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The passive house in Mediterranean area: parametric analysis and dynamic simulation of the thermal behaviour of an innovative prototype

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Abstract

A parametric analysis for an innovative prototype of passive building, located in south Italy and for residential use, has been conducted to evaluate the thermal energy requirements for heating and cooling applications. The investigation was addressed by considering also the aspect of sustainability, by employing natural materials such as dry sand and wood fibre, and the correspondent effects on the energy performances of the envelope. These materials are usually available on site; they increase the building thermal capacity, which represents a crucial aspect for hot climates, and finally could even be reused after building disposal. The construction system based on the completely dry assembling technique makes the exploitation of the mentioned materials possible. The results of the parametric study were obtained by means of the Design Builder dynamic software, by investigating the glazed surfaces, the control of solar radiation and the exploitation of nocturnal free-cooling. A parametric study allowed for optimization of the envelope, by respecting the limit values of 15 kWh/m² suggested by the standard *passivhaus* in its extended formulation for warm climates.

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Keywords: Passive house, Dry assembled opaque walls, Building simulations, Heating and cooling energy needs

1. Introduction

The energy crisis of recent years and the compelling need to face climate change produced by global warming have greatly increased interest in designing sustainable buildings [1]. In modern constructions, the target of *sustainability* is achieved also by using new eco-compatible materials and by testing advanced constructive methodologies, enabling the reuse of all components upon building disposal [2]. The performances of the involved materials and of the constructive technique depend on climatic conditions

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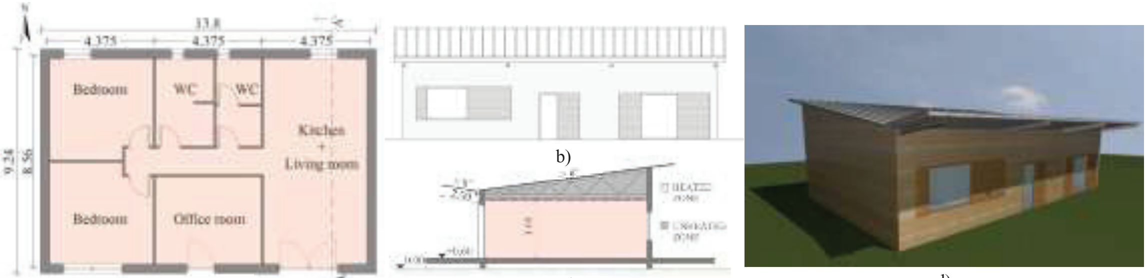
[3], and affect the sizing criteria, particularly in the residential sector [4]. Since the summer energy requirement can be greater than winter one in Mediterranean area [5], the envelope thermal inertia is noteworthy in order to reduce the indoor overheating risk [6]. Moreover, an appropriate insulation thickness in opaque walls and the adopted windowed surfaces must be chosen in relation to the local climate, to avoid that the reduction of the winter needs is lower than the growth of the cooling needs [7]. In order to conciliate the aspects concerning thermal inertia, solar gains and thermal losses, alternative construction systems must be adopted [8].

In this paper, the thermal performances of an innovative envelope, built with dry assembling technology under the climatic condition of south Italy, are investigated. The adopted system provides a major flexibility of use by realizing modular units, reduces construction time and improves the global building quality. The walls are assembled by employing mainly dry sand and wood fibres, in order to increase the thermal capacity, to obtain better dynamic behaviour and to achieve energy savings. In the latter case, reference energy performance indexes of 15 kWh/m²year were adopted, in accordance with the extended formulation of the *passivhaus* standard [9]. These materials, moreover, are natural, widely available on site and could be recovered after building disposal, in order to increase the global sustainability level of the whole structure [10, 11, 12]. The building energy needs were investigated by the dynamic simulation code Design Builder in function of different variables; subsequently, an envelope configuration was detected to optimize energy consumptions.

2. Building envelope description

The investigated building presents an air-conditioned surface of 123.4 m² on one floor with a height of 3 m; the correspondent gross volume is 370.1 m³ resulting in a shape factor of 1.03 [13]. Fig. 1 shows the perspective, plan and section views of the investigated building in the initial conditions. Successively, some characteristics were varied in order to optimize the energy performances.



a) c) d)

Fig. 1 - Reference building: (a) Plan, (b) South façade, (c) A-A' Section, (d) 3D View

Steel beams form the building supporting structure, while the dispersing vertical and horizontal elements are realized in situ and are modular to facilitate envelope assembling. The steel structure allows a faster disassembling than reinforced concrete; the perimeter walls are mounted directly on the frame and present the layering described in Tab. 1. The dry sand with a thickness of 6 cm is confined in two plywood panels fixed by appropriate struts. The insulation layer is in recyclable and biodegradable wood fibre (λ=0.038 W/mK), and also offers good acoustic properties. Tab.1 reports some dynamic characteristics, such as the time shift, the attenuation factor and the periodic transmittance [14]. Fig. 2 shows the external wall composition. The ground floor presents dry sand encapsulated in a cardboard honeycomb structure, positioned under a dry gypsum fibre layer, and uses corrugated steel sheets as the supporting structure (see Tab. 2 and Fig. 3). We simulated the latter as a wall with a fixed boundary temperature approximately equal to the monthly average temperature of the outdoor air [15]. Analogous layering without dry sand was adopted for the pitched roof, not adjacent to the air-conditioned volume due to the presence of a suspended ceiling, with an overall loss coefficient U=0.213 W/m²K.

