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The optimization of the building-plant system for a nZEB wood technology construction in Mediterranean Italian area

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Abstract: This paper deals with a research carried out by the University of Florence on the thermal and energetic performances of a nZEB building in Mediterranean area. Heterogeneous component performances have been analyzed and critically evaluated. Results from different calculation methods for energy consumptions have been compared. Some solar shading devices have been evaluated in order to reduce the energy need for cooling in the building that at the moment is under construction. A monitoring campaign to assess all over the year thermal and energetic performances of the building is presented. Main results of the research are presented as for the thermal properties of the components, the energy balance of the building implemented with an external fixed solar shading. The thermal monitoring of the components with probes put in the layers of the walls and the roof is described as well.

Keywords: keyword1: nZEB; keyword2: building performances; keyword3: energy evaluation

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1. Introduction

The Energy Performance of Buildings Directive recast 2010 [1] introduces the concept and the definition of the ‘nearly zero-energy building’ (nZEB). In the directive ‘nearly zero-energy building’ means “a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”. Since the Commission does not give minimum or maximum harmonized requirements, it will be up to the Member States to define what for them exactly constitutes a "very high energy performance“ on the base of the cost optimal performance level. The cost optimal level could be represent “the energy performance that leads to the lowest cost during the estimated economic lifecycle" (the latter determined by Member States). In the definition, local conditions can be obviously taken into account, but the uniform methodology can be used in all Member States.

EPBD recast requires that after 31 Dec 2018, public authorities that occupy and own a new building shall ensure that the building is a nearly zero energy building, and by 31 Dec 2020, all new buildings are nearly zero energy buildings.

According to the EPBD recast, the Italian Decree of 26 June 2015 [2] defines the requirements of the nZEB, whether new or existing construction. In particular, the following parameters should be lower than the values calculated for the reference building (a virtual building geometrically equivalent to the design building, but offering the energy parameters and the minimum current thermal characteristics): the transmission heat transfer global coefficient averaged over envelope dispersing surface (H'_T), the summer solar equivalent area per unit area, the energy performance index for winter heating (EP_H) and summer cooling (EP_C), the global primary energy performance index (EP_{gl}) both total and non-renewable, the efficiency of the heating, cooling and domestic hot water systems. Moreover, renewable sources should be present in compliance with the minimum standards set out in the Legislative Decree 3 March 2011, n. 28.

For buildings in the Mediterranean area, the cooling demand is high as the heating demand and is going to increase due to increasing comfort requirements; as a matter of fact cooling systems are thus becoming standard systems for new or refurnished building, as well as heating systems. Since Mediterranean buildings have to "perform" effectively both in heating and in cooling mode, some strategies should be taken into consideration in order to match the nZEB requirements in this climate area: the optimization of the building envelope for all the year and not for the sole heating season to reduce the energy need as much as possible (insulation, increased use of daylight, thermal activation of the mass, shading devices, etc.) and the increase of the heating and cooling technical systems energy efficiencies, by using the best available technology (heat recovery, increase the efficiency of air conditioning systems, etc.) and by enhancing the production of heat and electricity from on-site renewable sources (solar thermal, PV, heat pumps, district heating powered by renewable fuels, etc.).

Many pilot projects across Europe (REHVA Task Force "Nearly Zero Energy Buildings"), which may be called as nZEB buildings, and many researches have shown that sometimes simulations may provide too optimistic results not achieved in practice, both in terms of building-plant system performance and of indoor environmental comfort; as a matter of fact a monitoring of the building is often necessary.

2. Description of the building

This paper presents some results of a Research carried out by the Environmental Physic Laboratory of the University of Florence dealing with thermal and energetic analysis of a new nZEB platform frame building. The building under analysis is a detached house (one-story building) in Tuscany (Figure 1, 2 and 3); it is built with a platform frame technology combined with a reinforced concrete slab for the floors. Climatic and building data are reported in Table 1.

The garage and the cellar, with a reinforced concrete structure, are placed In the unheated basement. Aim of the building is to reach the nZEB target as defined in Italian Decree of 26 June 2015 [2].

