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# A nearly Zero Energy Building in Mediterranean climate: a case study in Mesagne (Apulia)

**R Stasi[1], S Paterno[2], A Stragapede[2], S Liuzzi[1], P Stefanizzi[1]**

[1] Department of Civil Engineering and Architecture, Polytechnic University of Bari, Bari, Italy
[2] CFE, Centro di Fisica Edile, Gravina in Puglia (BA), Italy
stefania.liuzzi@poliba.it

**Abstract.** This paper presents the case study of an nZEB building located in the municipality of Mesagne (Apulia, BR). It is a building of 309 m$^2$ of usable floor space with two floors above ground. The building is a proof that a correct integrated design of the HVAC system and the building envelope can easily lead to an nZEB building with high performance in terms of energy consumption and comfort. The external envelope of the building is a structure in tufa blocks plus a mixture of hemp and hydraulic lime plus blocks of hemp and lime. Hemp lime is a mix of renewably sourced hemp shiv, a specially formulated lime binder and water. The air conditioning system is based on a controlled mechanical ventilation with air pre-treatment through an underground tube exchanger. A numerical simulation of the overall building-plant system performance was made with DesignBuilder in order to evaluate the energy consumption for air conditioning and the thermohygrometric comfort in the building. Several simulations were carried out to compare the incidence of different building-plant system on total energy consumptions: one without earth-to-air heat exchanger, one without heat-recovery and recirculation, one without solar shading.

## 1. Introduction

The growing awareness of the outcomes of anthropic action on climate changes, the unquestionable acceptance of the exhaustiveness of fossil sources, the renewed attention to sustainability, the evolution of knowledge and techniques as well as the study and implementation of new materials, are pushing the world of constructions and design towards a renewed environmental sensitivity.

The challenge, therefore, to which building design is subjected, is to solve the dichotomy between the achievement of ever higher levels of comfort and the need to limit the energy consumption and to minimize the environmental impact of buildings. To meet these new requirements, the European Community [1] has directed, with increasingly stringent regulations, the design towards progressively higher standards culminating in the prescription construction of "nearly zero energy" buildings. According to the Global Alliance for Buildings and Construction [2], established on COP21, the growing population and the rapid increase in purchasing power in emerging economies and developing countries could increase energy demand in buildings up to 50% by 2050. In Europe, the construction sector absorbs about 40% of the final energy [3], it is therefore evident that the issue of energy efficiency is increasingly assuming a great importance in the energy policies of European states. In 2007 the well-known "20-20-20 Climate Energy Package" [4, 5] was enacted to ensure that, by 2020, the EU's greenhouse gas emissions should be reduced by 20% compared to 1990 values, 20% of the total energy should come from renewable sources and there should be an increase in energy efficiency of 20%.

Several researches have been carried out to analyse different aspects linked to nZEB buildings. Among them, D'Agostino et al. [6] proposed a study about data on energy consumption and nZEB in Europe and affirmed that in Europe the average primary energy for a single-family house is about 0-50 kWh/m$^2$y. Guillén-Lambea et al. [7]-evaluated the potential of energy recovery for ventilation air in dwellings in the South of Europe showing how, in Mediterranean climate, the use of energy recovery could produce from 20% to 40% energy saving. Ascione et al. [8] studied the performance of earth-to-air heat exchanger (EAHX) for NZEB office in Mediterranean climate, demonstrating that the EAHX could reduce the energy consumption by 29% for heating and by 40% for cooling. Murano et al. [9] evaluated the effect of glazing on nZEB performance and found out that the orientation of windows has a significant impact on the energy performance building. They concluded that it is always a good practice to use a high-performance shading device to reduce the overall energy demand despite it negatively effects on the heating energy behaviour of the building.

This paper studies, by a dynamic simulation of a case study, the global efficiency of these above-mentioned factors combined in an nZEB building.

