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Study of innovative solutions of the building envelope for passive houses in Mediterranean areas

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Abstract

In Mediterranean climate, passive houses have to be designed to contrast overheating, considering the dynamic behaviour of the opaque envelope, the effect of shading devices and free-cooling. These aspects prevail on the use of elevated insulation thickness and large windowed surfaces toward South. Innovative technical solutions involving dry assembled opaque walls with natural materials and the role of thermal inertia combined with free-cooling, are investigated. A reference building with thermal energy requirements lower than 15 kWh/m², both in winter and in summer, was identified analysing the thermal bridges in the structural nodes and the rational exploitation of solar heat gains.

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Keywords: dry assembled walls, envelope dynamic behavior, structural nodes, simulations, thermal energy demands

1. Introduction

The theme of sustainability in new buildings has reached considerable importance due to the difficult to attain two apparent conflicting targets: the reduction of the impact on the outdoor environment and the achievement of indoor thermal comfort condition [1]. The environmental impact of a building involves not only its management, but also the construction, the supply of the raw materials, their transportation and the eventual disposal of the same building [2]. The exploitation of particular materials associated to adequate sizing procedures and the employment of renewable

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Nomenclature

f_a	Attenuation factor [-]
$g_\perp$	Normal solar transmittance [-]
g_{gl+sh}	Normal solar transmittance with shading device [-]
κ_M	Thermal capacity per unit area [$J\cdot K^{-1}\cdot m^{-2}$];
M_S	Surface mass [$kg\cdot m^{-2}$]
S	Time shift [h]
U	Thermal transmittances of opaque and transparent walls [$W\cdot m^{-2}\cdot K^{-1}$]
Y_{IE}	Periodic thermal transmittance of opaque walls [$W\cdot m^{-2}\cdot K^{-1}$]

sources to supply the air-conditioning plants, allow for the achievement of sustainable buildings [3]. Compared to traditional constructions, in continental climatic contexts passive houses are designed to attain limited energy consumption in heating applications, because the latter are predominant on cooling demands [4]. For this reason, building walls are equipped with high insulation thickness, to reduce transmission thermal losses, and large glazed surfaces facing South to maximize solar gains. However, if the same approach in warmer climatic context is used, the energy performances of the building are strongly penalized in summer [5]. In Mediterranean areas, in fact, thermal comfort conditions are compromised by indoor air overheating, also in winter. Therefore, building envelopes have to be equipped with suitable technical solutions to favour the nightly natural ventilation and the control of the solar radiation transmitted through glazed surfaces and opaque walls [6]. In the latter case, reduced value of the periodic thermal transmittance are recommended, because adequate time shifts and attenuation factors of the transmitted thermal wave allow for summer thermal loads removal by exploiting the nocturnal free-cooling. Additionally, the envelope sustainability can be improved by reducing the quantity of materials required for its realization, employing natural resources available in proximity of the construction site with the possibility to recover them during the building disposal [7]. In this paper, feasible building opaque envelopes for passive houses located in Mediterranean area and based on the employment of dry assembled walls, have been investigated. The general aim of the present work is the definition of a new housing model contextualized to the Mediterranean climate, which is more responsive to the current needs of the housing market and, at the same time, which addresses the major challenges imposed by the sustainability themes. Dry assembled walls allow for an easy building assembly, whereas an appropriate arrangement of layers with different properties can provide lightweight and robustness building envelope with high thermal inertia [8]. Dry assembled horizontal and vertical walls, with suitable layering systems, are able to realize flexible envelopes and to reduce the construction time. Moreover, the same walls can be built directly on site according to established sizes, in order to minimize the material wastage, and assembling them on appropriate frames, allow for the respect of the local anti-seismic legislation favouring the attainment of aesthetic and functional requirements. In order to validate the actual performances of the best technical solution individuated among the several examined cases, energy evaluations of a reference passive house optimized for the Mediterranean context, have been carried out by dynamic simulations in DesignBuilder® environment [9].

