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A STUDY ON DESIGN OPTIMIZATION OF A NEAR NET-ZERO ENERGY HOUSE

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ABSTRACT

Net Zero Energy Building design is a very important issue, since to reach the 2020 goal, an effective combination of envelope energy efficiency and integrated renewable systems is required. This paper investigates the case of a house located in northern Italy, in a temperate climate with warm summer. Starting from the actual energy-efficient design of the house, parametric analyses are developed with the aim of understanding the effects of alternative / additional strategies that may lead to the "nearly zero energy" performance. The variables considered in the parametrical analysis are related to the building envelope. On the energy demand side, passive solar design techniques such as passive solar heating, insulation and air tightness, solar control windows, shading and interior layout were taken into account to reduce the energy demand of the building. Innovative materials in the design and construction of the vertical and horizontal envelope were considered as well. Energy modeling was performed with the TRNSYS software in order to assess the energy transient behaviour of the house.

Key words: High Energy Efficiency, Dry Lightweight System, NZEB Buildings, Renewable Energy Sources.

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Introduction

Energy use in buildings worldwide accounts for over 40% of primary energy use and 24% of greenhouse gas emissions [1]. Energy use and emissions include both direct, on site use of fossil-fuels and indirect use from electricity, district heating and cooling systems and embodied energy in construction materials. Several International Energy Agency (IEA) countries have adopted a vision of “net zero energy buildings” as long-term goals of their energy policies [2].

A net zero energy building (NZEB) provides a technically feasible approach to reduce energy consumption in buildings. Such a building is grid-tied, net metered and produces as much energy on-site as it uses in a typical year. The design and the optimization of this kind of building is still an open issue and is getting more and more importance in Europe also because of the new Directive 2010/31/EU, which is the main EU-wide legislative instrument to improve energy performance in buildings [3]. Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings and ensure the certification of their energy performance. In particular, the NZEB standard will become mandatory in 2019 for public buildings and in 2021 for private ones.

The concept of NZEB includes the synergy between energy-efficient construction and renewable energy use to achieve a neutral energy balance over an annual cycle. Taking into account the energy exchange with a grid overcomes the limitations of energy-autonomous buildings with the need for seasonal energy storage on-site [4]. A NZEB implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from a renewable energy supply system. It also normally implies that the grid is used to supply electrical power when there is no renewable power available, and the building will export power back to the grid when it has excess power generation. This gives, as a result, a net zero export of power from the building to the grid. The net zero energy building design concept is a progression from passive sustainable design, as the contribution of active energy systems is more thoroughly considered in the design process.

A re-design study was carried out and described in this paper to understand if the application of different design strategies could have led a real case study (E3 – Edificio Energeticamente Evoluto) to achieve net-zero energy status [5].

A TRNSYS 16 [6] model was used to assess each upgrade for energy performance and thermal comfort. In particular, the paper describes a sensitivity analysis that was carried out to investigate the energy consumption of the building according to the variation of different design parameters.

Reference building

The case study is an existing residential building sited in Colognola, a small town near Bergamo in northern Italy, consisting of two independent homes sharing a party wall. The northern façade, fully integrated with the context, is opposed to the south side towards the garden, where sunscreens, loggias and conservatories, acting as thermal collectors, create a more vibrant elevation, highlighted by the regular rhythm of the wooden structure of the balconies. The West side has no openings and is characterized by a ventilated skin of timber slats to avoid summer overheating of the envelope. Figure 1 shows the plans and the cross section of the building.