Table 1. Employed materials in the wall layering

Layer	**Thickness [m]**	**Thermal conductivity λ [W/mK]**	**Specific heat *C* [J/KgK]**	**Density ρ [kg/m^3]**
1.External coating (wood)	0.024	0.130	1600	500
2.Waterproof	0.003	0.200	1000	900
3.Wood fibre panel	0.04	0.038	2100	140
4.OSB Panel	0.02	0.130	1700	650
5. Wood fibre panel	0.12	0.038	2100	140
6.OSB PAnel	0.02	0.130	1700	650
7.Plywood panel	0.015	0.440	1600	600
8.Dry sand and wood struts	0.06	0.579	1000	1558
9.Plywood panel	0.015	0.440	1600	600
10.Gypsum sheet	0.012	0.380	1000	1222
11.Internal coating	0.005	0.380	1000	1600
Total thickness [m]	**0.334**			
Overall loss coeff. [W/m²K]	**0.196**			
Periodic transm. [W/m²K]	**0.015**			
Time lag [h]	**17.23**			
Attenuation factor [-]	**0.078**			

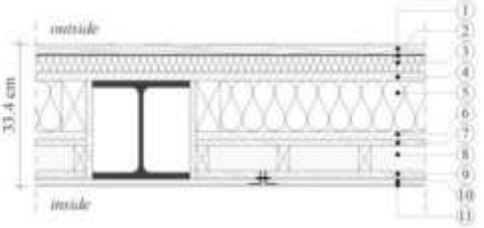
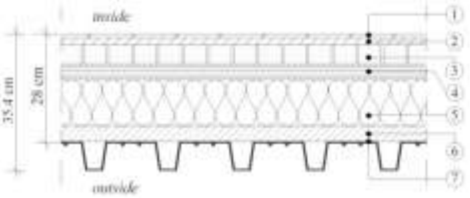


Fig. 2. External vertical wall layering

Table 2. Employed materials in the ground floor layering

Layer	**Thickness [m]**	**Thermal conductivity λ [W/mK]**	**Specific heat *C* [J/KgK]**	**Density ρ [kg/m^3]**
1.Wood covering	0.011	0.145	1600	817
2.Gypsum sheet	0.018	0.380	1000	1222
3.Dry sand	0.05	0.600	910	1700
4.Concrete-wood panel	0.04	0.260	1880	1350
5 Wood fibre panel	0.12	0.038	2100	140
6.OSB panel	0.04	0.130	1700	650
7.Corrugated steel sheet	0.001	50	450	7800
Total thickness	**0.280**			
Overall loss coeff [W/m^{2}K]	**0.250**			
Periodic transm [W/m^{2}K]	**0.030**			

Fig. 3. Ground floor layering



The glazed surfaces are equipped with low-emission panes and are only north facing and south facing (5 m² and 14 m² in the initial configuration), to allow the eventual aggregation of more modular units (see

Tab. 3). An overhang, initially designed as 2 m length and 8° tilted, was provided for the south wall. The energy needs were evaluated for set point temperatures of 20°C and 26 °C, by setting internal thermal fluxes of 4.21 W/m² and a constant air-change ventilation stream of 0.3 vol/h, in continuous plant operation regime [16]. The simulation results were conducted by using hourly climatic data related to the city of Cosenza (Italy, Lat. 39.3°N) [17]. Despite the excellent dynamic characteristics of the walls, in the initial envelope configuration a heating requirement of 7.45 kWh/m² and a cooling requirement of 26.84 kWh/m² were determined. Therefore, a considerable improvement of the summer performances must be achieved in order to respect the limit values of the *passivhaus* standard.

