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# Comparison of numerical and experimental performances of nZEB residential building in Putignano (Apulia Region)

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**Abstract.** The sustainability of the European Regions, in terms of society and economy and environment, is strongly based on renewable energy and resource efficiency. This implies the large scale deployment of nearly Zero – Energy Buildings (nZEBs). As well as the technology is already available and proven. However the diffusion of nZEB in Mediterranean areas is a challenge for the local market actors considering the short time. In this direction our research is oriented, proposing the case study of the first passive building in Putignano (Apulia). The goal is to observe the impact of the comfort setting on energy demand during the everyday life. This new approach aims at simultaneously considering both the energy performance and the comfort and health of the inhabitants. The case study includes the simulation model and the measuring campaign. It aims to verify if occupants of nZEB will be aware of the qualities of their home and learn to manage and monitor energy consumption independently. The concept is to observe the impact of comfort setting on energy demand during the everyday life in heating season of the passivhaus tenants.

## 1. Introduction

The International Energy Agency (IEA Market Report 2018) reported that in 2017 the energy use in the building sector continues to go up, but without energy efficiency improvements since 2000, energy use would been 12% higher [1]. The EPBD Directive (Directive 2002/91/CE) and its successive recast, Directive 2010/31/UE, introducing the nearly Zero Energy Building standard for all new constructions in 2020, has been a good driver to achieve this target. Nowadays the new EPBD Directive 2018/844/EU [2], introduces new targets to go towards a low and zero emission building stock, and demands to decarbonise the building stock, which is responsible for approximately 36 % of all $CO_2$ emissions in the Union, by 2050. This new approach aims at simultaneously considering both the energy performance and the comfort and health of the inhabitants. It means that occupants of nZEB will be aware of the qualities of their home and learn to manage and monitor energy consumption independently. It is a great challenge especially for Southern Europe Countries that are less prepared than Northern Europe ones in putting into effect the actions required to implement the nZEB standards at large scale [3]. As well as the technology is already available and proven; however the diffusion of nZEB in Mediterranean areas is a challenge for the local market actors considering the short time. In addition the Mediterranean climate provides a high potential to exploit passive strategies for building design [4]. Starting from these considerations, the work aims to collect useful data for evaluating the energy performance of the first passive building in Putignano (Apulia) and for evaluating the comfort and awareness of its inhabitants. The concept is to observe the impact of comfort setting on energy demand during the everyday life in heating season of the passivhaus tenants. Moreover, energy simulation was performed to compare experimental data with numerical data of the model elaborated during the construction. The results will contribute to cover the lack of research examining the impact of comfort setting on energy demand in warm climates, specifically, this impact has not been studied for nZEB [5].

In this direction, the work contributed to the National nZEB Observatory paving the way to the creation of the Regional nZEB Observatory. In 2017, ENEA launched a national nZEB Observatory that allowed statistics on number and type of nZEBs, information on regional policies, public and private initiatives for information and training and the state of research in the sector. Despite the still limited number, there is a rapid increase in nZEBs, also due to the even more stringent obligations imposed in advance with respect to the deadlines of 2019 and 2021.

## 2. Case study building

The building is the first residential Passivhaus building in Apulia region, a building of three levels and eight apartments. The building has been occupied since June 2018. The building envelope, designed in full compliance with the Passivhaus criteria, provides for insulation a coat by a thick layer of insulating material. In addition to wrapping in a manner as continuous as possible the perimeter walls, it also insulate the intermediate floors and walls facing unheated spaces, such as stairwells and garages, in order to reduce energy losses. Two different insulating materials were used:

- Expanded Polystyrene, for external vertical walls, for vertical walls facing the stairwell and for the insulation of thermal bridges;
- Rock wool, for intermediate floors, horizontal envelop components facing outdoor and unheated spaces.

**Figure 1.** Render of the Building (North-East elevation).

The HVAC system consists of a compact solution for heating, cooling, hot water production and mechanical controlled ventilation. The system consists of a Compact P module, by Nilan, a heat pump capable of recovering the heat of the exhaust air flow and to transfer it to both the fresh air flow and the DHW storage. A small air conditioning unit, working as a booster in parallel to the Compact Unit, allow reaching more quickly the comfort parameters, covering at the same time the peak loads. An integrated control system permit the operation of both the units comparing the measured parameters to the required comfort set point. All the operating data are registered on a cloud server to allow the analysis of the main comfort parameters and the monitoring of the function to facilitate any required maintenance or setting activities.