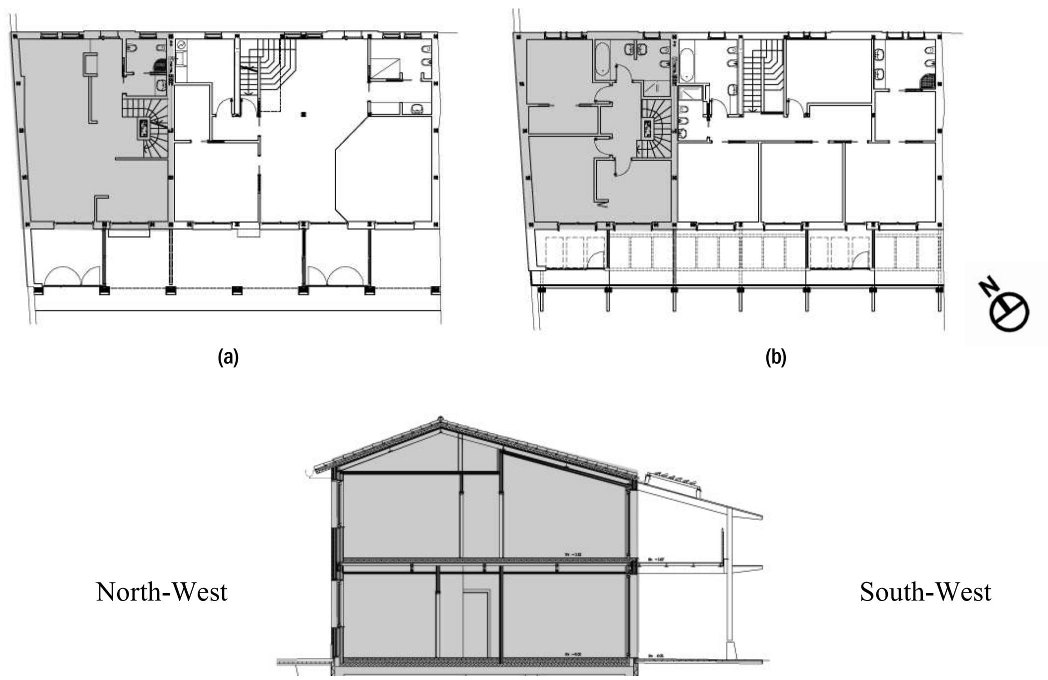

Figure 1: Plan of the first(a) and second floor (b) and the cross section of the building (c).

The envelope is based on a lightweight, stratified, dry-assembled construction system. This delivers a very high thermal performance, with very good behaviour both in winter and summer (energy rating is “A Gold” according to KlimaHaus protocol).

The heating system is based on a high-efficiency natural gas condensing boiler (efficiency at 30% partial load = 109%) combined to a radiant floor system working at low temperature (flow temperatures of 28°C and 40°C, modulated by external probe and local temperature regulation in each room). In order to minimize energy consumption and to ensure the necessary hygienic conditions inside the rooms, a mechanical ventilation system is provided to each of the two independent flats. Each unit is equipped with a cross-flow heat exchanger with 90% efficiency. Solar collectors provide more than 50% of the required domestic hot water.

The areas and U-values for both opaque and glazed parts of the building envelope are summarized in Table 1.

Table 1: Geometrical and physical properties of the envelope.

	U-value (W/m^2K)	Area (m^2)
External wall:		
– South-West	0.12	41.3
– North-West	0.12	67.0
– North-East	0.12	44.9
Floor	0.16	80.0
Roof	0.09	80.0
Window:		
– South-West	0.95	19.1
– North-East	0.95	7.6

Numerical modelling and building energy performance

The TRNSYS 16 software was used in order to perform a transient simulation of the energy behaviour of the building and in particular of the flat highlighted in Figure 1.
The weather data of Bergamo was adopted for the simulation. The city lies 249 m above sea level, with a latitude of 45.70°N and a longitude of 9.67°E. Annual total solar radiation in Bergamo is 1,398 kWh/m2 with approximately 1,900 hours of sunshine.

A four people family was supposed to live in the building and the internal loads were composed by sensible and latent heats generated by people, lighting and machines or equipment placed inside the building.

Occupation of the building was set from 3 p.m. to 8 a.m. during the week and for 24 hours during the week-end.

Heating, cooling, ventilation and humidity control systems were considered as ideal for all the simulations. The heating system is operating between November and March; the cooling system is set to activate in July and August only when indoor temperature is higher than 26°C, while the threshold for humidity control is 60% independently of the indoor temperature. In the remaining months, the building is in free-running condition.

