Impact of glazing system on the energy performance of a nZEB under climate change scenarios

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***Abstract* — The paper is focused on the evaluation of how windows design influences the energy performance of a nearly zero energy building, including the effects of the climate change. The case study is a single-story dwelling built in Benevento (South Italy, Mediterranean climate) with high performance. With five-years monitored meteorological data, the typical meteorological year is defined. This climatic condition represents the reference scenario for evaluating the performance with different types of windows and for the definition of future medium and long term climate projections, generated using the *CCWorldWeatherGen* tool. From these comparisons, the resilience of the nearly zero energy building is evaluated in terms of variation of heating and cooling energy demand and primary energy percentage difference (ΔPE). The results show that the selective, low-e clear double glazing may be able to better mitigate the summer overheating effect, with an increase of 23% in energy need for cooling at 2050.**

Keywords— nZEB; Mediterranean climate; climate change; window design; building resilience.

I. Introduction

The design of the transparent envelope of buildings is a very critical aspect if the full decarbonisation goal of the civil sector and the climate change effects are considered simultaneously. Indeed, the windows strongly affect the thermal losses and the direct solar gains with overheating risk [1]. The attention of the scientific community is mainly focused on the study of so-called smart or dynamic windows. These solutions, compared to traditional static windows, have the potential to improve the building energy performance also fronting the climate change effects. However, the diffusion of smart glasses requires the overcoming of some important critical issues (high costs, switching speed, chromatic dominant and chromatic range) [2]. Instead, the static solutions are based on the exclusive control of solar gain or heat loss [3].

Although in the new nearly zero energy buildings (nZEB) glazing systems can play a vital role, not many papers are available about this topic for the design of resilient nearly zero energy building (nZEB). For instance, in [4] it was observed that combining installation of solar film with retrofit double glazing reduces the annual HVAC energy consumption by up to 20% but in current climate conditions. As reported in [5], the NZEB design is different in a climate change scenario than estimated from current weather, having slightly lower levels of insulation, improved envelope, airtightness and equipment, lighter colored surfaces with higher reflectance roof and walls, and better solar control from windows (lower G-factor) to reduce cooling needs. Combining these measures, it has been demonstrated that a nZEB in Stockholm could be configured as a positive energy building showing a 40% reduction of the energy demand for heating and cooling in a long-term scenario.

Pending further progress on dynamic glazing, the main gap in the scientific community on this topic is represented by the lack of studies on the long-term effect of static design solutions. This issue concerns the resilience analysis of an nZEB since, in the light of expected climate change, it is not clear which is the best design strategy to adopt for a new building and for a energy retrofit intervention.

The novelty introduced by this study is to provide the designer with an analysis criterion based on a dual design point of view (new building and energy requalification) regarding the present and future effects of efficient glazing solutions. With reference to nZEBs in a typical Mediterranean climate, 8 glazing types were examined under current and future climate conditions. Two climate projections (years 2050 and 2080) were generated for Benevento, a small city in southern Italy.

II. Case Study

For the aim of this paper, the chosen case study is a nearly zero energy building located in a typical Mediterranean climate. In detail, the building was built in Benevento and for this reason it is named BNZEB (Fig.1a). It was possible to refer to this case study since it is a real experimental laboratory of the University of Sannio in Benevento.

The building envelope is made of cross laminated wood with two layers of fiber-wood insulation with different density; the windows are double-glazed system with argon-filled cavities and low-e coating and PVC frames.

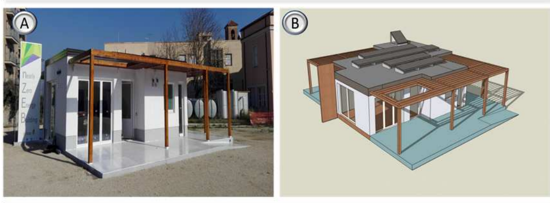

Fig. 1 a) Real case study; b) Building simulation model.

An aerothermal heat pump can provide heating, cooling, domestic hot water and mechanical ventilation, with an internal filter and an active thermodynamic heat recovery

A detailed description of the technical solutions has been already proposed by Ascione et al. [6]. The authors have also presented the construction and validation of the numerical model (Fig. 1b) of BNZEB. Briefly, *Design Builder* [7] has been used for the graphical construction and then it has been simulated with *EnergyPlus* [8]. The output of simulation has been compared with the monitored data (both consumptions and indoor parameters) following the approach proposed by M&V Guidelines [9].

III. METHOD

For the case study, a weather files (.epw extension) is built directly from meteorological data monitored between 2015 and 2020 by weather station located on the roof of the MATRIX test-room at a height of about 7.20 m from the ground level [10], located in the urban center of Benevento (41 ° 07'54.1 "N, 14 ° 47'03.7" E).