Table 1 – Data refereed to the building and the location

Geographic location	Arezzo
Climatic zone	E
HDD	2014
Heating season	From 15/10 to 15/4; 183 days
Floor area	186 m^2
Heated volume	631 m3
S/V	0,82 m^2/m^3

Figure 1 – Building plan

Figure 2 – Building section A-A

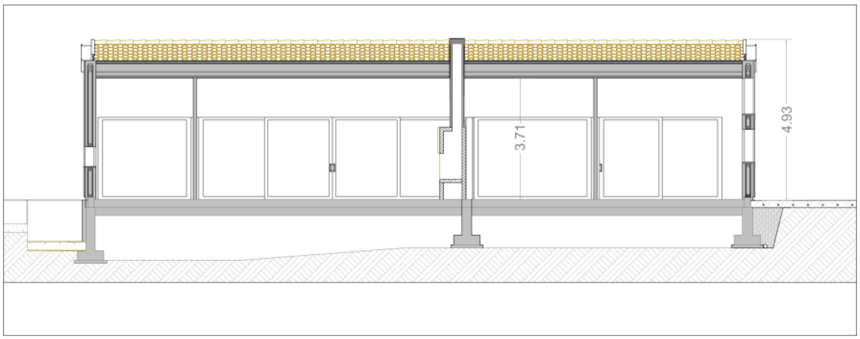
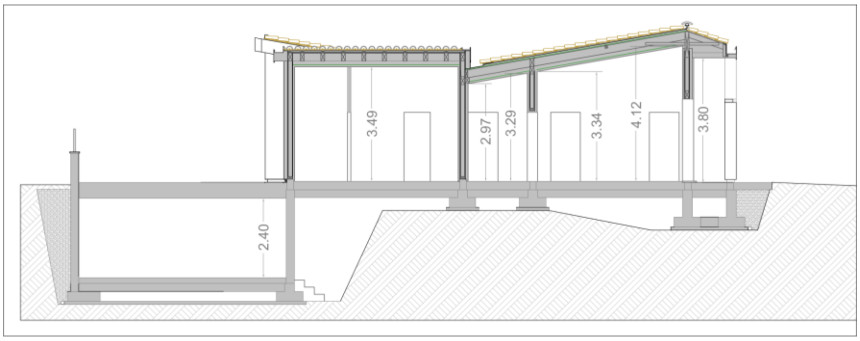


Figure 3 – Building section B-B



In the building also solar panels for hot water production and PV panels are integrated in the roof. Solar panels guarantee a production of 65,8% of the total hot water demand, while PV panels produces about 5000 kWh per year. A heat pump with a COP of 3,91 and a EER of 2,77 is installed. A mechanical ventilation system (VMC) guarantee h24 an air flow in every room varying from 1 vol/h to 1,5 vol/h; nominal heat recovery efficiency of the VMC is of 84%.

The research dealing with this new nZEB building includes tree main phases:

- in the first phase main thermal characteristics of the building envelope have been calculated and critically evaluated in comparison with nZEB target; the building components have been analyzed both with simplified and detailed (for heterogeneous components and thermal bridges) calculation methods;
- in the second phase energy simulations of the building have been carried out with dedicated softwares both in steady state and dynamic conditions; building envelope energy requirements in winter and summer seasons have been assessed and critically analyzed;
- the third phase deals with on site monitoring of thermal performances and thermal comfort.

In the present paper only results related to the first and second phase are full described; for the third phase only the methodology is reported as the building is actually under construction.

Figures 4 and 5 refer to the building under construction and underline its technology as well as the great South-West oriented window in the living room filling the entire wall.

Figure 4 – Living room of the building under construction

Figure 5 – Hallway of the building under construction

3. Analysis of the building components

The analysis of the thermal performances of the opaque building envelope comprehend the calculation of different indicators in accordance with the Italian standards:

- thermal transmittance U (UNI EN ISO 6946:2008) [3];
- periodic thermal transmittance Y_{IE} (UNI EN ISO 13786:2008)[4];
- surface mass index M_s (D.lgs 311/2006 e s.m.i.)[5];
- vapor condensation risk (UNI EN ISO 13788:2013)[6].

As regards thermal transmittance, calculated values have been compared with the reference nZEB ones reported in the Italian Decree of 26 June 2015 for the climatic zone E (Arezzo).

Moreover, in order to evaluate the inertial performances of the components the Y_{IE} indicator has been assessed even if the local thermal irradiation is less than the reference value ($I_{m,s}$=290 W/m^2).

Table 2 reports the description of the envelope with the layers of the components while the main results of thermal analysis are collected in Table 3.

