the framework of the Project CBET – Cross Border Energy Trainings, funded by the Interreg ALCOTRA 2014-2020 Program of the European Union and aimed to increase the educational, training and professional skills on energy efficiency, renewable energy sources and green buildings in the cross-border area between Italy and France. The test bench, called Maison CBET, consists of a transportable standard container modified in a heated, ventilated and air-conditioned habitable office. The opaque and glazed components of the thermal envelope can be easily modified from uninsulated to well insulated, with a wide range of options, as well as shielded against solar radiation. A complete HVAC system is also installed. This is based on electric devices that can be switched on selectively and are powered by separate power lines, continuously monitored by a real time data acquisition system. Weather data and internal comfort parameters are contemporarily monitored. This paper presents a prototype of the test bench that is currently under construction and will be installed in the campus of the Lycée Léonard de Vinci at Antibes, France.

1. INTRODUCTION

CBET – Cross Border Energy Trainings is a project aimed to increase the educational, training and professional skills in the cross-border area between Italy and France [1]. It is one of the projects funded by the Interreg V ALCOTRA 2014-2020 Program of the European Union European for cross-border cooperation between France and Italy [2]. Territorial cooperation is crucial to favor the sustainable development of neighboring territories such as those along the Alpine border between Italy and France and thus achieve a better quality of life. In this regard, CBET is experimenting and activating innovative training actions for young graduates aimed to develop technical skills in the context of energy efficiency, renewable energy sources, and bio-building. The final objective is to create a shared teaching model that enhances the skills acquired during the training actions of the Project.

Among CBET actions, an innovative test bench has been designed, called “Maison d’Essai CBET”, or “Maison CBET”. It consists of a transportable standard container modified in a heated, ventilated and air-conditioned habitable office. The opaque and glazed components of the thermal envelope can be easily modified from uninsulated to well insulated, with a wide range of options, as well as shielded against solar radiation. A complete heating, ventilation and air conditioning (HVAC) system is also installed. This is based on electric devices that can be switched on selectively and are powered by separate power lines, continuously monitored by a real time data acquisition system. Weather data and internal comfort parameters are contemporarily monitored. Indeed, the energy performance of envelope components such as insulation materials [3], glazed elements [4,5] and radiative properties relevant to solar radiation [6] can be separately tested by standard test methods, yet separate performance data may not allow to predict accurately the overall thermal behavior of a building as resulting from the complex interaction of envelope and HVAC system under transient ambient conditions. On the other hand, dynamic simulation models represent a suitable tool to support building design from very preliminary phases, since they allow an accurate prediction of the constructions

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requirements, their environmental performance, and indoor comfort conditions for their occupants [7], nonetheless they require skilled users, accurate input data and proper validation. Therefore, Maison CBET has been developed to provide a realistic and easy to implement training system that can allow to “touch by hand” the effects, in terms of energy needs and thermal comfort, of a wide and comprehensive range of design choices.

Entering into details, the thermal envelope of Maison CBET includes door and windows that can be easily modified from uninsulated single pane to insulated double or triple pane glazing, and from standard glass to selective glazing with also venetian solar shielding, thanks to a multiple-sash architecture. Moreover, cavities are built internally all over the opaque vertical walls and the roof by means of removable panels, so that thermal insulation can be changed from absent to a wide range of insulation materials installed in the cavities. The roof covering is black coated externally to allow absorption of solar gains, yet it can be shielded by a white sliding curtain that allows simulating the effects of installation of a solar reflective cool roofs. The HVAC system consists of single flow ventilation or double-flow ventilation with heat recovery, electric heating that can range from floor heating panels to mono-block heat pump, and air conditioning. Each device for HVAC and lighting is powered by a separate power line, and each power line is continuously monitored by a real time data acquisition system. Weather data are measured by a weather station, whereas internal comfort is monitored by a wet bulb globe temperature (WBGT) probe. Moreover, a complete 1 kWp photovoltaic system can be installed on top of the roof.