2. Technological criteria adopted for opaque walls

The proposed technological solutions concern a building structure frame made by steel beams, on which dry assembled walls can be easily mounted. The steel frame is required to respect the current seismic standards without compromising the choice of the internal environment subdivision. Moreover, the same frame structure allows a quick installation of ground and ceiling precast floors. Conversely, a steel frame could highlight the presence of thermal bridges, therefore appropriate correction actions have to be analysed adequately. The investigated wall layering systems consider traditional and innovative components to reduce the delivered thermal fluxes, both in winter and in summer, guaranteeing insulation properties and a suitable thermal inertia; the latter is required to rationalize the role of solar heat gains in the building. In winter, these are stored in the inner side and re-used during the night, whereas in summer solar gains are stored into the walls to avoid the indoor air overheating, and successively transferred towards outdoor by exploiting nightly free-cooling. For this reason, massive layers located on the inner surface of the opaque walls were considered, in particular the employment of a low cost and abundant material available in the construction site as the dry sand. In the following section, the investigated layering solutions for horizontal and vertical walls, are described.

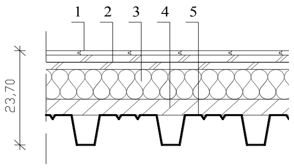
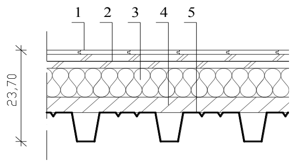
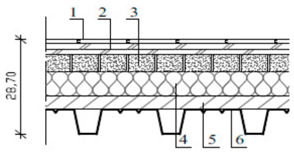
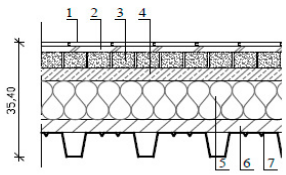
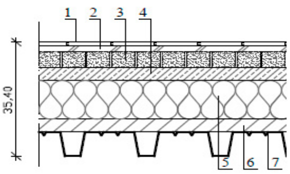
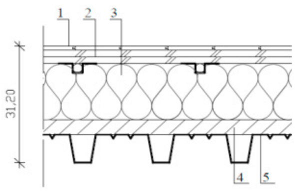
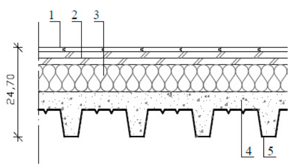
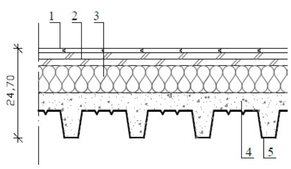
2.1. Ground floor layering

Ground floors transfer noticeable thermal energy towards the soil, therefore they assume a great importance for the energy performance of buildings located in warm climates [10]. These structures have to be sized in appropriate manner, because they have to reduce the winter thermal losses, but they must exploit the same losses as more as possible during summer. Moreover, due to the great available surface, they can be exploited as energy storage systems, therefore the surface mass represents a significant thermal property, as well as the thermal transmittance. Different solutions have been investigated, however in every analysed layering a steel corrugated sheet acts as supporting layer and guarantees the connection with the building frame, whereas wood is the natural material used to realize the internal covering. This typology of ground floor is an example of "uncooperative" system, where the steel corrugated sheet constitutes the floor deck without the employment of concrete binder. In some basement configurations, dry sand contained in honeycomb cardboard, or employed as filler material in the corrugated sheet, has been considered to increase the thermal capacity. Other layers, such as composite panels in concrete-wood, OSB panels and layers of gypsum fibres have been involved to increase the structure robustness. Regarding the insulation layer, different materials were investigated: cork panels, wood fibre panels, mineralized wood wool panels, mineral wool. In order to make a comparison with traditional insulation materials, a ground floor configuration equipped with expanded polystyrene, was also considered. In Tab. 1 the main thermal parameters of the layers employed for vertical and horizontal walls, deduced from EN ISO 10456 standard, are listed [8]. In Tab. 2, the layers constituting the investigated solutions of the ground floor, are described and shown. The insulation material represents the difference between B.1 and B.2 solutions, because in the latter mineral wool replaces the layer of mineralized wood wool. Compared to the B.1 solution, the B.3 system presents an additional dry sand layer to increase the thermal mass. Solutions B.4 and B.5 employ different insulation layers (composite panel, wood fibre and cork), while B.6 is equipped with a traditional layer of expanded polystyrene. Finally, a mineralized wood wool panel is contemplated in B.7 with thermal mass growth obtained by dry sand filled in the corrugated sheet; in B.8, an insulation layer of wood fibre panel replaces the wood wool.

Table 1. Thermo-physical characteristics of the involved materials.