## 2. The case study

The studied building is a single-family house located in Mesagne, a small town near Brindisi, in South Italy. It was built in 2017 according to the Passive House and nZEB standards.

The residential building develops for 309 m$^2$ on two levels. The first level of 225,71 m$^2$ and the second one of 84,40 m$^2$. From the compositional point of view, the building respect the typical Mediterranean standards and it is conceived as a complex intermingling of simple volumes; four parallelepipeds that fit together, whose fulcrum is the central double-height parallelepiped where the living room is located. It is the central junction of the composition, dividing the living area from the sleeping area at the ground floor and through the vertical connection leads to the upper floor where it is placed a second sleeping area. To the building block are added various terraces in staggered levels used as verandas, patios and outdoor relax areas. The total climatized surface is about 227 m$^2$ for an overall climatized volume of 679 m$^3$. The building is the result of a careful planning linked to the climatic context (table 1) to which it belongs. The typical Mediterranean climate is characterized by hot and humid summers and mild winters. The solar heat gain, especially during the summer, is not negligible and if not carefully analysed, it can make a significant contribution to the analysis of the cooling load.

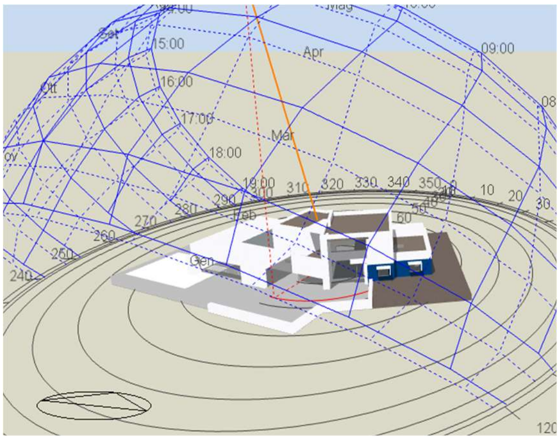

**Figure 1.** Solar study of the Building.

**Table 1.** Main geographic and climatic case study characteristics.

| | Unit | Value |
|---|---|---|
| Latitude | [°] | 40 ° 34'24.76'' N |
| Longitude | [°] | 17 ° 47'29.56'' E |
| Altitude | [m asl] | 60 |
| Climate zone | [-] | C |
| Maximum site outside air dry bulb temp. | [°C] | 36,4 (16th Aug.) |
| Minimum site outside air dry bulb temp. | [°C] | -0,2 (18th Jan.) |
| HDD Heating Degrees Days | [K day] | 900-1400 |
| Maximum direct solar radiation | [W/m$^2$] | 935,73 (25th May) |

The building design is a sum of different strategies aimed at obtaining the less energy consumption according to the nZEB standards. Firstly, it is designed a highly performant envelope with the use of eco-friendly materials; secondly several passive strategies are carried out for the climate control such as a detailed analysis of the best orientation, a complex system of solar shading, a reduced surface to volume ratio and at last it is introduced a high efficiency plant system with air pre-treatment by an underground tube exchanger combined with heat recovery unit.

### *2.1 Orientation and solar gain control*

The specific location of the site is 40 ° 34'24.76'' N and 17 ° 47'29.56'' E and it is located at 60 m a.s.l. The predominant orientation of the building is along the East-West axis with large walls facing South.

This prevailing development, in the Mediterranean climate, makes it possible to guarantee the minimum possible shade on the facades in winter, allowing the incoming of solar radiation. The transparent closures are mostly placed on the southern front. The total south-facing windowed area is 40.98 m$^2$, while the north-facing area is 15.47 m$^2$. To limit the solar gains, in the summer months, on the openings exposed to the south, where the maximum incident radiation in the summer is close to Zenit, horizontal overhangs have been planned. On the East and on the West side, where the greatest solar contributions take place, both in thermal and dazzling form, at early morning and at sunset, vertical overhangs have been provided. A schematization of the solar screen provided to control the summer solar loads is shown in figure 2, a solar study of the biggest south-facing windowed area is exposed on figure 3.