The results related to the “as built” configuration are shown in Figure 2 by means of the monthly energy balance. In July and August the value of Qcool is not negligible because of the activation of both the humidity control and of the cooling system. The annual energy for ideal heating (Qheat) is equal to 6.4 kWh/m2y, while the annual energy for ideal cooling (Qcool) is 2.4 kWh/m2y.

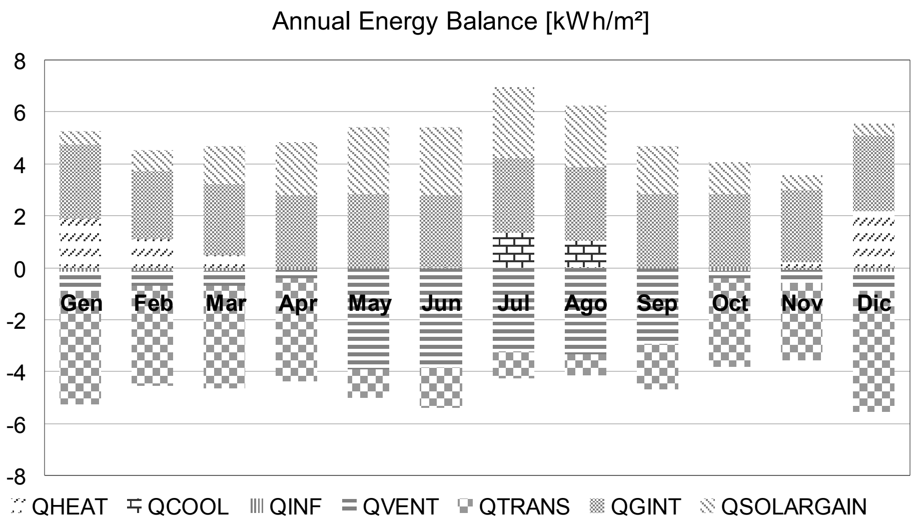

Figure 2: Annual energy balance of the “as built” situation.

As a first re-design measure, mechanical night ventilation was introduced during these months, in order to reduce this load and avoid the use of the cooling system. In Figure 3 is possible to observe the oscillation of internal temperature for different ventilation rates (1, 2, 3, 4, 5 and 6 Vol/h) for some days of July. Temperatures appear to be strongly affected by the ventilation rate up to 2 Vol/h. For this reason, all the following simulations were performed considering summer night flushing at this ventilation rate.

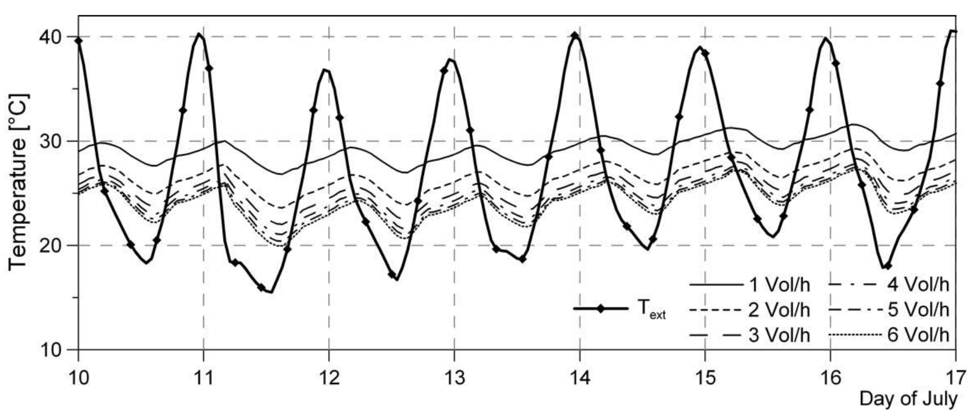

Figure 3: Internal temperature histories for different rates of mechanical night ventilation (10 – 17 July).

Parametric analysis

A parametric analysis was carried out to define which parameter is affecting more the annual energy balance of the building: window sizes on the South-West and North-East sides, increased thermal mass of the external walls and building orientation were considered for this sensitivity analysis. Each of these parameters was varied keeping all the others constant and equal to those of the "as built" situation.