Material	ρ [kg· m^{-3}]	c_p [J·kg^{-1}·K^{-1}]	Ms [kg·m^{-2}]	λ [W·m^{-1}·K^{-1}]
Wooden floor	817	1600	9	0.145
Wooden coating	500	1600	12	0.130
Gypsum fibre sheet	1222	1000	22	0.380
Gypsum	1600	1000	16	0.800
OSB panel	650	1700	26	0.130
Reinforced concrete panel	1150	1000	14	0.350
Wood fibre panel	140	2100	11	0.038
Mineralized wood wool	347	1810	26	0.065
Plywood panel	600	1600	9	0.440
Cork panel	150	1674	6	0.041
Concrete-wood comp. panel	1350	1880	54	0.260
Dry sand	1700	910	85	0.083
Steel corrugated sheet	7800	450	8	50.00
Waterproofing	900	1000	2.7	0.200
Waterproofing skim coat	1700	1200	5.1	0.560
Breathable membrane	343	1700	0.19	0.220
Expanded polystyrene	20	1450	3	0.035
Expanded polyurethane	38	1400	1.9	0.024

Table 2. Layering of the investigated basement floors.

B.1		1. Wooden floor 2. Gypsum fibre layer 3. Mineralized wood wool 4. OSB panel 5. Steel corrugated sheet	1.1 cm 3.6 cm 7.5 cm 4.0 cm 0.1 cm (7.5 gross)
B.2		1. Wooden floor 2. Gypsum fibre layer 3. Mineral wool 4. OSB panel 5. Steel corrugated sheet	1.1 cm 3.6 cm 7.5 cm 4.0 cm 0.1 cm (7.5 gross)
B.3		1. Wooden floor 2. Gypsum fibre layer 3. Dry sand 4. Mineralized wood wool 5. OSB panel 6. Steel corrugated sheet	1.1 cm 3.6 cm 5.0 cm 7.5 cm 4.0 cm 0.1 cm (7.5 gross)
B.4		1. Wooden floor 2. Gypsum fibre layer 3. Dry sand 4. Concrete-wood composite panel 5. Wood fibre panel 6. OSB panel 7. Steel corrugated sheet	1.1 cm 1.8 cm 5.0 cm 4.0 cm 12.0 cm 4.0 cm 0.1 cm (7.5 gross)
B.5		1. Wooden floor 2. Gypsum fibre layer 3. Dry sand 4. Cork panel 5. Wood fibre panel 6. OSB panel 7. Steel corrugated sheet	1.1 cm 1.8 cm 5.0 cm 4.0 cm 12.0 cm 4.0 cm 0.1 cm (7.5 gross)
B.6		1. Wooden floor 2. Gypsum fibre layer 3. Expanded polystyrene 4. OSB panel 5. Steel corrugated sheet	1.1 cm 3.6 cm 15.0 cm 4.0 cm 0.1 cm (7.5 gross)
B.7		1. Wooden 2. Gypsum fibre layer 3. Mineralized wood wool 4. Dry sand 5. Steel corrugated sheet	1.1 cm 3.6 cm 7.5 cm 5.0 cm 0.1 cm (7.5 gross)
B.8		1. Wooden floor 2. Gypsum fibre layer 3. Wood fibre panel 4. Dry sand 5. Steel corrugated sheet	1.1 cm 3.6 cm 7.5 cm 5.0 cm 0.1 cm (7.5 gross)

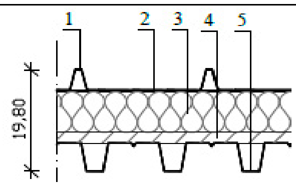
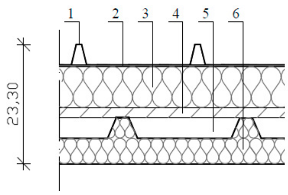
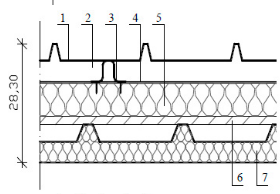
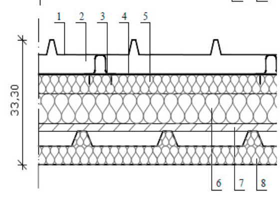
The role of the dry sand concerns not only the increment of the thermal mass, but represents a good solution as acoustic absorber and a suitable layer where technical plants can be placed. OSB panels are particularly suitable for support functions, widely used for flooring, roofing and cladding of walls, but also in other applications where they are used as functional structural elements. Gypsum fibre sheets are usually employed as dry levelling slab instead of traditional light-concrete slabs. Concrete-wood composite panels combine good insulation and structural properties. The considered materials, opportunely assembled, are able to realize building envelopes with several positive properties:

- reduce the construction time;
- improve the thermal and acoustic characteristics;
- are fire-resistant;
- allow for an easy structure inspection;
- realize light-weight structures with acceptable thermal capacity;
- facilitate the technical plant installation;
- can be recovered during the building demolition.