As reported in [11], with these data a typical meteorological year (TMY) was defined using the Sandia [12] method. In addition, two future climate projections are defined, starting from the TMY. The *CCWorldWeatherGen* [13] weather generator, made available by the University of Southampton, was used. A medium-term climate projection and another long-term one were generated, with reference to the periods 2041-2070 ('2050s') and 2071-2100 ('2080s'). Respectively, these are named CC_MT and CC_LT.

The main goal of the present paper is to evaluate how the building reacts to present and future levels of solar radiation by varying the glazing system. Eight glazing models are examined, considering both double and triple glasses with argon or air, clear or colored and with static or dynamic behavior (Table I).

First of all, for the results with TMY, the comparisons are made in terms of energy needs for heating and cooling and the percentage change in the total primary energy consumption of the building (ΔEP).

For the results with future climate projections, the comparisons of energy needs for heating and cooling are proposed on the basis of a dual vision by the designer and in particular for the design of a new nearly zero energy building (ΔHn and ΔCn) and for a retrofit intervention on the state of fact (ΔHr and ΔCr).

In the first case, for each alternative solution, the energy needs in the medium and long-term scenarios are examined with respect to the same building configuration simulated with TMY. In the second case, the comparisons are made with respect to the state of fact (Base Case) evaluated in the current climatic conditions (TMY).

TABLE I. DESIGN VARIABLES

Variable	*ID*	*Description*
Glazing type	*Base Case*	Clear low-e double glazing, 3/13/3, Argon: Ug ≈ 1.1 W/(m^{2}K), g=0.58.
	D_C 3-13 Arg	Clear double glazing, 3/13/3, Argon: Ug ≈ 2.56 W/(m^{2}K), g=0.76.
	D_B 6-13 Arg	Colored (blue) double glazing, 6/13/6, Argon: Ug ≈ 2.51 W/(m^{2}K), g=0.49.
	D_LESSC 6-13 Arg	Clear low-e, selective spectral double glazing, 6/13/6, Argon: Ug ≈ 1.34 W/(m^{2}K), g=0.42.
	D_CLI 3-13 Arg	Clear low-iron double glazing, 3/13/3, Arg, Ug ≈ 2.56 W/(m^{2}K), g=0.83.
	T_C 3-13 Arg	Clear triple glazing, 3/13/3/13/3, Argon: Ug ≈ 1.62 W/(m^{2}K), g=0.69.
	T_ LEC 3-13 Arg	Clear low-e triple glazing, 3/13/3/13/3, Argon: Ug ≈ 1.06 W/(m^{2}K), g=0.58.
	T_ LEFC 3-13 Air	Low-e triple glazing with polyester film (88), 3/13/3/13/3, Air: Ug ≈ 1.30 W/(m^{2}K), g=0.58.
	Thermochromic	Thermochromic triple glazing, 6/6/6/6/6, Air: Ug ≈ 2.13 W/(m^{2}K), solar trasmission from 0.68 (@24°C) to 0.33 (@75°C).
Shield	*Internal*	Blind with high reflectivity slats with seasonal schedule
	External	Horizontal protrusions, 1.0 m Overhang

IV. RESULTS

Fig. 2 shows the simulation results with replacement of glazing type in the current conditions (TMY file). In terms of energy heating and cooling demand, the most important variations with respect to the Base Case (with low-e double glass) are observed with the solutions identified as *D_B 6-13 Arg*, *D_LESSC 6-13 Arg* and *Thermochromic*.

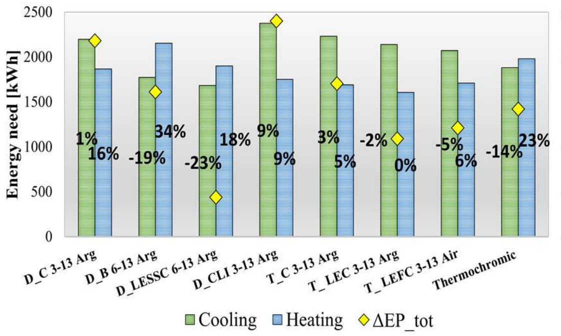

Fig. 2 Energy simulation results with current climate file (TMY)

As reported in Table 1, colored double glass (*D_B 6-13 Arg*) is particularly opaque to solar radiation (g=0.49). Furthermore, it has a high thermal transmittance value, equal to 2.51 W/(m^{2}K). Therefore, the reduced incoming solar gains and the low level of thermal insulation cause the greatest percentage increase in the energy need for heating (+43%). Compare to the Base Case, the percentage variation of total primary energy is negligible.

Thermochromic coating changes its colour by varying its crystal structure above a particular environmental temperature. In detail, solar transmission of this glass varies between 0.68 at 24°C to 0.33 at 75°C.