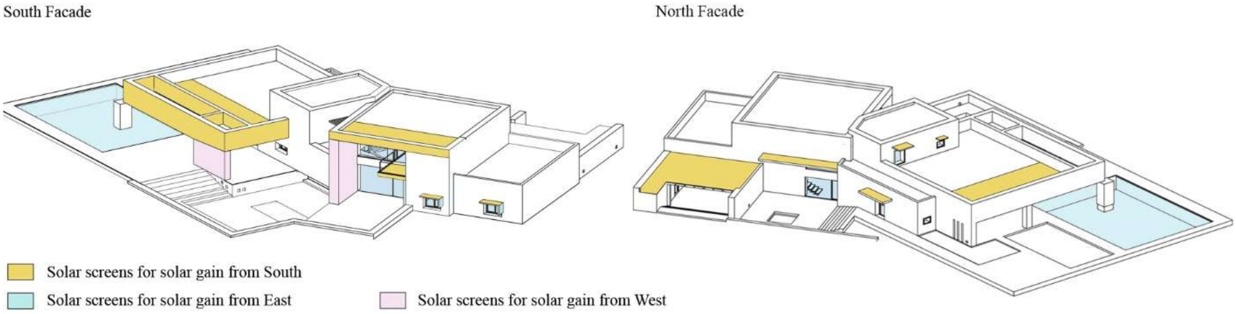

**Figure 2.** Solar screen provided in the case study.

In order to optimize the internal comfort, the layout of the interiors has also been the subject of a careful study. At North, where the building is coldest, filter areas such as bathrooms, storage, entrance and vertical connection have been placed. At South, where in winter it is possible to capture the maximum solar radiation, the most lived-in environments of the house have been inserted such as bedrooms, kitchen and living room.

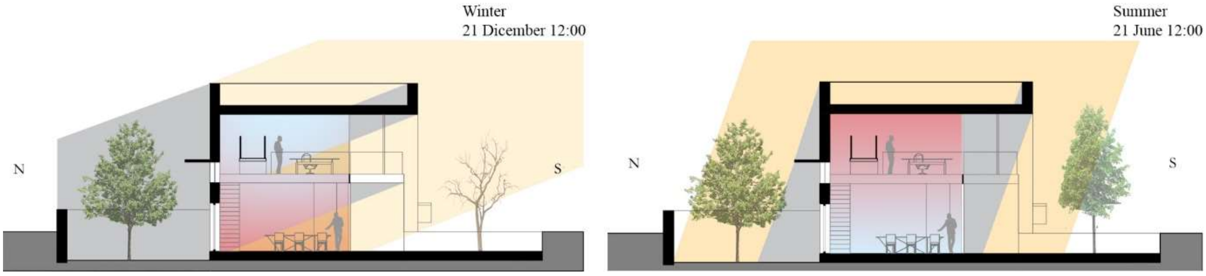

**Figure 3.** Solar study of a building section.

To avoid the summer overheating of the external walls and roof, light colours are been used to ensure a high level of albedo. White paint is used for external wall, white stone for external floor and white gravel for top roof. The introduction of a swimming pool was planned in the project. This is positioned at South-West area, the hottest area of the building. Its aim is to cool the hot air coming from the South thanks to the evaporation of the water.

### *2.2 External envelope*

The building envelope is designed to achieve an elevated standard of thermal performance. The common feature of all its parts is represented by high insulation and relevant thermal mass. The external walls are made of three layers, tufa blocks (Apulian calcarenite), a mixture of hemp and hydraulic lime and hemp-lime blocks, for a total thickness of 64,5 cm. The flat roof is designed as a warm roof, made of five layers among which 26 cm of XPS panels and a layer of white gravel for an overall thickness of 71 cm. The stratigraphy of the earth floor provides a reinforced concrete foundation slab with a ventilated crawl space with cellular glass gravel and insulated with XPS panels. The windows used are made of PVC frame with triple LoE glazing argon filled. The values of thermal transmittance of all envelope components, shown in table 1, demonstrate the high insulation level obtained by the building. These values are strongly below the limits set for nZEB buildings by the Italian legislation [10].