2.2. Ceiling floor layering

Ceiling floors have to guarantee high thermal inertia and impermeability to rainfall. The role of the thermal inertia of horizontal or pitched roofs is more evident in summer, because higher solar paths allow for remarkable thermal loads transferred through the structure. Therefore, materials with higher thermal capacity and waterproof coatings have been involved; in some solutions, the layers layout allows for a natural ventilation of the ceiling to reduce the effects of the absorbed solar radiation. The supporting structure is constituted by one or more steel corrugated sheets, by exploiting materials already described for the ground floor. The Tab. 3 lists the examined configurations.

Table 3. Layering of the investigated ceiling floors.

C.1		1. Steel corrugated sheet	0.1 cm (4 cm gross)
		2. Waterproofing	0.3 cm
		3. Wood fibre panel	8.0 cm
		4. OSB panel	2.0 cm
		5. Steel corrugated sheet	0.1 cm (5.5 cm gross)
C.2		1. Steel corrugated sheet	0.1 cm (4 cm gross)
		2. Waterproofing	0.3 cm
		3. Mineral wool wood	8.0 cm
		4. OSB panel	2.0 cm
		5. Air-gap	5.0 cm
		6. Steel corrugated sheet	0.1 cm (4 cm gross)
C.3		1. Steel corrugated sheet	0.1 cm (4 cm gross)
		2. Air-gap	5.0 cm
		3. Metallic support	- cm
		4. Breathable membrane	0.3 cm
		5. Mineral wool	8.0 cm
		6. OSB panel	2.0 cm
		7. Air-gap and steel corrugated sheet	0.1 cm (9 cm gross)
C.4		1. Steel corrugated sheet	0.1 cm (4 cm gross)
		2. Air-gap	5.0 cm
		3. Metallic support	- cm
		4. Breathable membrane	0.3 cm
		5. Concrete-wood composite panel	5.0 cm
		6. Wood fibre panel	8.0 cm
		7. OSB panel	2.0 cm
		8. Air-gap and steel corrugated sheet	0.1 cm (9 cm gross)

Compared to the C.1 solution, C.2 is equipped with an additional insulation layer of mineral wool, an internal air-gap and a different displacement of the lower corrugated sheet. C.3 layering involves a ventilated air gap on the external side, whereas wood fibre panel and an additional composite panel as insulation material, are employed in the C.4 solution (with ventilated air gap). Contrarily to the first solution, ceiling configurations C.2, C.3 and C.4 employ insulated corrugated steel sheet panels.

2.3. Vertical walls layering

The employment of precise layers sequences has to ensure in a unique element the properties of thermal and acoustic insulation, the structural load transmission towards the ground, the internal space partition and the fire-resistance. These features can be reached especially assembling appropriate panels that allow:

- quick building fabric assembling;
- possibility to modify the panels in appropriate size by engraving and cutting techniques;
- panel connection to the structure frame by self-supporting screws;
- high impact strength and wind resistance;
- stability to the thermal stress due to the night-day temperature cycles;
- absence of crumbling or swelling effects due to moisture absorption.

For every investigated solution, the achievement of suitable values of steady and periodic thermal transmittances, are required [11]. In order to reinforce the vertical wall, an internal metallic frame realized with standardized profiles, is adopted. The several layering are described in Tab. 4, starting from the external to the internal side. The W.1 system uses wood fibre panels as insulation material, and reinforced concrete panel to give rigidity to the structure. Contrarily, the W.2 solution employs the same materials, but the insulation layer and an additional air gap on the internal side were added. In order to facilitate the wall assembly, W.3 system is equipped with pipes to dislocate loose sand, and an additional insulation layer (wood fibre panel). The W.4 solution is constituted by encapsulated dry sand located in the air gap (inside appropriate bags) on the internal side, whereas tubes containing dry sand, a higher insulation thickness and other elements that confer major robustness to the wall, constitute the W.5 vertical wall. A precast and reinforced system, composed by plywood panels containing dry sand, and a layer of expanded polyurethane, are employed in the W.6 solution. Finally, the W.7 configuration uses wood fibre panels as insulating layer to replace the expanded polyurethane. Conservatively, thermal properties of dry loose sand do not consider the encapsulating material properties and the additional thermal resistances due to the creation of air gaps.