The observed results show that the glazed surfaces, in the current climate conditions (TMY), are characterized, due to their exposure, by incoming solar radiation for many hours even in the winter months. Consequently, the thermochromic coating is also activated in the heating period and hinders solar gain. The energy need for heating increases of 29% and the cooling one decreases of 14%. These percentage variations have a negligible effect on the total primary energy demand of building.

The spectral selective double glass, unlike thermochromic glass, is a static solution. However, in the climate conditions under investigation, the solution *D_LESSC 6-13 Arg* minimizes the solar gain in the cooling period, since it is characterized by the lower value of the solar factor (g=0.42). Furthermore, the thermal transmittance of this solution is equal to 1.13 W/m^2 K and it involves a lower increase in the energy need for heating, compared to thermochromic glass. Compared to the Base Case, heating energy need increases of around +18% and cooling energy need decreases of -23%. Consequently, on an annual basis, an overall reduction in total primary energy of about 3% is observed.

Low-iron double glass (*D_CLI 3-13 Arg*) is a type of high-clarity glass that is made from silica with very low amount of iron. This type of glass allows the passage of light radiation and the solar gains. Indeed, with the application of this component, the maximum increase in energy need for cooling is observed, compared to the Base Case (+ 9%). At the same time, despite the maximum value of the solar factor (g=0.83), this glass is affected by its low level of thermal insulation (U_g= 2.56 W/m^2 K) and leads to an increase of 12% of the energy need for heating. Solutions with triple glazing do not lead to significant improvements or worsening of energy needs for heating and cooling. However, the solution identified as *T_ LEC 3-13 Arg* is the only one that leads to a negligible variation in the heating energy need, with a percentage decrease of cooling energy need, approximately equal to -2%. In terms of total primary energy, the maximum percentage increase, with respect to the Base Case, was observed with the solution identified as *D_CLI 3-13 Arg* (+5%). Therefore, the observed variations are comparable but with less impact with glasses based on solar gains control. This effect, albeit minimal, is positive as the transition to a climate dominated by cooling is predictable for Benevento in future. In particular, the building resilience in relation to possible future climate change was assessed on the basis of two points of view, both for a new building and for the energy retrofit of an existing building. In the first case, for each solution simulated with CC_MT (2050s) and CC_LT (2080s), the percentage variations of the energy requirements, ΔHn and ΔCn respectively, were assessed with respect to the same solution simulated with TMY. In the second case, all the alternative solutions simulated with the future climate projections were compared with the Base Case simulated with TMY.

The findings are shown in Fig. 3 and Fig. 4 for the medium-term and long-term scenario, respectively.

From the point of view of new construction and energy retrofit, climate change favors the building resilience in winter season with all glazing types considered.

On average, with CC_MT and CC_LT, both ΔHn and ΔHr are equal to -56% and -66%, respectively. Some interesting observations can be made in terms of energy needs for cooling. First of all, no solution has an adaptive behavior with respect to climate change. However, different mitigating effects of the increased internal overheating were found. In this sense, thermochromic glass surprises most of all. This dynamic component, compared to the current climate condition (TMY), proves not yet able to improve the obstruction of further solar gains due to higher levels of temperature and solar radiation in the future.

Moreover, the designer could make different choices depending on the point of view adopted. Indeed, although the goal is to minimize energy needs and, therefore, the total

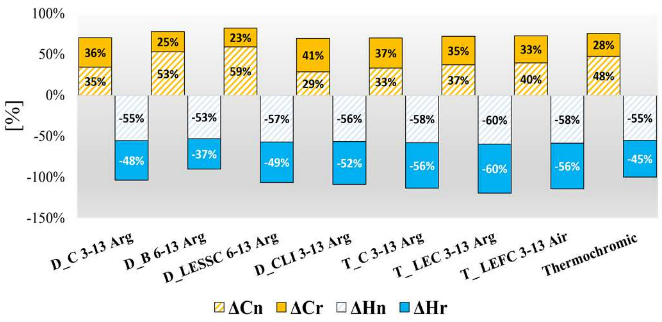

Fig. 3 Percentage variations in energy needs for heating and cooling - CC_2050.

primary energy of building, different observations can be made in terms of the resilience of the alternative solutions proposed with respect to the expected climate change. In the perspective to design a new building, ΔCn is around +42% and +57% with CC_MT and CC__LT, respectively. In particular, the maximum percentage increase was observed with the solutions identified as *D_LESSC 6-13 Arg* and *D_B 6-13 Arg*, with which ΔCn is about 59% and 53%, respectively, at 2050.