Table 2 – Components description (from inside to outside)

Layer	Thickness s [m]	thermal conductivity λ [W/(m·K)]	Density ρ [kg/m^3]	Specific heat capacity c_p [J/(kg·K)]
External wooden wall				
Gypsum plasterboard	0.0125	0.250	900	1000
PVC vapour barrier	0.0030	0.160	1390	900
Rockwool “211”	0.0400	0.035	40	1'030
Oriented strand board	0.0180	0.130	650	1'700
Rockwool “211”	0.1200	0.035	40	1'030
Oriented strand board	0.0180	0.130	650	1'700
Expanded polystyrene “EPS 100”	0.1200	0.036	20	1'500
Cement/lime plaster	0.0100	0.900	1800	1000
Floor (on basement)				
Ceramic tiles flooring	0.0100	1.300	2300	840
Reinforced concrete screed	0.1000	1.490	2200	880
Polyurethane foam insulation “Stiferite GT”	0.1400	0.024	36	1450
Reinforced concrete screed	0.0400	1.490	2200	880
Concrete/brick slab	0.2000	0.660	1100	840
Cement/lime plaster	0.0100	0.900	1800	1000
Ground floor				
Laminate wood flooring	0.0100	1.430	500	1500
Reinforced concrete screed	0.1000	1.490	2200	880
Polyurethane foam insulation “Stiferite GT”	0.1400	0.024	36	1450
Reinforced concrete screed	0.0400	1.490	2200	880
Concrete/brick slab	0.2000	0.660	1100	840
Cement/lime plaster	0.0100	0.900	1800	1000
Roof				
Gypsum plasterboard	0.0125	0.250	900	1000
Unventilated air layer	0.0300	0.188	1.3	1000
PVC vapour barrier	0.0030	0.160	1390	900
Rockwool “Hard Rock Energy"	0.1200	0.036	220	1030
Rockwool “211”	0.1400	0.035	40	1030
Unventilated air gap (upwards)	0.1000	0.000	1.3	1008
Oriented strand board	0.0220	0.130	650	1700
Vapour retarder	0.0040	0.230	1100	1000
Slightly ventilated air layer	0.0800	0.520	1.300	1008
Oriented strand board	0.0220	0.130	650	1700
Bitumen	0.0040	0.170	1200	1000

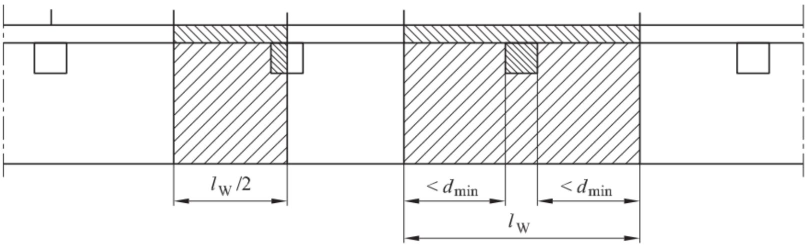
Table 3 – Thermal performances of the opaque envelope

Components	Total thickness (m)	Thermal transmittance U (W/m²K)	Inertial performances: Y_{IE} (W/m²K) Ms (kg/m²) f_a (-) S (h)	Condensation risk	
				Surface condensation	Interstitial condensation
External wooden wall	0,341	0,119	Y_{IE} = 0,017 Ms = 36,370 f_a = 0,142 S = 11,170	✓	✓
Floor (on basement)	0,500	0,152	Y_{IE} = 0,006 Ms = 556,040 f_a = 0,041 S = 16,410	✓	✓
Ground floor	0,500	0,153	Y_{IE} = 0,009 Ms = 538,040 f_a = 0,056 S = 15,540	✓	✓
Roof	0,537	0,119	Y_{IE} = 0,028 Ms = 74,243 f_a = 0,237 S = 12,960	✓	✓

As a result of the steady state analysis, all the opaque components present very low transmittance values compared with the reference ones of the nZEB target and good inertial performances. No condensation risk has been highlighted.

Nevertheless, the platform frame technology requires a more detailed analysis for the heterogeneous components (walls and roof) that present a wooden structure with a 0,625m distance between studs. For this reason some components have been assessed both with the calculation method reported in UNI EN ISO 6946:2008 (as heterogeneous components) and with a 2D finite element analysis tool (Bisco®). The thermal transmittance of the external wall calculated in accordance with UNI EN ISO 6946:2008-§ 6.2 is equal to 0,135 W/m²K, 12,5% greater than the value calculated in accordance with UNI EN ISO 6946:2008. In fig 6 the geometric model used in the calculation code Bisco to define the external wall is reported.

Figure 6 – Linear thermal bridge and symmetry plans used in the analysis (legend: d_{min} = minimum thickness; l_w = fixed distance) [from: UNI EN ISO 10211:2008]



Platform frame technology produces a different behavior of the external wall, as well as the roof, in correspondence respectively of the wooden studs and joists and the large thermal insulation layer made of mineral wood (16 cm for the wall and 26 cm for the roof).