Both the North-East and South-West window surfaces were varied between 20% and 80% of the total surface of the façade. The results are represented respectively in Figures 4a and 4b, by means of both the total annual loads (H+C) and just the heating load (H).

The "as built" value for each parameter is shown in the graph by means of the bold dashed vertical line.

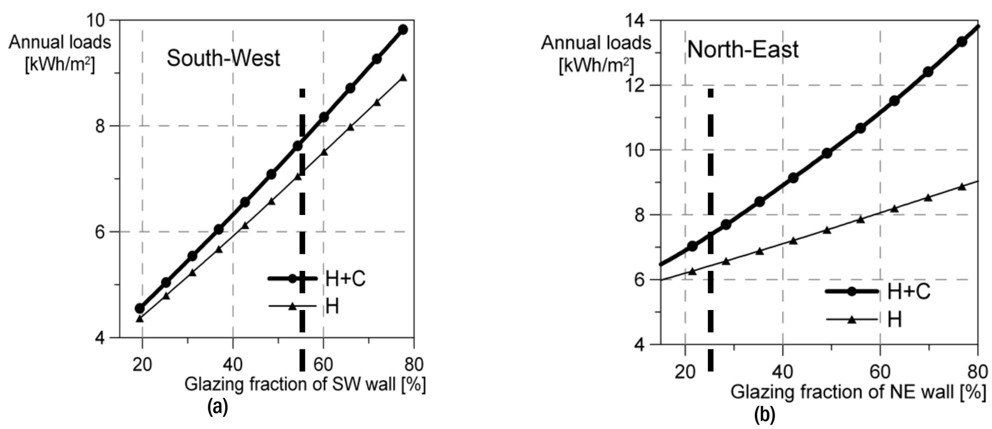

Figure 4: Annual loads for different glazing fractions on SW (a) and NE (b) wall.

The results show that the annual loads increase as surfaces become more transparent; in particular it is interesting to observe the linearity of the response. In the case of North-East surface, an increasing contribute of the cooling energy is very evident when the glazing fraction is higher. As a matter of fact, the H+C line is steeper than the H one. It is worth noting that only the South-West façade has a shading system in the form of an overhanging element.

The introduction of a concrete layer inside the external wall, with a thickness ranging between 2 and 8 cm, was considered in order to assess if this additional thermal mass would change significantly the conductive heat flow in summer. The results are shown in Figure 5 by means of the annual combined loads for heating and cooling (H+C). The contribution of thermal mass in a highly insulated opaque envelope can be considered negligible when one looks at the overall energy behaviour of the building.

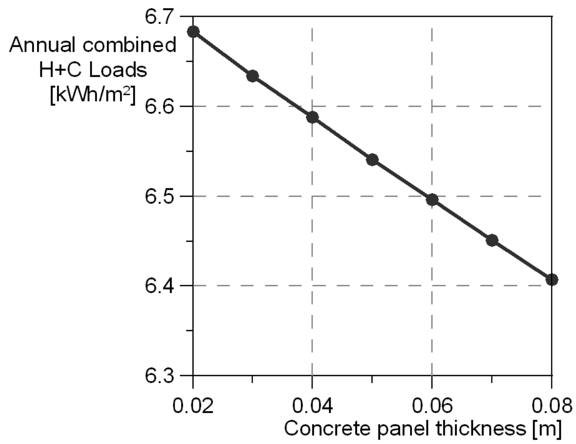

Figure 5: Annual loads for different concrete panel thickness in the external wall.

Finally, the building orientation was changed, by a 360° rotation of the building around its centre. Figures 6a and 6b represent the results respectively in terms of the solar gain and the annual combined load for all the considered orientations. The surface facing South-West in the "as built" situation was considered as the reference in the definition of the orientation. Although solar gains vary significantly as the most glazed surface (SW) turns, the overall energy demand remains rather constant, and in any case extremely limited, as a result of the very high levels of thermal insulation of the building envelope.