As shown in Fig. 5, this result is also confirmed in terms of energy need for cooling (ΔEc). Taking the time horizon to 2050 as a reference, the maximum value is observed with the spectral selective double glazing (+995 kWh). The second highest increase is that with colored double glazing (+944 kWh), while the minimum increase was observed with the solution called *D_CLI 3-13 Arg* (+687 kWh). The explanation for these observations may lie in the fact that optimized solutions to favor solar gains are less affected by the transition to a cooling-dominated climate. On the contrary, climate change would seem to penalize static glasses more opaque to solar radiation, such as the spectral selective and the double colored one. This result allows to understand the importance of building resilience.

The same findings lead to different conclusions when the aim is the design of energy retrofit. Taking Base Case simulated with TMY as reference, with CC_MT the energy need for

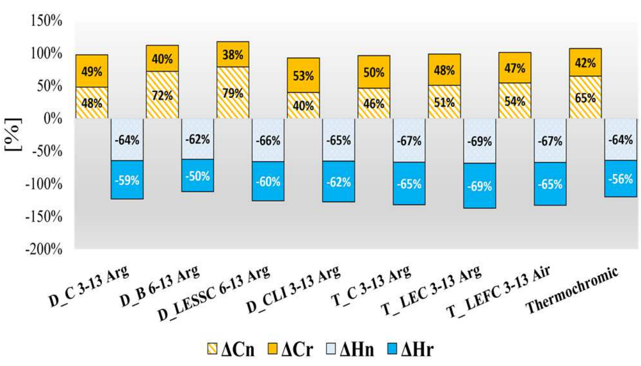

Fig. 4 Percentage variations in energy needs for heating and cooling - CC_2080.

cooling increases by 9% with *D_LESSC 6-13 Arg* and by 10% with *D_B 6-13 Arg*.

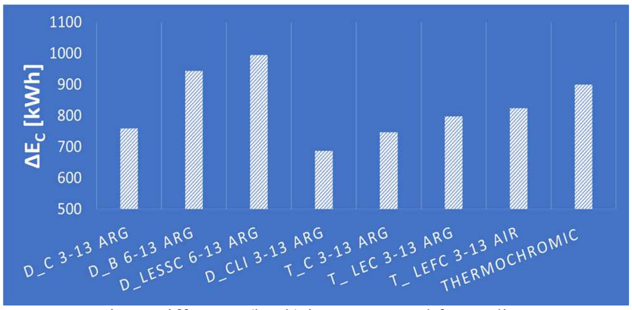

Fig. 5 Difference (kWh) in energy need for cooling.

These are the lowest observed percentage differences. The maximum percentage increase was observed with low-iron double glazing with low ferrous content. The same is true with CC_LT. In this case the energy need for cooling increases of 15% and 16%, respectively with *D_LESSC 6-13 Arg* and *D_B 6-13 Arg*. Instead, with the application of *D_CLI 3-13* Arg the maximum percentage increase in the cooling energy demand becomes approximately of 40%. With reference to the transparent envelope of a real nzeb, the global relevance of the main results observed is that the analysis of the building resilience with respect to climate change may not always favor the choice of the most efficient solution to reduce energy demand. A more efficient solution under current climate conditions may perform worse due to climate change. However, although the legislations of European Countries impose the nZEB target for new buildings, the decarbonisation goal mainly depends on the retrofitting of existing buildings. In this sense, the study shows that, if the solution is a static glass, the effects of climate change could have less influence on the analysis of the best solutions. However, further advances in numerical modeling of dynamic glasses are needed to be able to make reliable comparisons with static solutions.

V. CONCLUSION

The achievement of decarbonization goals is only possible through careful design of the nearly zero energy buildings by taking into account reliable current and future climatic conditions. About it, this paper proposes the evaluation of the resilience of the design choices made for the BNZEB, a nearly zero energy building built in Benevento, a city of South Italy. Under current climatic conditions the effects of many static glasses on energy needs for heating and cooling are contrasting and the maximum primary energy reduction was observed with spectral selective low-e double glazing (ΔEP $\approx$ -3%).When the future climate is analyzed the minimization of primary energy is closely linked to the containment of the cooling energy need. Considering the retrofit intervention, the best static solutions are those identified with D_LESSC 6-13 Arg and D_B 6-13 Arg with which ΔCr is about 25% and 23%, respectively, at 2050.

Spectral selective low-e double glazing is the solution that leads to the minimum energy need for cooling, both with current (TMY) and future (CC_MT and CC_LT) climate conditions. This static solution is able to optimize the solar gain and heat loss controls. However, despite the possible transition to a cooling-dominated climate for Benevento, this glazing is the least resilient showing the maximum kWh increase in the energy need for cooling, if the same solution simulated in the current climate conditions (TMY) is taken as a reference ($\Delta E_C \approx 995$ kWh). Future developments of this study may consist in analyzing the short and long term effects on the energy balance of the BNZEB and indoor comfort. For example, the different windows examined can be compared in terms of variation of building's self-consumption of electricity and discomfort hours.

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