The not negligible difference between the two calculated values for the external wall required a more in-depth analysis that has been carried out with a numeric evaluation method in accordance with UNI EN ISO 10211:2008 [7]. Therefore the specific requirements of the two-dimensional model refereed to the technology nodes have been defined together wit the boundary conditions in order to calculate thermal fluxes and the internal surface temperatures.

From the thermal balance of the analysed components heat fluxes and isothermal curves have been deducted for the heterogeneous external wall and the roof.

In figures 5 and 6 temperature trends and heat fluxes are reported.

Figure 7 – Isothermal and thermal flux lines for the external wall

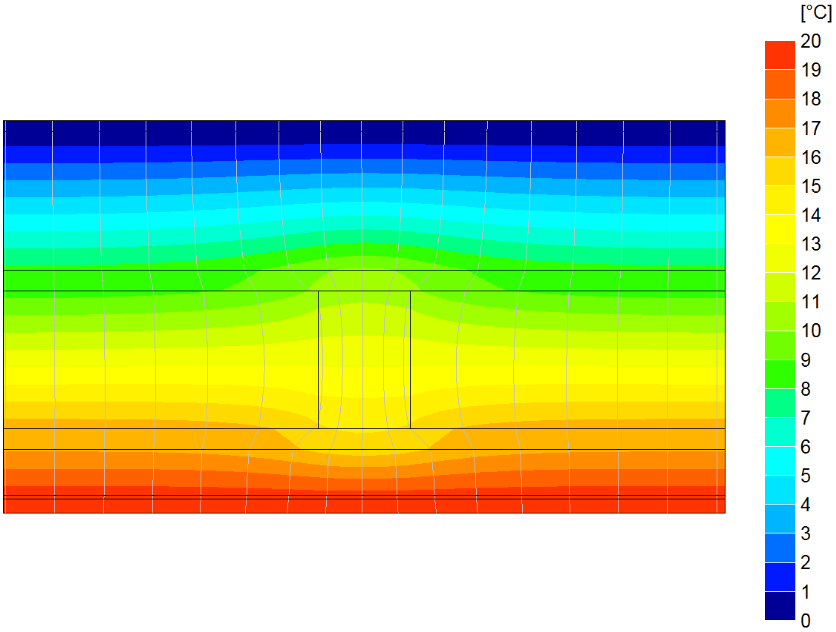
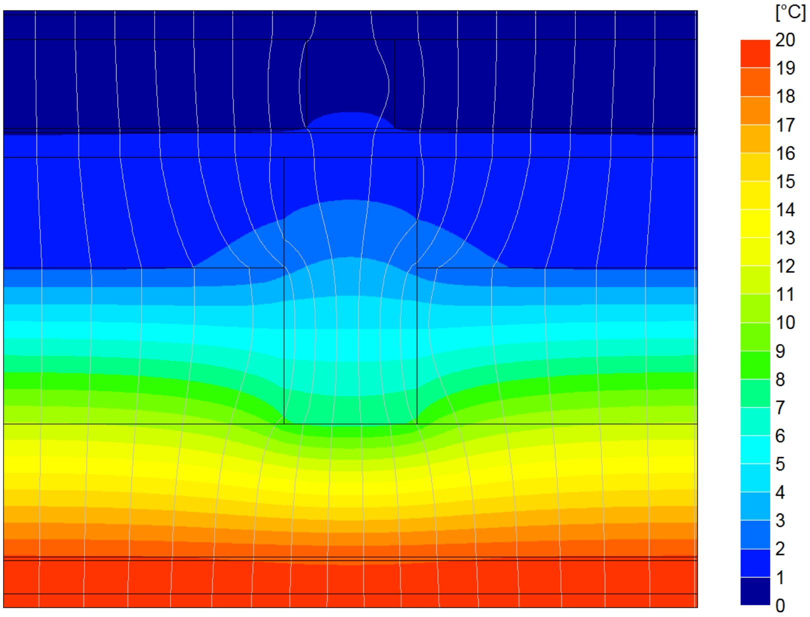


Figure 8 – Isothermal and thermal flux lines for the roof



From the analysis also surface temperatures in the different layers have been calculated and reported in Table 2 (external wall) and Table 3 (roof).