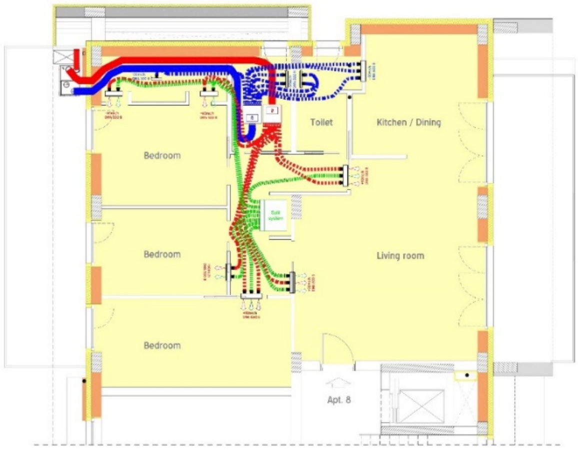

**Figure 2**. Air distribution in the Apartment n. 8.

The compact system consists of a heat pump capable of recovering the extraction air flow heat and transfer it to the renewal air flow and to a DHW tank. In winter conditions, the heat pump is designed in order to partially condensate the refrigerant on the thermal storage tank, so as to dispose the overheating of the refrigerant fluid, and then to complete the condensation on the fresh air flow heat exchanger. The extraction and renewal flows, pass through a recovery heat exchanger with high efficiency, in order to maximize the energy performance of the whole unit.

An integrated management system guarantees a flexible behaviour: the air change rate as well as the fan speed and the desired indoor temperature are fully customizable, furthermore weekly scheduling, warnings and alarms can be set. According to the conditioning of the indoor environment, the Compact unit has four modes of operation, automatically managed by the control system, depending on the internal and external conditions of the building: 1) passive heat recovery; 2) active heat recovery; 3) bypass; 4) active cooling. In the passive heat recovery mode, the exhaust air from the environment through the heat exchanger releases energy to the external air supply. The temperature level of the fresh air at the outlet of the exchanger is already sufficient to meet the needs of the house, for which the compressor will not turn on. During the intermediate seasons, when the indoor temperature is higher than the outside, thanks to the free-cooling mode, it is possible to introduce in the house directly the external fresh air to achieve the comfort conditions in the indoor environment. The unit, by means of its internal 100% by-pass, prevents the passage of fresh air in the passive heat recovery, injecting it directly into the room. The exhaust air, after crossing the recovery, is ejected. In this operation mode the only energy absorptions of the unit is due to the fans, and it amounts to a few tens of Watts.

Finally, a photovoltaic system of 17 panels of 270 Wp each with a total area of approximately 27.03 $m^2$ for a total of 4.6 kWp are installed on the roof, in order to cover the electric energy needs.

**Table 1.** Main data of Apartment 8 according to Italian Decree (DM 26.02.2015) for nZEB.

| | | | |
|---|---|---|---|
| $H'_T$ | 0.27 < 0.58 | $EP_{gl,tot}$ | 26.54 < 52.60 |
| $A_{sol,est}/A_{sup,utile}$ | 0.015 < 0.030 | $\eta_H$ | 2.32 > 0.72 |
| $EP_{H,nd}$ | 7.39 < 16.70 | $\eta_W$ | 0.76 > 0.58 |
| $EP_{C,nd}$ | 30.20 < 33.44 | *PV-prod.* | 66.88% > 50% |

*2.1 Building performance simulation (BPS)*

Building Performance Simulation (BPS) tools can predict interactions between building constructions, HVAC systems, user behaviour and weather conditions, providing a rapid and realistic feedback about the building performance during a selected time step, such as summer and winter season.

A building-plant system model has been created with DesignBuilder software and it has been analysed in detail in order to assess the response of the building to the typical Mediterranean climate. It has been created an extremely detailed model of the building that includes a long series of data, such as:

- Site details: Location, weather data;
- Building model data: Geometric building data; Occupancy (number of people living in the place and the times of occupancy); Home equipment;
- Construction data: Stratigraphy (floors, roofs, windows, walls); Lighting; Airtightness; Thermal bridges;
- Heating/Cooling set point temperatures;
- Minimum Air Exchange Rate;
- HVAC system.