**Table 2.** Thermal transmittance U (W/m$^2$K) of the case study envelope

| | U-values (W/m$^2$K) | U- values for Buildings by 2021 |
|---|---|---|
| Ground floor | 0.233 | < 0.34 |
| External wall | 0.127 | < 0.38 |
| Below grade wall | 0.153 | < 0.34 |
| Flat roof | 0.136 | < 0.33 |
| Windows | 0.800 | < 2.20 |

A finite element analysis of linear thermal bridging (Roof-Wall, Wall-Ground flood, Wall-Wall (corner), Wall-Ex. Floor, Lintel above window, Jamb at windows, Sill below window), according to UNI EN ISO 10211 was performed in order to evaluate their incidence on overall thermal losses. Outdoor linear transmittance ($\psi$) was ranging from 0.00 to 0.339 W/m·K. The infiltration rate of the envelope at 50 Pa, obtained with the blower door test, was 0.60 ac/h in line with the Passive House requirements.

### *2.2.1 External wall*

The solution adopted to define the external walls has provided the use of sustainable materials, i.e. the tufa blocks and the hemp lime for the wall assembly. Periodic thermal transmittance (YIE), according to UNI EN ISO 13786, is 0.0055 W/m$^2$K. The thermal characteristics of the materials are shown in figure 4 and table 3.

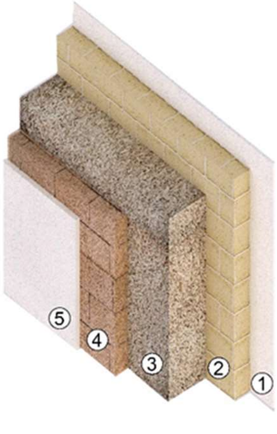

**Figure 4.** External wall layers.

**Table 3.** Thermophysical properties

| N | Material | Thickness (m) | Conductivity $\lambda$ (W/m·K) | Density $\rho$ (kg/m$^3$) | Specific heat c (J/kg·K) | Vap. Fac. $\mu$ (-) |
|---|---|---|---|---|---|---|
| | Indoor | | | | | |
| 1 | Gypsum plaster | 0.02 | 0.700 | 1340 | 840 | 150 |
| 2 | Tufa blocks | 0.10 | 0.550 | 1400 | 950 | 4 |
| 3 | Mix of hemp and hydraulic lime | 0.40 | 0.064 | 200 | 1500 | 5 |
| 4 | Hemp-lime block | 0.12 | 0.096 | 330 | 1870 | 5 |
| 5 | Cement plaster | 0.005 | 0.900 | 1860 | 840 | 20 |

Apulian calcarenite, called tufa block, is a typical local stone material, deriving from the cementation of calcareous rock sediments, generally in a marine environment. Its characteristics are a good mechanical strength, good workability and, thanks to its porosity, a quite good vapor permeability. Its use from the sustainability point of view can be justified by considering several factors. It is a natural material widely diffused in the territory; the incidence of its transport with relative $CO_2$ emissions is very low and finally it is a recyclable and easily reusable. The mixture of hemp-lime is a bio composite material obtained by combining the woody part of the stem, or the shives, and a binder based on hydraulic lime with the addition of water. Its use can reduce the demand of artificial insulation materials helping to reduce the dependence on fossil fuels and it turns out to be a material with a very low disposal impact. The bio composite is totally recyclable as if crumbled and re-mixed in a cement mixer with new lime and water it can be used for masonry, foundations, and crawl spaces.