3. Thermal characterization of the proposed opaque walls

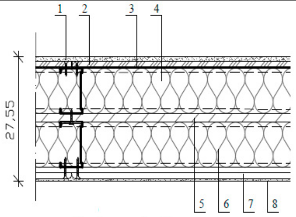
By means of the data reported in Tab. 1, the following thermal parameters for vertical walls and ceiling floors have been calculated, and the correspondent results listed in Tab. 5:

- thermal transmittance;
- periodic thermal transmittance;
- surface mass;
- thermal capacity per unit area;
- time shift of the thermal wave;
- attenuation factor of the thermal wave;

Regarding the ceiling floors, the solution C.1 offers an acceptable value of the thermal transmittance, but the structure provides a high periodic transmittance value (higher than the limit value set by the current Italian legislation in the field of building energy performances), therefore dynamic parameters can be further improved [12].

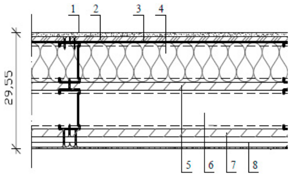
Table 4. Layering of the investigated vertical walls.

W.1



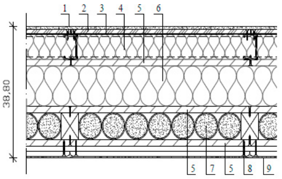
1.	Gypsum	0.5 cm
2.	Reinforced concrete panel	10.0 cm
3.	Waterproofing	0.3 cm
4.	Wood fibre panel	2.0 cm
5.	OSB panel	2.0 cm
6.	Woos fibre panel	10.0 cm
7.	Two gypsum sheets	2.2 cm
8.	Gypsum	0.5 cm

W.2



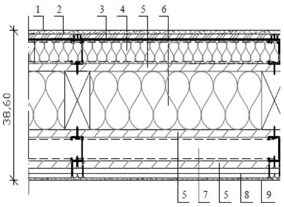
1.	Gypsum	0.5 cm
2.	Reinforced concrete panel	10.0 cm
3.	Waterproofing	0.3 cm
4.	Wood fibre panel	7.0 cm
5.	OSB panel	2.0 cm
6.	Air gap	7.0 cm
7.	Two gypsum sheets	2.2 cm
8.	Gypsum	0.5 cm

W.3



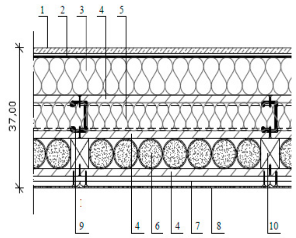
1.	Gypsum	0.5 cm
2.	Reinforced concrete panel	10.0 cm
3.	Breathable membrane	0.3 cm
4.	Wood fibre panel	4.0 cm
5.	OSB panel	2.0 cm
6.	Wood fibre panel	12.0 cm
7.	Dry sand encapsulated in pipes	7.0 cm
8.	Two gypsum sheets	2.5 cm
9.	Gypsum	0.5 cm

W.4



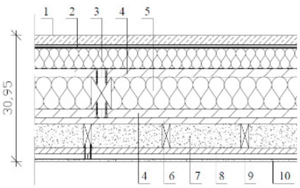
1.	Gypsum	0.5 cm
2.	Reinforced concrete panel	10.0 cm
3.	Waterproofing	0.3 cm
4.	Wood fibre panel	4.0 cm
5.	OSB panel	2.0 cm
6.	Wood fibre panel	12.0 cm
7.	Air gap	6.8 cm
8.	Two gypsum sheets	2.5 cm
9.	Gypsum	0.5 cm

W.5



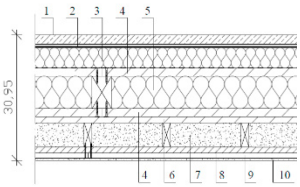
1.	Wood coating	1.5 cm
2.	Waterproofing + air gap	2.3 cm
3.	Wood fibre panel	12.0 cm
4.	OSB panel	2.0 cm
5.	Wood fibre panel	5.5 cm
6.	Dry sand encapsulated in pipes	7.0 cm
7.	Two gypsum sheets	2.2 cm
8.	Gypsum	0.5 cm
9.	Metallic support	5.5 cm
10.	Wooden studs	7.0 cm