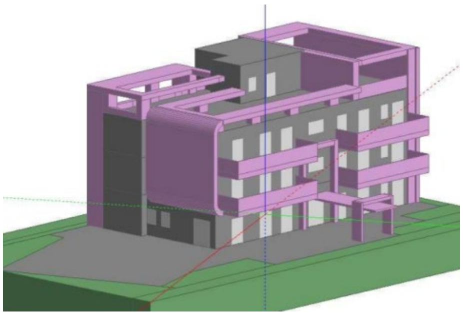

**Figure 3.** DesignBuilder model.

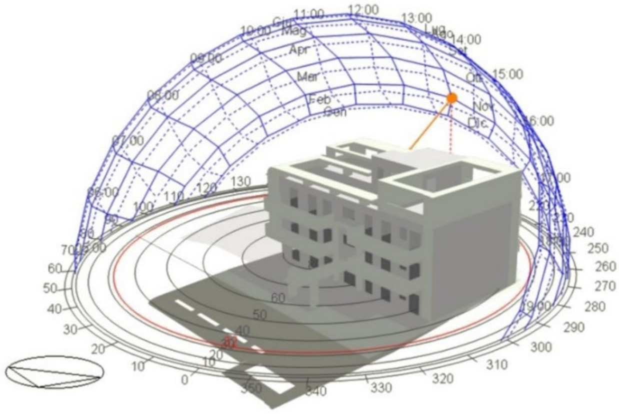

**Figure 4.** Solar study by DesignBuilder

The results collected from the building dynamic simulation phase have been used to predict the risk of overheating during the summer, to assess the adopted design solutions, to predict internal temperatures, air quality and lighting levels and to evaluate heating and cooling demand. The aim was to create a three-dimensional model as faithful to reality in order to estimate how the building-plant system can react to different boundary conditions. The numerical simulation has been able to put in evidence how the building envelop interacts with the HVAC system. In Fig. 5, e.g., is reported the results of DesignBuilder simulation for a summer time (1-6 August). It is evident how the cooling recovery works in order to reduce the cooling needs.

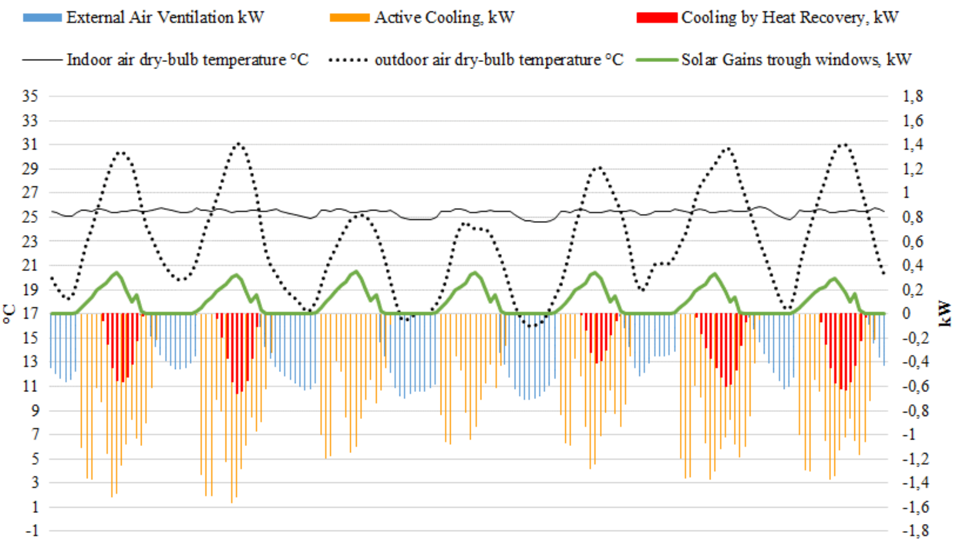


**Figure 5.** DesignBuilder simulation for the period 1-6 August.

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## 3. Experimental data

### *3.1 U-value measurement*

Thermal transmittance (*U*) is an indicator of the building envelope thermal properties and a key parameter for evaluation of heat losses through the building elements. An effective and simple method for determining thermal transmittance is in situ measurement, which is governed by ISO 9869-1: 2014 [7]. Measurements were carried out on the external opaque wall using TESTO 435-2 device. The test duration was 72 hours (3 days). To get a detailed analysis 6 data logs were done per hour. The average *U*-value obtained at the end of the period is 0.131 W/m²K. It does not deviate much from the *U*-value determined by the calculation based on the thermal characteristics of the building elements (*U*=0.128 W/m²K).