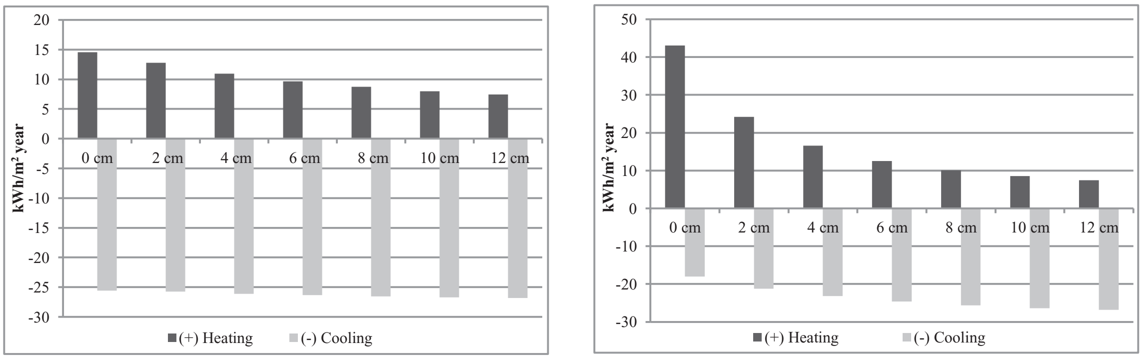
Table 3. Employed glazed surfaces in function of the exposition for the initial envelope configuration

Exposition	**Glass type**	**Solar gain coefficient $g_\perp$**	**Overall loss coefficient U_w [W/m²K]**
North	Low-ε triple pane (ε_2=ε_5=0.1) 3/13/3/13/3 with Argon	0.474	0.780
South	Low-ε double pane (ε2=0.2) 3/13/3 with Argon	0.691	1.712

3. Parametric analysis

In order to contain the cooling demand, without strongly compromising heating requirements, several parameters were modified: the insulation thickness in the walls, the solar gain coefficient and the overall loss coefficient of the windowed surfaces, the percentage of south glazed surface, the overhang length and the nocturnal air flow rate for the summer free-cooling. The thickness of the wood fibre panes in the vertical walls varied from 0 to 12 cm; the latter value produces a reduction of 50% of the heating requirements but it affects the cooling needs marginally, by observing a negligible increment of 5% (Fig. 4a). By varying the insulation thickness in the covering roof, a small reduction of the energy needs both in winter and in summer was determined, while the employment of 12 cm of insulation thickness in the ground floor produces a reduction of 80% of the heating demand, but increases the cooling energy requirements slightly (Fig. 4b).

Several glazed surfaces with different solar gain coefficient ($g_\perp$) and the heat loss coefficient of the transparent surface (U_g) were investigated for the south exposure (see Tab. 4). In Fig. 5 the energy requirements with the considered window system are shown. Small solar gain coefficients allow a substantial reduction of the cooling requirements but a considerable increment of the heating needs. For the windows facing north the exploitation of transparent surfaces with low overall loss coefficients appears appropriate. The variation of the south glazed surface is more significant, as shown in Fig. 6a. By reducing the transparent surface from the initial 14 m² to 9 m², the cooling needs are still higher than the limit value while the winter performances are satisfactory. A further reduction of the cooling needs is achievable by modifying the overhang length (Fig. 6b), by observing that beyond 1.8 m the energy variations are negligible, but the summer limit is still not respected. Therefore, a nocturnal free cooling operating between the 23:00 p.m. and the 7:00 a.m. in the hotter months of June, July and August is strongly required, by allowing a further reduction of the cooling requirements of about 20%.



(a) (b)

Fig. 4. Variation of the building energy requirements with insulation thickness in vertical walls (a) and in function of the insulation thickness in the ground floor (b)

4. Envelope optimization

The envelope in its initial configuration showed good winter performances but inadequate summer energy requirements. We investigated several solutions to reduce the cooling needs, without worsening the heating performances excessively.

Table 4. Thermal and optical characteristics of the investigated windows

CODE	DESCRIPTION	$g_\perp$	U_g [W/m^{2}K]
V1	Low-ε double pane (ε_2=0.1) 6/13/6 with Argon	0.568	1.493
V2	Low-ε double pane (ε_2=0.2) 3/13/3 with Argon	0.691	1.712
V3	Low-ε double pane (ε_2=0.1) 6/13/6 with Air	0.38	1.761
V4	Low-ε double pane Elec Abs Bleached 6/13/6 with Air	0.476	1.616
V5	Low-ε double pane Selective 3/13/6 with Argon	0.432	1.346
V6	Low-ε double pane Selective 3/13/6 with Air	0.433	1.640
V7	Low-ε double pane Selective 6/6/6 with Air	0.315	2.334
V8	Double pane Reflective-A-L t 6/13/6 with Argon	0.136	2.028
V9	Double pane Reflective-C-H 6/13/6 with Argon	0.216	2.209
V10	Double panel Reflective-B-H 6/13/6 with Air	0.248	2.443
V11	Double pane Low Iron 3/13/6 with Argon	0.829	2.556
V12	Double pane clear with 6/13/6 with Argon	0.704	2.511