Table 3 – Surface temperatures in the different layers of the external wall

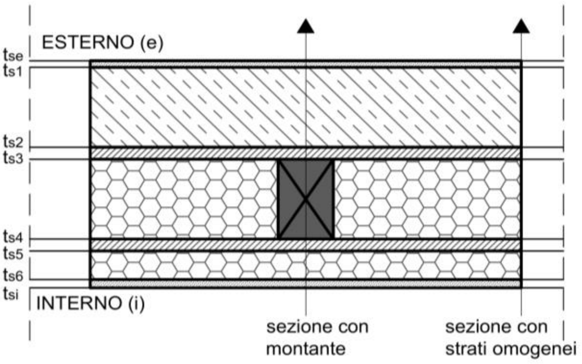
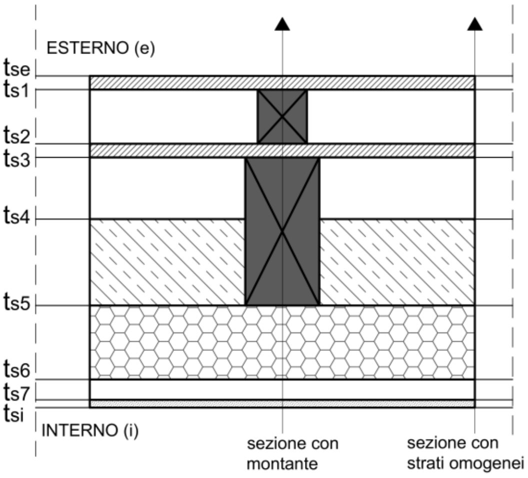
Layers	External homogeneous wall – Superficial temperatures (°C)	External wall , wooden stud – Superficial temperatures (°C)	External wall scheme
t_e	0	0	
t_{se}	0,1	0,11	
t_{s1}	0,12	0,16	
t_{s2}	8,22	10,12	
t_{s3}	8,54	10,67	
t_{s4}	16,5	14,87	
t_{s5}	16,87	15,44	
t_{s6}	19,58	19,41	
t_{si}	19,69	19,58	
t_i	20	20	

Table 4 – surface temperatures in the different layers of the roof

Layers	External homogeneous wall – Superficial temperatures (°C)	External wall , wooden stud – Superficial temperatures (°C)	Roof scheme
t_e	0	0	
t_{se}	0,12	0,08	
t_{s1}	0,61	0,43	
t_{s2}	0,9	1,12	
t_{s3}	1,38	1,46	
t_{s4}	1,87	3,18 (wooden stud)	
t_{s5}	11,03	7,72	
t_{s6}	19,11	18,91	
t_{s7}	19,55	19,45	
t_{si}	19,67	19,6	
t_i	20	20	

In table 5 thermal transmittance for the external wall and the roof calculated with Bisco® software are reported.

Table 5 – Thermal transmittance calculated with software Bisco®

Components	Analysed nodes	Equivalent thermal transmittance (W/m^{2}K)
External wall	26921	0,13
Roof	42992	0,14
Boundary conditions: $t_i = 20°C$; $t_e = 0°C$		

With Bisco® software also thermal bridge coefficients have been calculated for the main technological configurations of the building. In particular the following thermal bridge typologies have been analysed:

- convex angle of the external wall;
- connection between external wall and roof;
- connection between external wall and ground floor.

In Figures 9, 10, 11 and 12 calculation results are reported. Moreover, temperature trends and heat fluxes are highlighted. In Table 6 results of the calculation are reported.

Figure 9 – Convex angle of the external wall. Temperature trends and heat fluxes

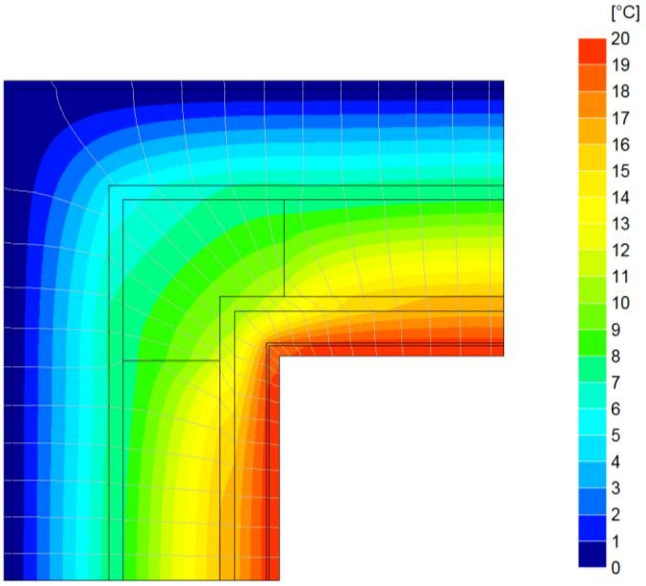


Figure 10 – Connection between external wall and roof. Temperature trends and heat fluxes