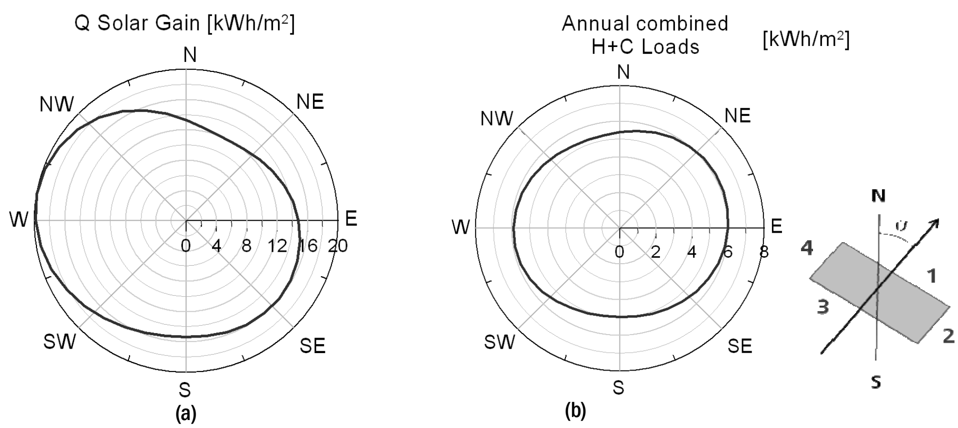

Figure 6: Solar gain (a) and Annual combined loads (b) for different building orientations.

Figure 7 summarizes all the results showing how much the variation of the main building characteristics influences the annual energy demand (H). The bar in this graph represent the difference between the maximum and the minimum annual energy demand (H) obtained for each parameter. The energy demand values were compared to the "as built" situation.

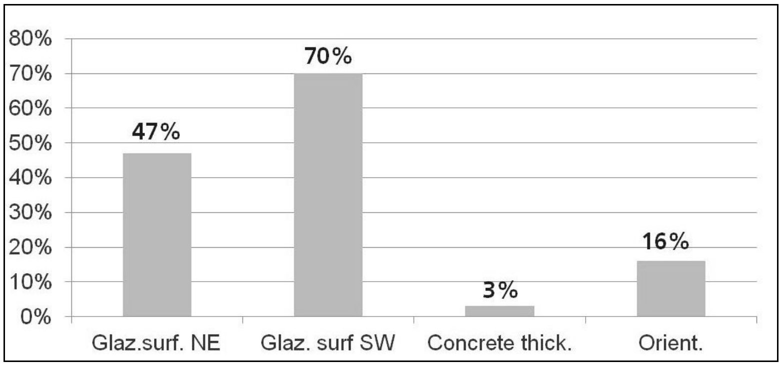

Figure 7: Influence of different parameters on the annual energy demand.

Conclusions

The numerical investigations allowed the authors to draw some conclusions on the case study of an "A Gold"-rated residential building in the temperate climate of northern Italy. First of all, for the building technology adopted, in the weather conditions here considered, the cooling system can be omitted and substituted by a night mechanical ventilation during the hottest months (July and August) in order to keep internal temperatures acceptable for the users. This aspect is particularly important, as mechanical cooling is typically an energy-intensive process. Sensitivity analyses showed how the energy performance of the building could be improved. A variation of the glazing surface has the largest influence, although the influence on heating load is limited to just a few kWh/m2 per year because of the very high levels of insulation of the building. In the mild temperate climate of northern Italy, the best practice performance levels delivered by passive strategies (mainly thermal insulation and passive solar gains) appear to be fully exploited for the heating season. The final step to achieve the NZEB standard requires an accurate integration of renewable energy systems in the building envelope in order to offset the annual energy demand.

Nomenclature

QHEAT	power of ideal heating (convective + radiative)
QCOOL	power of ideal cooling
QINF	infiltration gains
QVENT	ventilation gains
QTRANS	transmission into the wall from inner surface node (might be stored in the wall, going to a slab cooling or directly transmitted)
QGINT	internal gains (convective + radiative)
QSOLGAIN	absorbed solar gains on all inside surfaces of zones

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