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Experimental set-up for testing active and passive systems for energy savings in buildings – Lessons learnt

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ABSTRACT

This paper describes a building prototype experimental set-up used for testing active and passive systems for energy savings, presenting the used methodology, reviewing the main experimental results and identifying limitations. The test facility is located in Puigverd de Lleida (Spain) and has been experimentally evaluating different materials, technologies and systems which might be integrated in building design to provide energy savings for space heating and cooling since 2002. The research fields of passive technologies covered the effect of using different insulating materials, construction systems based on sustainable materials, addition of phase change materials in building envelopes and green infrastructures such as green roofs and walls. On the other hand, the active systems tested were focused in exploiting different available renewable energy source available, such a solar thermal, free-cooling with night air, or geothermal heat, using thermal energy storage systems to shift the heating and cooling loads.

1. Introduction

The high energy consumption of the building sector has been identified as a key issue in the worldwide energy scenario and has modified important energy policies and legislations [1]. These new policies restrict the use of primary energy sources for heating and cooling and stimulate the use of renewable energies in the sector, which supposes an important challenge for architects and engineers all over the world. Within this context the research and innovation are crucial to introduce new technologies in the building sector [2].

Numerical simulation based on Building Energy Simulation Tools (BEST), such as Energy Plus or TAS, which are commonly used during the design phase of buildings, are also used to investigate the performance of different construction systems, technologies or building materials [3,4]. In addition, experimental measurements at lab scale have been widely used to characterize the thermal resistance [5] sound insulation [6] or fire resistance and mechanical properties [7] of different new materials. Moreover, testing at lab scale has been also used to analyse the thermal performance of different systems [8,9].

Nevertheless, experimental measurements under real environmental conditions are required not only to validate numerical models but to convince the building sector in applying and using the new developed technologies. In this sense, some researchers have implemented their systems in already existing buildings to demonstrate their performance [10,11]. This experimental approach provides important and useful information since it tests the developed new materials, systems and technologies when are included in real building application. However, it is usually difficult to evaluate the effect of the new installed technology in detail and distinguish the specific contribution of the new installed technology from the whole performance of the building. Moreover, the required cost investment for this experimental approach is usually very high and unaffordable during the testing phase of the technologies, especially for those with a technology readiness level (TRL) [12] below 8.

In this context, experimental building prototypes have become popular to test and compare the performance of materials and systems under real conditions, without the high costs associated with experimentation using real buildings, and the ability of isolating the variable or group of variables which are the scope of research. Revel et al. [13] used four building prototypes located in Madrid (Spain) to test the performance of cool coloured ceramic tiles, acrylic paints and bituminous membranes for building envelopes. Mandilaras et al. [14] compared the performance and thermal resistance of a Vacuum Insulation Panels (VIP) against expanded polystyrene (EPS) in a two-storey prototype building located inside the campus of the National Technical University of Athens (Greece).

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Fig. 1. Experimental set-up in Puigverd de Lleida (Spain).

Furthermore, apart from comparison studies, house-like prototypes have been used to study different specific technologies and methodologies. Albatici et al. [15] used a house-like prototype to validate the use of quantitative infrared thermography in evaluating the thermal transmittance in steady state of building envelopes. In addition, Li et al. [16] tested the performance of a solar thermal curtain wall under real conditions and Li et al. [17] demonstrated experimentally the influence of windows films on the overall building energy consumption.

As shown from literature, due to high cost of investment and maintenance, the set-ups containing experimental building prototypes are usually focused on testing specific technologies. An exception to this can be found in the experimental set-up located in Puigverd de Lleida (Spain) (Fig. 1). This set-up contains 22 house-like cubicles and has been testing building passive and active systems since 2002. The experience and lessons learnt during the different experimental campaigns are compiled and presented in this paper. Moreover, several problems and limitations have been found during the different experimental campaigns carried out in the facility, which are identified and addressed.

2. Methodology

2.1. Overview of the experimental set-up

The experimental set-up located in Puigverd de Lleida has been used for testing both active and passive systems for energy savings in buildings under continental-Mediterranean weather conditions, Csa (warm temperate, dry and hot summer) according to Köppen-Geiger climate classification [18]. A sketch of the facility and the distribution of the 22 cubicles are shown in Fig. 2.