A prototype of Maison CBET is being built, to be installed in the campus of the Lycée Léonard de Vinci at Antibes, France. Its design and working principles are analyzed in this paper.

2. THERMAL ENVELOPE

The prototype of Maison CBET that is currently under construction consists of a transportable 20’ standard container with door and window glazed elements carved in the metal wallboards (Fig. 1). The use of a container is justified by the need of transporting the test bench from the production site to the first use place, and from that to any other place.

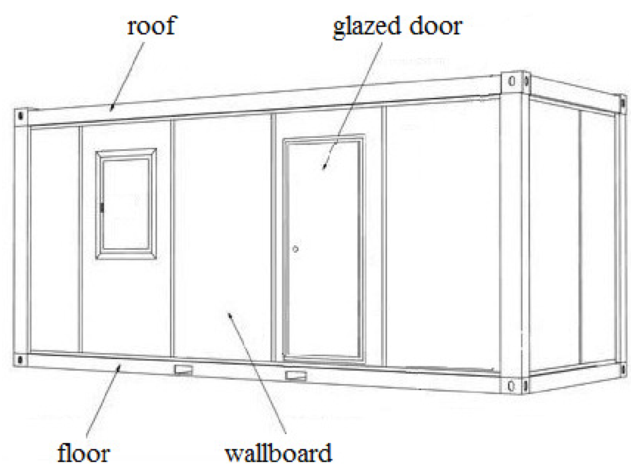

FIGURE 1. Sketch of a habitable standard container with glazed elements.

Cavities are built internally all over the opaque vertical walls and the roof by means of removable panels separated from the external metal wallboards by wooden joists, so that the thermal insulation can be changed from practically absent to a wide range of insulation materials installed in the cavities. Only the floor is permanently insulated with glass wool. The cavity thickness is 100 mm, so that the worst thermal transmittance value (U-value) calculated according to ISO 6946 [8] for empty cavity and winter conditions is around 3.0 W(m^2K) for the roof, and around 2.7 W(m^2K) for the vertical walls. The thermal transmittance can be easily lowered to 0.5 W(m^2K) or less by filling the cavities with panels or wraps of common insulation materials such as glass wool, Rockwool, wood wool, polystyrene, polyurethane, etc.

Glazed elements are installed in the vertical walls. For the prototype, two glazed doors with size 210 cm x 80 cm are installed on one of the two longest walls, intended to face south, whereas a smaller glazed window with size 60 cm x 60 cm is installed in the mid of the opposite wall, *i.e.* facing north, in order to possibly enable natural ventilation. The architecture of the glazed elements can be quickly and effortlessly modified from uninsulated single pane to insulated double pane glazing, and from standard glass to selective glazing with also venetian solar shielding, thanks to a multiple-sash architecture (Fig. 2).

FIGURE 2. Multiple-sash glazed element with venetian blind [9].

TABLE 1. U-value and g-value options for a multiple sash glazed elements.

Single-pane sash	Double-pane sash	Venetian blind	U-value $(W/(m^2K))$	g-value
Closed	Open	Open	5.0	0.85
Open	Closed	Open	1.1-1.5	0.67
Closed	Closed	Open	0.7-1.1	0.50
Closed	Open	Closed	5.0	<0.10
Open	Closed	Closed	1.1-1.5	<0.10
Closed	Closed	Closed	0.7-1.1	<0.10

The glazed element architecture allows a wide range of combinations, summarized in Tab. 1, for the thermal transmittance (U-value), estimated according to ISO 10077-1 [10], and for the solar gain factor (G-value), estimated according to ISO 52022-1 [11]. Further combinations can be obtained by applying a solar-control film (*e.g.* [12]) onto the glass of the single-pane sash, whose g-value can be made as low as 0.35 or even less.