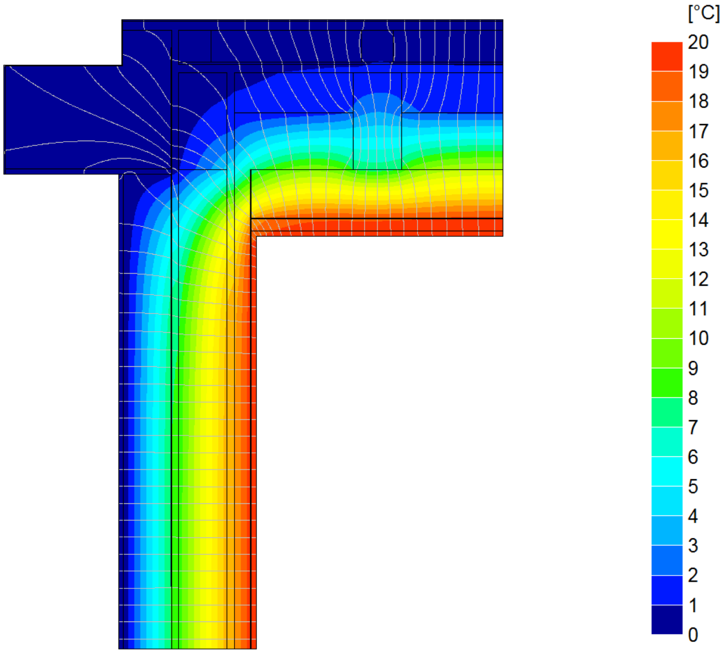


Figure 11 – Connection between external wall and ground floor. Temperature trends and heat fluxes

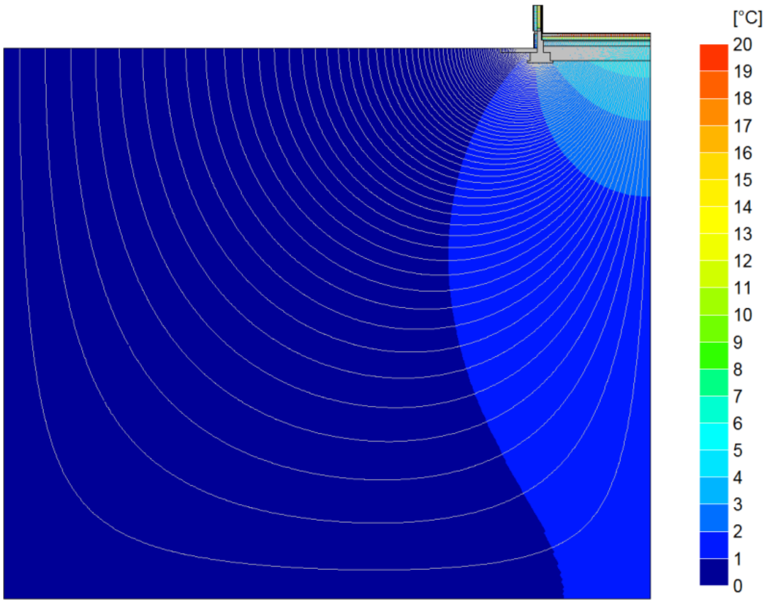


Figure 12 – Connection between external wall and ground floor. Temperature trends and heat fluxes (detail)