W.6



1.	Wood coating	3.3 cm
2.	Waterproofing + air gap	1.3 cm
3.	Expanded polyurethane	4.5 cm
4.	OSB panel	2.0 cm
5.	Expanded polyurethane	9.0 cm
6.	Plywood panel	1.5 cm
7.	Encapsulated dry sand	6.8 cm
8.	Plywood panel	1.0 cm
9.	Gypsum sheet	1.0 cm
10.	Gypsum	0.5 cm

W.7



1.	Wood coating	3.3 cm
2.	Waterproofing + air gap	1.3 cm
3.	Wood fibre panel	4.5 cm
4.	OSB panel	2.0 cm
5.	Wood fibre panel	9.0 cm
6.	Plywood panel	1.5 cm
7.	Encapsulated dry sand	6.8 cm
8.	Plywood panel	1.0 cm
9.	Gypsum sheet	1.0 cm
10.	Gypsum	0.5 cm

In the solution C.2, the natural ventilation in the air-gap is activated exclusively in summer to favor the removal of the absorbed solar radiation, while the insulation layer is represented by mineral wool and corrugated steel sheet. This configuration allows for an evident improvement of the thermal transmittance and of the dynamic parameters. Moving the air-gap on the external side (solution C.3), thermal transmittance and periodic transmittance assume better values, with S=5.9 hours and f_a lower than 0.43. If wood fiber and concrete-wood panels are adopted as insulation layers (solution C.4), the thermal performances are further improved by reaching a thermal transmittance lower than 0.200 $W·m^{-2}·K^{-1}$, with S=12.9 hours and f_a= 0.152.

Regarding vertical opaque walls, OSB panels and a double insulation layer of wood fiber panel (solution W.1), provide good performances, but the structure is too light-weight. Replacing the wood fiber panel with encapsulated sand (W.2), the specific mass is considerably increased, with performances indexes slightly variable. If loose dry sand is dislocated into pipes (W.3), by adding a supplementary insulation layer on the external side, optimal performances in terms of thermal losses and dynamic behavior, are detected. A double insulation layer of wood fibre panels, without encapsulated dry sand on the inner side (W.4), provides good performances, but the total wall thickness is greater than the prior analyzed solutions. A further improvement can be achieved by filling the air-gap with loose sand, but this solution could provide structural problems with possible panel buckling.The solution W.5 employs newly dry sand in metallic pipes, but the external side is made by wood coating to form a reduced ventilated air-gap. Good thermal transmittance values have been determined, as well as dynamic parameters, but the displacement of the loose sand in the pipes lead to a non-homogenous massive layer. A combination of expanded polyurethane and precast massive layers (W.6), the latter realized with loose sand contained between plywood panels reinforced by wood studs, provides good results, but the structure is too lightweight also in this case. Finally, in the W.7 solution, wood fibre panels replace the expanded polyurethane, providing better dynamic parameters but an increment of the thermal losses through the wall.

Regarding the ground floor, thermal transmittances varying between 0.206 $W·m^{-2}·K^{-1}$ (B.6) and 0.618 $W·m^{-2}·K^{-1}$ (B.7), were detected. These solutions produce lightweight ground floor, while the configuration B.5 seems to be the best compromise between thermal transmittance (0.248 $W·m^{-2}·K^{-1}$) and surface mass (220 $kg·m^{-2}$). In Tab.5, the best considered thermal properties are highlighted in bold; regarding the ceiling, the C.4 system presents the best performance indexes, except the thermal capacity per unit of area. With reference to vertical walls, W.3 provides good results in terms of periodic transmittance and surface mass, while W.4 offers the greatest time shift and W.6 is preferable to reduce thermal losses and to store solar gains. However, dynamic simulations carried out on a reference building with actual climatic data will identify the optimal solution in order to detect the layering system that better conciliates the winter and the summer conflicting needs, in terms of minimal annual thermal energy requirements.

Table 5. Main thermal properties of the vertical walls and ceiling floors.