### *2.3 Plant system*

The HVAC system consists in fan-coil units connected to an air-to-water heat pump and controlled mechanical ventilation. The nominal thermal power of the heat pump is 13.30 kW with a COP equal to 3.54 in winter mode with an external air temperature of 7 °C and a water outlet temperature of 45 °C. The cooling capacity, in summer, is about 10.70 kW with an EER of 3.44 with air at 35 °C and water at 7 °C. The heat pump also provides domestic hot water.

The energy demand is reduced by an earth-to-air heat exchanger that pre-heats the ventilation outside air in winter and cools it in summer. Its use also allows the operation of the free cooling system connected to the CMV system. The ground exchanger is placed at 1.50 m under the ground level and it is made of a system of 70 meters of polypropylene pipes with DN 200 mm connected to an outside air suction tower. The air handling unit is equipped with a double cross-flow heat recovery unit (declared efficiency 0.86) with filtration and integrated treatment with passive heat renewal and recovery. Moreover, the building uses on-site renewable energy got with PV monocrystalline silicon panels on the roof of the building.

## 3. Results

An hourly dynamic simulation by DesignBuilder software [11] was carried out to evaluate the comfort level and the overall building energy consumption. As shown in figure 5c, building-plant system is able to guarantee the setpoint temperature to the limits useful for indoor comfort. In winter, a constant temperature of 20 °C is reached, in summer the indoor temperature does not exceed 26 °C. The heating electricity consumption peaks occur nearby the minimum dry bulb external temperature.

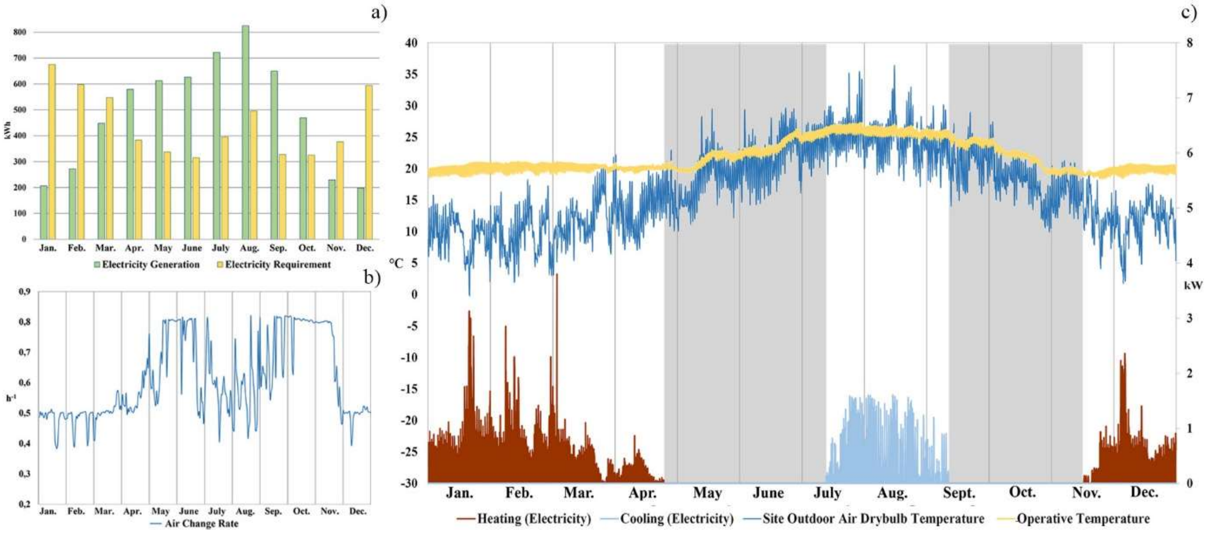

**Figure 5.** a) Monthly electricity requirement and electricity generation by PV system, b) Air Change rate, c) Annual Building-Plant system analysis.

