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Passive design strategies and performance of Net Energy Plus Houses

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ABSTRACT

The first step in order to comply with the European Union goals of Near to Zero Energy Buildings is to reduce the energy consumption in buildings. Most of the building consumption is related to the use of active systems to maintain the interior comfort. Passive design strategies contribute to improve the interior comfort conditions, increasing the energy efficiency in buildings and reducing their energy consumption. In this work, an analysis of the passive strategies used in Net Energy Plus Houses has been made. The participating houses of the Solar Decathlon Europe 2012 competition were used as case studies. The passive design strategies of these houses were compared with the annual simulations, and the competition monitored data, especially during the Passive Monitored Period. The analysis included the thermal properties of the building envelope, geometric parameters, ratios and others passive solutions such as Thermal Energy Storage systems, evaporative cooling, night ventilation, solar gains and night sky radiation cooling. The results reflect the impact of passive design strategies on the houses' comfort and efficiency, as well as their influence in helping to achieve the Zero Energy Buildings category.

1. Introduction

The Energy Performance of Buildings Directive (EPBD) [1], published in 2002, constitutes a significant step of the European Union to maintain competitiveness, security of energy supply and meet the commitments on climate change made under the Kyoto protocol. This directive emphasizes two main aspects: the reduction of the energy consumption and the improvement of the energy efficiency in buildings. The recast EPBD was adopted eight years later [2], introduce new requirements related to the Zero Energy Building (ZEB), for both existing and new construction. This directive settles the necessity to develop Near to Zero Energy Buildings (Near to ZEB). Buildings must increase their energy efficiency and generate energy to compensate their consumption. In this directive, Near to ZEB is defined as a building that has very high energy performance, and the nearly zero or very low amount of energy required is covered to a very significant extent by energy from renewable sources, produced on-site or nearby. This is a definition with several undefined terms, accompanied by phrases as nearly, very high, very low and very significant. It is not determinate how near to zero is enough to be considered Near to ZEB. Additionally, there are other imprecise items in the directive as the balance period, the balance boundary, the balancing method and energy weighting factors. Several researchers are working on clarifying and harmonizing the existing definitions, and proposing energy balance methods [3–6].

Despite the indefiniteness in the recast EPBD, this directive emphasizes fundamental aspects of the ZEB. One of them is that these buildings must have high energy performance. The first EPBD indicates that, to achieve high energy performance, it is necessary to reduce consumption and increase the efficiency of buildings' systems and services. Most of the energy consumption in buildings is related to protection from the external climate, and the need to use mechanical systems to maintain a comfortable indoor environment [7]. Therefore, the passive design strategies are a significant key to achieve the goals of the both EPBD. Passive strategies may help to increase the interior comfort, reducing the need of active HVAC systems.

Solar Decathlon Europe (SDE) is a biennial international competition based on the American Solar Decathlon competition organized by the U.S. Department of Energy (DOE). The SDE was created through an agreement signed between the governments of Spain and United States. These competitions challenge university students from all over the world to design, build and operate

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sustainable Zero Energy houses [8]. Since the SDE houses are grid connected, upon verifying that they comply with the ZEB requirement, they can be termed Net ZEB. In relation with Net ZEB, Voss et al. [9,10] remark that this term is commonly used to describe the synergy between energy efficiency buildings and the renewable energy utilization to get an energy balance over an annual cycle.

During the final phase of the SDE competition, each participating team assembles its house in Madrid at the competition site, named as '*Villa Solar*'. There, the houses performance is continuously monitored while undergoing the ten consisting contests of the competition. There are two types of contests: juried contest, evaluated by a multidisciplinary jury, and measured contests, evaluated by means of measurements in real time [11].

SDE rules promote the implementation of passive strategies as a way to reduce building energy consumption and increase their efficiency [12,13]. From the preliminary house design, the participating teams must describe the passive solutions that they plan to use. The teams must carry out energy simulation on their houses in each phase of the project. With these simulations, they can verify the effectiveness of theirs design strategies. The houses passive behavior plays a decisive role in the competition since to succeed they must operate with low energy consumption. The use of passive solutions contributes to earn points in both monitored and juried contests. Proper selection of passive strategies has a direct influence on the results of two monitored contests: comfort conditions and energy balance. While the houses were in the '*Villa Solar*', the effectiveness of theirs passive design solutions, at least for weather conditions on those days, was evaluated by the SDE monitoring system [14]. Additionally, passive design strategies are taking into account by most of the juries: architecture, engineering, energy efficiency, sustainability and market viability.