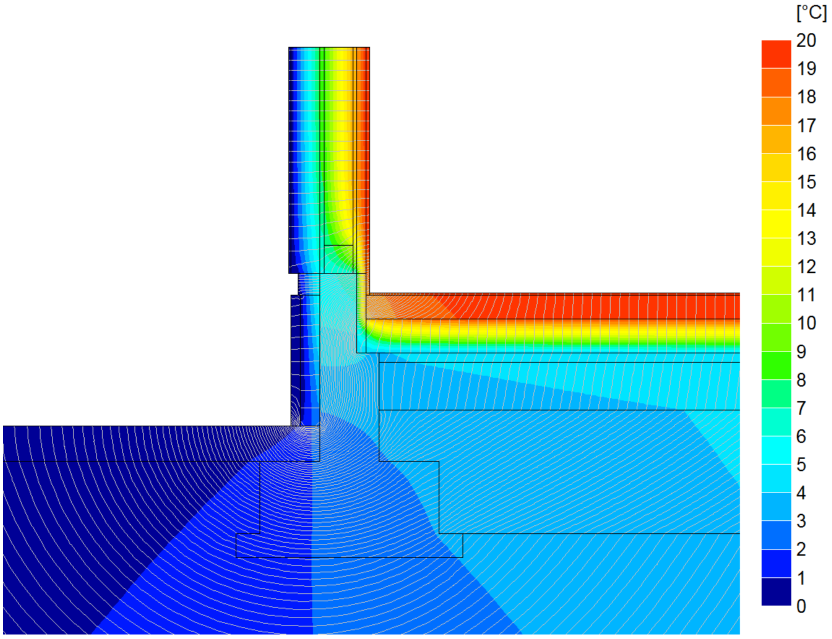


Table 6 – Thermal bridge coefficient from Bisco® software

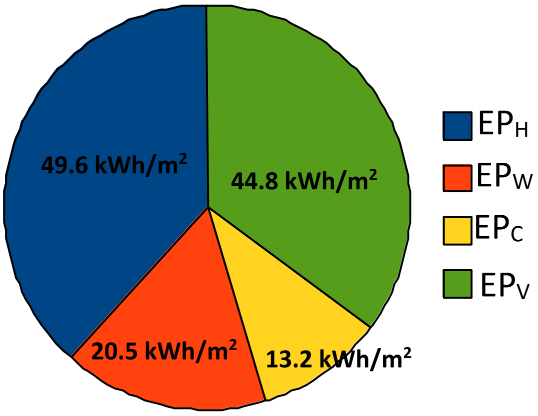
Technological connection	Analysed nodes	Thermal bridge coefficient (W/mK)
convex angle of the external wall	87560	0,04
connection between external wall and roof	120128	0,05
connection between external wall and ground floor	66099	0,07
Boundary conditions: t_i = 20°C; t_e = 0°C		

4. Energy performance analysis

The energy performance analysis of the building has been carried out both with a steady state calculation code used for the energy certification and with a dynamic simulation code (design Builder) [8,9,10].

As for the steady state evaluation, in Figure 13 the analysis of the energy needs for heating (EP_H), hot water (EP_W), cooling (EP_C) and ventilation (EP_V) is reported.

Figure 13 – Global energy need for the nZEB building



The dynamic analysis carried on with a dedicated software (Design Builder) underlines the energy need in terms of $EP_{H,nd}$ and $EP_{C,nd}$ (Figure 14). From this evaluation the importance of a new shading system is underlined to avoid overheating of the living room in the summer season. Four typologies have been selected and compared with the base case (A):

- solution B: internal mobile curtain with t = 0,7 and a = 0,1;
- solution C: internal mobile curtain with t = 0,3 and a = 0,3;
- solution D: external fixed shading (Figure 15)
- solution E: external venetian blinds 30° tilted.

Figure 14 – Energy need in winter, summer and global in kWh/m2

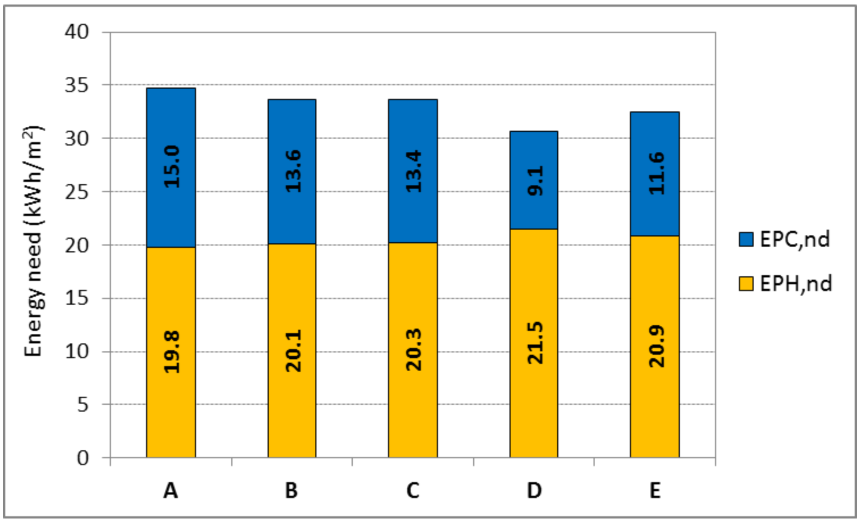
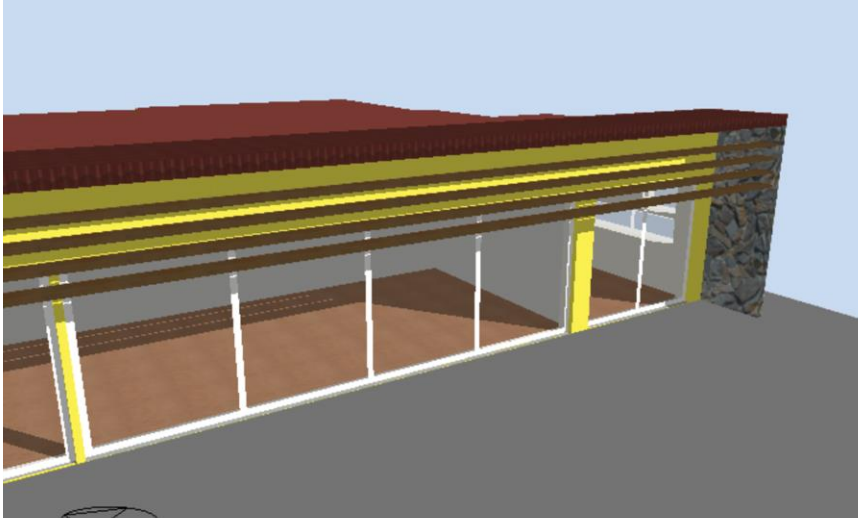