Solution	U [$W·m^{-2}·K^{-1}$]	Y_{IE} [$W·m^{-2}·K^{-1}$]	M_S [$kg·m^{-2}$]	κ_M [$J·K^{-1}·m^{-2}$]	S [h]	f_a [-]
C.1	0.414	0.353	42.5	**25610**	3.9	0.916
C.2	0.195	0.080	17.1	8565	5.9	0.426
C.3	0.195	0.081	32.9	8731	5.9	0.427
C.4	**0.185**	**0.027**	**109.2**	8731	**12.9**	**0.152**
W.1	0.176	0.022	100.0	22000	14.7	0.130
W.2	0.292	0.033	267.1	121450	13.2	0.118
W.3	0.168	**0.004**	**275.6**	124201	20.9	**0.024**
W.4	0.158	**0.004**	229.7	121450	**21.4**	0.026
W.5	0.173	0.005	255.0	124201	19.6	0.030
W.6	**0.136**	0.013	177.8	**133581**	14.0	0.098
W.7	0.216	0.023	188.6	**133581**	15.8	0.105

4. Structural nodes and thermal bridges

Referring to the proposed structures, several critical points have to be analysed to evaluate suitable solutions able to contrast the thermal bridge effect:

- the coupling between vertical walls and steel pillars;

- the intersection between the ground floor and the perimeter walls;
- the intersection between ceiling floor and the perimeter walls;
- the coupling between the windowed system and the correspondent wall;

In the first case, the complete integration of the vertical walls with the discontinuous points represented by the steel pillars, is required. Therefore, the homogeneous insulation system on the external side of the vertical wall common to the examined solutions, is appropriate. In order to facilitate the wall assembly, see Fig. 1, a steel plate (a) settled on the HE 200 pillar sides is required. By supposing the employment of the W.7 solution, the external OSB panel and the external wood fibre panels assure the continuity of the insulation layer on the external perimeter of the building envelope.

Regarding the second structural node, the steel corrugated sheet of the ground floor has to be joined with the steel frame; at the same time, the internal part of the vertical wall W.7 (layers n. 5, 6 and 7) has to be installed before the floor insulating layer. Successively, the precast panel containing the loose sand can be installed on the ground floor, by employing a stiffening beam to prevent insulation crushing of the floor, putting in place also the massive layer of the same ground floor (see Figure 2 where the exploitation of the B.5 system is supposed). This method allows for a continuity of the insulating layer between the horizontal and the vertical walls, forming a continuous insulation skin around the building envelope.

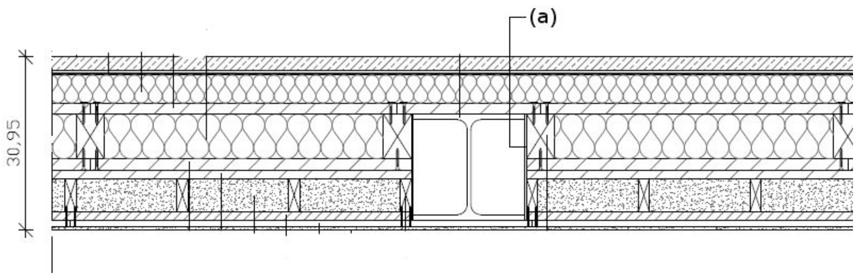


Fig. 1. Particular of the coupling between vertical wall and steel pillar.

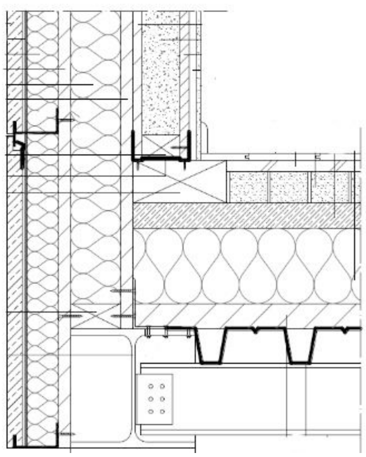


Fig. 2. Particular of the lowest vertical/horizontal wall junction.

In order to join the ceiling floor and the vertical wall, only the external side of the vertical wall continues until the highest part of the envelope, in order to realize the ceiling insulation layer hooking and to guarantee the insulation continuity. The latter has to be installed successively the vertical wall, and it has to be assembled layer after layer to ensure the pillars connection and the uniformity of the insulation layer on the external side of the building envelope (see Fig. 3 where a connection between C.4 and W.7 systems is shown).