Since it has been previously stated, the experimental facility is used for testing different building construction systems, materials and technologies. The facility consists of 16 different single cubicles with same inner dimensions (2.4 m × 2.4 m × 2.4 m), 3 double-height cubicles (2.4 m × 2.4 m × 5.1 m) and 3 double width-cubicles (2.4 m × 5.25 m × 2.4 m). The experimental methodology for testing both active and passive technologies is based on comparative studies. This methodology allows the evaluation of the effect of each technology in the thermal and energy performance of the house-like cubicle in comparison to a reference cubicle, which is built identically as the previous but without the tested technology. Even though all envelopes and some roofs are different, the foundation consists in all cases of a reinforced concrete slab of 3 × 3 m with a gravel drainage layer.

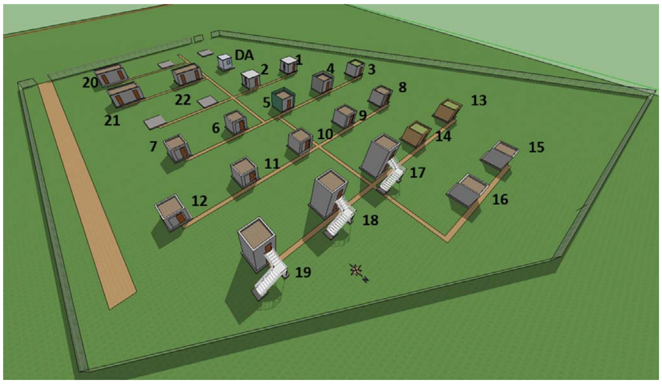

Fig. 2. Lay-out sketch of the experimental set-up.

Four different construction phases over this period have formed the current available facility. During the first construction period, in 2002 and within the European FP6 project MOPCON, two identically shaped house like cubicles (1 and 2 from Fig. 2) were built to test the effect of adding micro-encapsulated phase change material (PCM) into pre-fabricated concrete panels. Hence, according to the comparative methodology, one house-like cubicle was built with conventional concrete and the other one with concrete with microencapsulated Micronal® PCM from BASF. These two cubicles are the only ones in the set-up provided with windows, since it was measured that the effect of direct solar radiation in such small spaces were dominant and difficult the correct evaluation of the different systems.

The second construction period was on 2007, when seven house like cubicles 8–12, 15 and 16 from Fig. 2) were built to test different passive techniques such as the use of different insulations (polyurethane, mineral wool and polystyrene), the use of sensible thermal mass, and the use of macro-encapsulated PCM. Moreover, during the third construction phase in 2009, seven single cubicles 3–7, 13 and 14 from Fig. 2) were built to study the effect of green roofs and vertical greenery systems, the performance of rammed earth construction systems, and to test the use of new developed insulations. In addition, during this construction phase, three double height cubicles 17–19 from Fig. 2) were built to test a ventilated double skin facade and an active slab with PCM (within the national project MECLIDE and followed up in IN-PHASE), and two double width cubicles (20 and 21 from Fig. 2) which were used to test the incorporation of shape stabilized PCM layer with thermal and acoustic properties (within the project RESCONFORT and followed up in the European FP7 project REWASTEE). Finally, the fourth construction phase incorporated to the facility a double width cubicle (22 from Fig. 2) used to test a radiant wall coupled to a geothermal system

The dimensions and shape of the cubicles were selected to maximize the effect of the envelope in the performance of the building, and follows the compromise between being able to test the technologies under a realistic building scenario, and reduce as much as possible the costs related to the construction and dismantling of the building prototypes. Moreover, the orientation of all cubicles is North-South, with insulated doors and condenser units from heat pumps always facing north. Moreover, a shadow study was performed in order to ensure that all cubicles are tested as isolated building prototypes. In addition, each cubicle is provided with power supply and signal connection connected by underground paths to the data acquisition cubicle (DA from Fig. 2). The data acquisition is based on several data loggers (DL01 from STEP.SL www.stepsl.com) which are connected in parallel and send signal using the RS-485 bus transmission. These devices can read 12 analogic signals (Pt-100, 4–20 mA and 0–20 V) as well as read two digital signals and provide two digital outputs. Finally, a signal converter AC-250 is used to adapt the signal from RS-485 to USB.

In order to analyse the thermal performance of the different tested technologies, data is registered at five minutes interval. Several sensors are installed in each cubicle, which will be detailed in the following sections. Moreover, weather data is registered using two MIDDLETON SOLAR meters SK08 to capture horizontal and vertical global solar radiation, an ELEKTRONIK EE21 probe with a metallic shield to be protected against radiation to measure the outer air and humidity, and