The comfort conditions contest includes several sub-contests. The present analysis only included those that require energy consumption: interior temperatures, relative humidity, air quality and lighting level. The comfort conditions scoring stopped during the public visits, and started, again, 1 h after finished these periods. For dry bulb temperature monitoring, there were two sensors in each house, installed in poles at 150 cm from the finishing floor level. One was placed at the center of the living room and the other in the bedroom. In the temperature sub-contest, Teams earned points when the interior temperature was between 20 and 28 °C, and it is necessary maintain the interior temperature between 23 °C and 25 °C to obtain all available points. Humidity sensors were located next to the temperature ones. Teams earned points maintaining the relative humidity between 25 and 60%, and all available points were earned when the relative humidity level was between 40 and 55%. An air quality sensor was located on the same pole as the temperature sensor, and all available points are earned by keeping the CO_2 content in the air below 800 ppm. Also, a photometer was placed in the house workplace, and the light intensity of the area was measured following the competition schedule. Points were earned if the light level is maintained over 300 lx.

In the SDE 2012 competition, even greater stress was laid on the use of passive design solutions. The rules included for the first time the Passive Monitored Period [13]. This period consisted of 56 h, in which nothing in terms of monitoring or scoring changed, but the teams were able to use only passive systems or strategies to maintain the interior comfort. For the purposes of the competition, "passive" means any strategy or system that does not rely on thermodynamics cycles [15] or on devices designed to produce heat or cold.

The objective of the present work is to analyze the passive strategies as a help to achieve the goals of European Directives related with the ZEB, using the SDE 2012 houses were selected as case studies. The analysis is focused on how the passive design strategies may increase the interior comfort and contribute to the reduction energy consumption in buildings, and not include the study of the houses' energy production systems. It is organized as follows: Section 2 presents the passive strategies that help to achieve the Net Energy Plus Buildings. In Section 3, the Madrid city climate, building code requirements and appropriated strategies are explained. The analysis of the SDE 2012 houses' passive strategies is presented in Section 4. Section 5 focuses on the thermal and energy performance of the participating houses. Finally, conclusions are expounded in Section 6.

2. Passive strategies and the Net Energy Plus Houses

Recast EPBD states that a very high energy performance building can be considered as a Near to ZEB if it meets the following two conditions: require a very low amount of energy and be able to cover a very significant amount of their energy requirements by renewable energy sources, produced on-site or nearby [2]. Very low energy buildings can be achieved through good design practices and the selection of energy efficiency building technologies [16]. The use of high efficiency HVAC, lighting, equipment and appliances, as well as an adequate control system, are effective ways to reduce the energy consumption. However, the potential energy saving through an optimized design process, minimizing the heating and cooling loads, is usually more influential than the use of innovative HVAC solutions [16].

The optimized low-energy building design starts with the understanding of the building use, its interior comfort necessities, as well as the study of the natural and environmental resources available on the building site. Then, passive strategies for comfort must be established, taking advantage of the natural resources available. The passive design includes strategies for hygrothermal comfort, daylighting and air quality conditions. In terms of hygrothermal comfort, the heating period strategies look to optimize direct and indirect solar gains, Thermal Energy Storage and the reduction of heat losses. On the other hand, cooling period strategies include: keeping the heat from building up, removing the built-up heat and reducing the heat-generating sources. Some authors propose, in addition, taking advantage of natural heat sinks [15]. Depending on climatic conditions, adding or reducing the humidity also can be an effective strategy to increase the interior comfort in cooling periods.

An explicative diagram of a "Very high energy performance building" is shown in Fig. 1. Very high energy performance buildings can be Energy Plus Building (PEB), Zero Energy Building (ZEB) or Near to Zero Energy Building (NZEB), depending on the balance between energy demanded and generated. The use of passive strategies is one of the key actions to achieve any ZEB categories since be a "very low energy consumption building" is the first requisite. In the present study analysis of passive strategies was done in five areas: building envelope, orientation and geometrical parameters, other passive solutions and hybrid solutions [17,18].

2.1. Building envelope

Building envelope constitutes the limit between the interior and exterior conditions and its correct selection is one of the most effective ways to minimize the energy consumption related to interior thermal comfort. When the building envelope is conceived as a barrier that protect from the exterior conditions, the thermal transmittance (*U* value) is its most relevant characteristic. Building codes, as well as the voluntary certifications, are becoming more demanding in terms of the thermal transmittance of the envelope. In the literature, there has been some discussion as to whether the high standards of insulation may or may not lead to increased loads in summer. However, this can only be true if the average exterior