Cooling electricity consumption is limited to the period between July and September with peaks in August, when the dry-bulb outside temperature reaches its maximum up to 38 °C. In the mid-seasons, highlighted in grey, despite the high external temperatures, the system can guarantee indoor comfort without electricity consumption for cooling, but just thanks to mechanical ventilation combined with earth to air heat exchanger (free cooling). That interaction produces an air change rate time-varying as shown in figure 4b, ensuring a good IAQ throughout the year with values up to 0.8 $h^{-1}$, occasionally dropping to 0.4 $h^{-1}$.

The required yearly electricity consumption is about 40.68 $kWh/m^2y$, the total on site generated electricity by PV system is about 40.74 $kWh/m^2y$ .The total end consumption shows a share of heating equal to 5.30 $kWh/m^2y$, cooling 1.16 $kWh/m^2y$, mechanical ventilation 12.51 $kWh/m^2y$, domestic hot water production 4.72 $kWh/m^2y$, internal equipment 8.23 $kWh/m^2y$, and lighting indoor and outdoor respectively 7.19 $kWh/m^2y$ and 1.53 $kWh/m^2y$. The global electricity end use ($EU_{gl}$) is 23.70 $kWh/m^2y$,

sum of heating ($EU_h$), cooling ($EU_c$), ventilation ($EU_v$) and hot water production ($EU_w$). The corresponding primary energy ($EP_{gl,tot}$) is 24.30 kWh/m$^2$y sum of the renewable energy rate from onsite generation (figure 5a) and non-renewable one from grid.
Several simulations were performed to compare different plant variants. The first variant is the real one, the second variant takes into account the plant solution without the EAHX, the third one analyses the result got without heat recovery (HR) and recirculation (R) system and the last one reports energy consumption without solar screens (SS). Table 4 presents results for all variants.

**Table 4.** Comparison between variants.

| | EAHX | HR&R | SS | $EU_h$ kWh/m$^2$y | $EU_c$ kWh/m$^2$y | $EU_w$ kWh/m$^2$y | $EU_v$ kWh/m$^2$y | $EU_{gl}$ kWh/m$^2$y | $EP_{gl,tot}$ kWh/m$^2$y |
|---|---|---|---|---|---|---|---|---|---|
| *Variant 1* | X | X | X | 5.30 | 1.16 | 4.72 | 12.51 | 23.70 | 24.30 |
| *Variant 2* | - | X | X | 6.11 | 1.53 | 4.72 | 13.68 | 26.04 | 28.08 |
| *Variant 3* | - | - | X | 24.27 | 2.11 | 4.72 | 13.68 | 44.78 | 71.83 |
| *Variant 4* | X | X | - | 4.93 | 2.06 | 4.72 | 16.34 | 28.05 | 32.91 |

In total, the impact on consumption of the solution without EAHX (*variant 2*) generates an increase in electricity consumption of 15,3% for heating and 32% for cooling. The impact on consumption of the solution without heat recovery (*variant 3*) produces an increase in electricity consumption of 358% for heating and 82% for cooling. The *variant 4,* the one without the solar screen, compared to the electricity consumption for heating of the first variant with the presence of shadings, produces electricity consumption savings of approx. 7.2%. On the other hand, the electricity consumption for cooling, has grown by 78%.

## Conclusions

This paper shows as correct integrated design of the HVAC system and the building envelope can easily lead to an nZEB building with high performance in terms of energy consumption and comfort. The main demand of electricity in this nZEB building comes from mechanical ventilation. Significant energy benefits are obtained thanks to earth to air heat exchanger. By the use of EAHX the primary energy saved in winter is about 15.3% and in summer 32%. It is also observed that, especially in Mediterranean climate, the solar loads control turns out to be fundamental to reduce the energy demand for cooling. The total absence of solar shading generates an increase in the electricity consumption for cooling of about 78%. It is also noted that the use of the heat recovery unit and free cooling technology is important to reduce energy consumption especially in the mid seasons, when the indoor comfort is guaranteed just thanks to mechanical ventilation without energy demand for cooling/heating.

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