### *3.2 Blower-door test*

The early monitoring results show that the building meets the requirement of air tightness. Indeed the low air leakage rates that are required in the Passivhaus standard must be proven by the blower-door test. The air tightness test follows the standard UNI EN 13829: 2002 [8]. The air change rate must be below 0.6 ACH under the test conditions (50 Pa pressure difference between inside and outside). The EN 13829 standard lists two principal test methods, A (test of a building in use) and B (test of the building envelope). The Passive House standard explicitly requires the test be performed to Method A: the condition of the building envelope should represent its condition during the season in which heating or cooling systems are used. In addition, anything that can be closed, may be closed, all other items through the building envelope should be left as they are. The only exceptions to this are Mechanical Ventilation or Air Conditioning systems, which should be sealed off rather than just closed/turned off. The measurement results of the case study building are the following:

- Air change rate at 50 Pa: $n_{50} = \frac{\dot{V}_{50}}{V} = 0.31\ h^{-1}$
- Air permeability at 50 Pa: $q_{50} = \frac{\dot{V}_{50}}{A_E} = 0.421\ \frac{m^3}{hm^2}$

The Passivhaus Institute has introduced a requirement that the $q_{50}$ must also be less than or equal to 0.6 $h^{-1}$. According to Passivhaus Standard, it applies to buildings with a volume greater than 1500 $m^3$.

### *3.3 Data acquisition*

A data acquisition of several parameters is ongoing in situ. Several sensors are embedded in the Compact P module (Water and Air Temperatures, Set-points, Alarms, etc.).

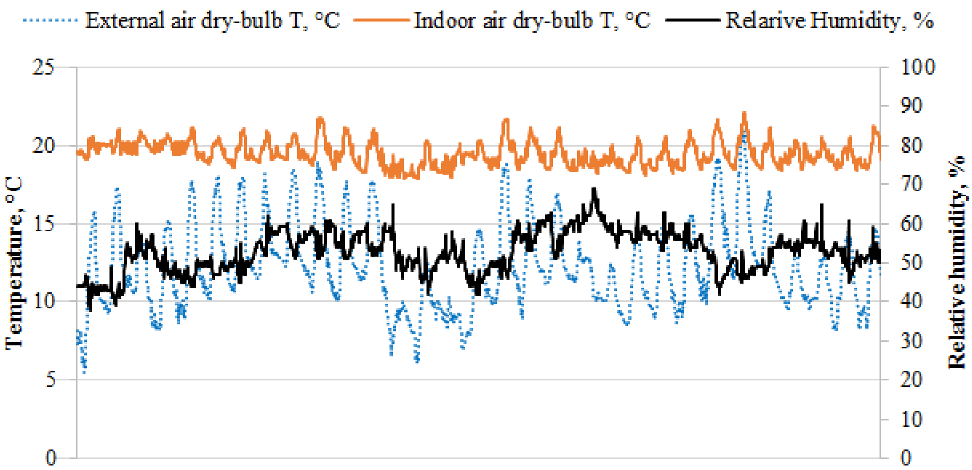


**Figure 6.** Data acquisition for the period 1-30 March 2019.

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In figure 6 are shown values of the Outdoor/Indoor air dry-bulb temperature and relative humidity of indoor air as monitored by the Compact P. It is clear how internal comfort conditions are ensured.

### *3.4 Occupants satisfaction*

An occupant survey was conducted according to the CBE-survey [6], created by the Center for the Built Environment (CBE) at the University of California. The goal of the post-occupancy evaluation is to obtain information about how occupants experience an nZEB dwelling, especially with regard to heating. Occupants perform various actions to satisfy their physical and non-physical needs in buildings. These actions greatly affect indoor climate parameters. In this case, the window opening behaviour is related to the perception of the environment. As confirmed by the survey, the windows are rarely opened in the early hours of the afternoon during the winter season and for a few minutes (less than 5 minutes). The motivation that drives the user is to improve the quality of the indoor air (dust, bad smells) in rooms such as bedrooms and kitchen. Regarding temperature control of the supply air, respondents stated that the temperature level is set to 18-21°C. The results show a generally high level of satisfaction with the temperature conditions and comfort in the apartment and the users are very satisfied with living in an nZEB dwelling.

## 4. Conclusions

The monitoring campaign is a first step of the research, covering the heating season, and it will go on in order to cover the whole year. The early monitoring outcomes show that the building is operating as designed and maintain stable comfort conditions easily managed by the inhabitants. More data will be collected in the next months to validate this assumption. The goal is to contribute with our research to the collection of nZEB data to evaluate possibilities and limitations under Mediterranean climate conditions both in term of energy demand and optimal thermal comfort.

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