The roof covering is black coated externally to allow absorption of solar gains. A solar reflectance below 10% is thus obtained, that is a solar absorptance in excess of 90%. Such a dark roof causes a strong absorption of solar radiation, which may be positive in terms of energy need for winter heating (yet the benefit is poor, especially if the roof is well insulated [13]), but it is highly negative with regard to summer cooling, especially with a roof structure having low thermal inertia. Moreover, the hot ceiling causes a high radiant temperature in the inhabited space and the radiant asymmetry known as the “hot-head effect”, which are highly detrimental of thermal comfort. A cool roof, that is a roof surface with high solar reflectance (in excess of 79-80%), can effectively counter the effects of solar radiation. The “cool-roof” behavior is obtained by shielding the roof surface by means of a white sliding curtain (Fig. 3), similar to those used to shield vacuum solar collectors in summer.

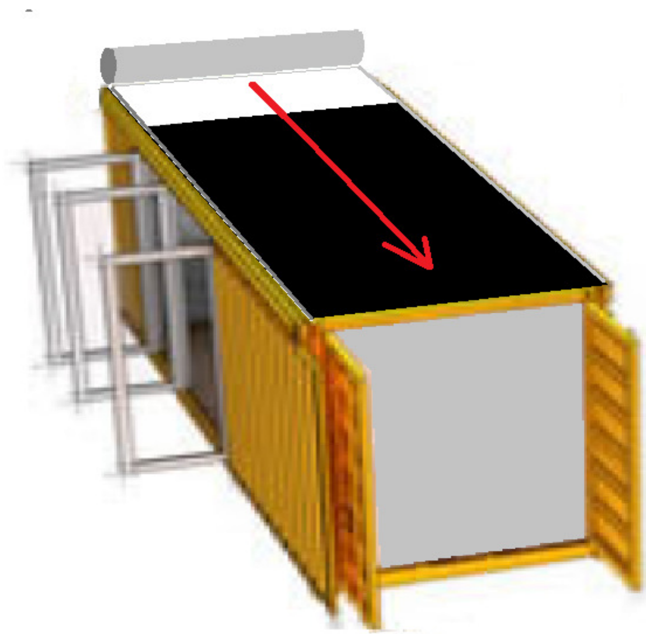

FIGURE 3. Dark roof with sliding white curtain.

3. HVAC SYSTEM

Maison CBET is provided with an autonomous electric system that can be easily connected to a standard grid plug. For sake of simplicity and safety, all devices of the HVAC system are electric. The components of the HVAC system, which includes single flow ventilation, or double-flow ventilation with heat recovery, winter heating that can range from floor heating panels to mono-block heat pump, and air conditioning, are listed in Tab. 2. Each device and lighting are powered by a separate power line, and each power line is continuously monitored by a real time data acquisition system.

Weather data are measured by a weather station monitoring outdoor and indoor temperatures, humidity, wind velocity, total solar irradiance. Internal comfort is monitored by a wet bulb globe temperature (WBGT) probe. Finally, installation of a complete 1 kWp photovoltaic system on top of the roof is planned.

TABLE 2. Devices and functions of the monitoring system and the HVAC system.

Component	Cold season	Hot season	Other
Power metering system			continuous monitoring
Lighting system			lighting
Extractor fan			ventilation (single flow)
Ventilation fan	heat recovery	heat recovery	ventilation (dual flow)
Floor heating panel	heating		
Electric fan forced heater	heating		
Mono-block heat pump	heating	cooling	dehumidification
Weather station			ambient data monitoring
WBGT probe			comfort monitoring
PV system (1kWp)			power generation

4. CONCLUSIVE REMARKS

A prototype of Maison CBET is under construction. Its completion and transfer to the installation site are planned by Autumn 2020. Generally speaking, an affordable system has been designed, with production cost lower than 40 k€ inclusive of VAT and shipping. The built prototype will provide a formidable test bench for training of designers and technicians, validation of models the simulate the thermal behavior of buildings, experimental analysis of advanced materials, devices and control strategies for energy efficiency and thermal comfort of buildings.

Next step, a complete information system for real-time and/or remote control and monitoring of Maison CBET will be developed, in order to set up a smart and easy to use system.

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