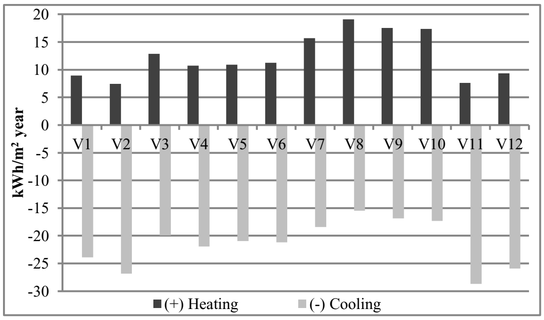
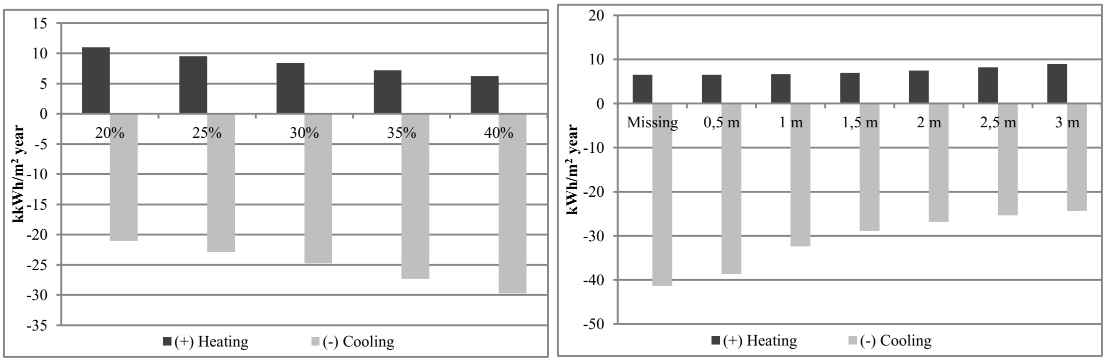


Fig. 5. Energy requirement in function of the thermal characteristics of the South windows



(a)

(b)

Fig. 6. Building energy requirements for the reference building by varying the extension of the glazed surface south facing (a), and the length of the overhang placed on the south wall (b)

The parametric study has highlighted that a suitable solution is the reduction of the insulation layer in the ground floor if the envelope is equipped with large south facing windowed surfaces, in order to facilitate the thermal power transfer toward the soil during summer. However, an adequate compromise with the correspondent increment of the heating requirements must be found. Alternatively, the reduction of the south windowed surface, preferably equipped with panes with low solar gain coefficients, appears more appropriate: the reduction of the winter solar gains is then compensated by the good insulation properties of the envelope walls. Moreover, in order to contain the summer requirements, the exploitation of a summer nocturnal free cooling is also required. By adopting 10 cm of insulation in the ground floor, 7 m² of windowed surface south facing ($g_\perp$=0.691,U_g=1.712 W/m²K), an overhang of 1.8m length and a nocturnal free cooling in summer, the achieved energy performance indexes are 14 kWh/m² and 13.9 kWh/m² per year respectively in winter and in summer. Alternatively, by adopting 9 m² of windowed surface with triple pane also for the south exposure, energy performance indexes of 14.5 kWh/m² and 12.9 kWh/m² per year have been obtained.

5. Conclusions

The energy performances of an envelope realized by a construction system based on the completely dry assembling technique, have been evaluated with the climatic conditions of the south Europe. A construction technique based on the employment of dry walls built with natural materials, such as dry sand and wood fibres, have been used to increase the structure sustainability. In opposition to passive houses built in continental climate, the results obtained by dynamic simulations with the Design Builder software have shown that:

large transparent surfaces with low solar gain coefficients south facing are penalizing for the excessive cooling requirements, which prevail on the reduction of the heating needs;

elevated insulation thicknesses and windows with low heat loss coefficient are equally required to compensate the reduction of the solar gains during winter;

an appropriate insulation thickness in the ground floor must be chosen in order to conciliate the reduction of winter thermal losses with the thermal transfer to the soil during summer;

a fixed overhang on south exposure slightly modifies the energy performance indexes;

the role of free cooling during the nocturnal hours, by working without mechanical ventilation systems, is substantial in order to respect of the summer limit;

windows with triple pane are also appropriate for the south exposure, but prevalently for the reduction of the solar load;

the employment of sand and wood panels in dry assembled walls confers them appropriate thermal inertia reaching satisfactory thermal dynamic characteristics.

An adequate choice of the several parameters which affect the energy performances of the envelope has allowed the achievement of energy performances indexes lower than the value of 15 kWh/m², as suggested from the passivhaus standard in the extended formulation. The results demonstrate that traditional procedures of passive houses built in continental climates are counterproductive in buildings located in the Mediterranean area and realized by means of unusual construction systems to respond to the particular climatic conditions.

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