Figure 15 – External fixed shading system for the living room window



5. On site monitoring

In order to comprehend the relationships between calculation and real performances of the building, a monitoring have also been planned.

The on-site monitoring includes the thermal performances of the building envelope, thermal comfort and real energy consumptions. Moreover, a monitoring of energy production from solar panels as well PV on the roof will be carried out.

As regard the evaluation of the thermal performance of the opaque envelope, some surface temperature probes have been added inside two external walls (with different orientation) and inside the roof. These probes will remain inside the components and will provide useful information about the thermal behavior of the platform frame structure in a typical Mediterranean site. Data will be collected all over the year to comprehend the different behavior of the building in the different seasons.

An important element for a complete assessment of the building is the thermal comfort evaluation that will be carried out in some periods when the building will be really used and joined to a survey for the occupants to define relationship between PMV index and utilization patterns.

Figures 16 and 17 report the probes installation inside the wall and the roof.

Figure 16 – Probes installation in the wall layers

Figure 17 – Probes installation in the roof layers

6. Discussion of the results

The analysis on the nZEB building under construction underlined some critical issue, summarized as follows:

- the use of wooden technologies in Mediterranean area has to be carefully evaluated not only with a steady state calculation code but also with a dynamic software in order to underline the relations between envelope and solar shading systems. In this case the use of different solar shading devices leads to a reduction in the energy need for summer cooling up to 27% with an external fixed shading.
- the heterogeneous components need a deep investigation in order to correctly assess the real transmittance values according with UNI EN ISO 10211:2008. as an example, the thermal transmittance of the the external wall calculated in accordance with UNI EN ISO 6946:2008-§ 6.2 is equal to 0,135 W/m^{2}K, 12,5% greater than the value calculated in accordance with UNI EN ISO 6946:2008 so the use of a dedicate software to obtain a more accurate value is needed.
- thermal balance of the building has to be evaluated also during occupation with an on site monitoring of the performance of the envelope with surface temperature probes inside the components layers. Surface temperature probes will monitor all over a year the components behavior.
- energy balance has to be evaluate during occupation with consumption and energy production monitoring. During occupation of the building energy consumptions will be monitored thanks to an home automation system.
- thermal comfort has to be evaluate during occupation and joined to a survey for the occupants to define relationship between PMV index and utilization patterns. A comfort station will be used to assess PMV index related to energy consumptions and occupants behavior.

All these elements are of fundamental importance to improve a correct design process of these technologies in Mediterranean ares when a nZEB target is aimed.

7. Conclusions

The design process and the construction of nZEB building in Mediterranean ares is an important challenge for the reduction of energy consumption of civil buildings.

The complexity of the design process itself needs to be supported by detailed analysis of the component performances taking into account also the summer period.

So the calculation methodologies have to be adapted to heterogeneous components, as platform frame, and the dynamic evaluation is necessary to verify the efficiency of shading device systems.

The validation of the presented methodology will give important information to a better design and construction of these kind of buildings. Once the construction of the building will be finished, all the extra costs necessary to achieve the nZEB target will be analyzed and assessed.

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