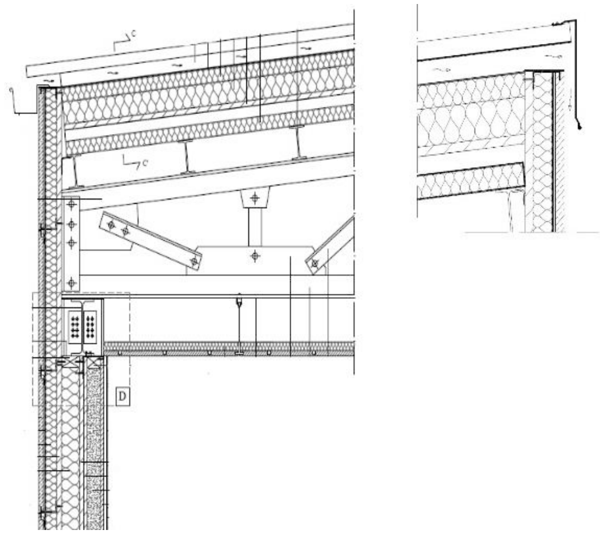


Fig. 3. Particular of the highest vertical/horizontal wall junction.

For the window-wall connection, three wood beams on the sides and the upper part of the wall hole, sized to support the vertical massive layer, are required. The thermal bridge linked to the sill presence is attenuated by rigid foam of EPS, while the external insulation layer continues on the inner side of the wall hole until the window frame.

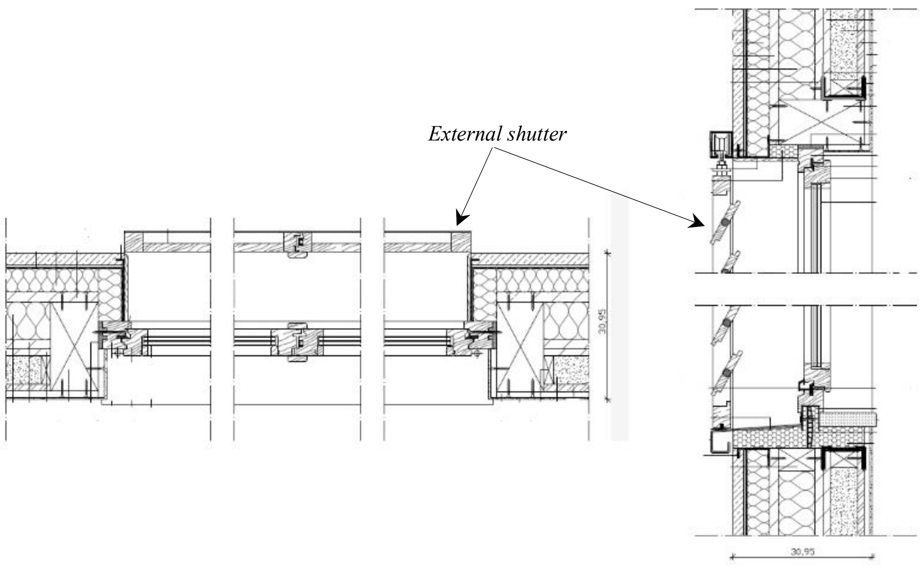


Fig. 4. Particulars of window/wall connection.

5. Energy performances evaluation

The results listed in Tab. 5 do not allow for the identification of the best typology of opaque elements, which provide the best building configuration with the minimum values of heating and cooling requirements. Generally, a good compromise between thermal losses, energy gains and thermal storage has to be identified. Well-insulated walls reduce the heating needs but, at the same time, impede the beneficial thermal losses during summer, with consequent cooling demand growth. Analogously, large windowed surfaces could decrease heating demands but the overheating risk in summer increases. Therefore, typical solutions exploited to limit heating energy requirements always produce an increment of the cooling demands, and vice versa. An accurate choice of the main design parameters of the building envelope must be carried out in order to obtain the minimal energy requirements at annual level. In order to achieve this target, also the thickness of the insulation layer in the considered wall configurations, was varied. For this reason, energy evaluations developed by DesignBuilder code on a reference building located in Cosenza (Italy, 39.3 °N), varying the typology of the considered opaque walls, were carried out with actual climatic data [13].

The common parameters of the reference building (Fig. 5) concern:

- the size (gross dimensions of 9.24×13.8×3 m);
- 5 m² and 9 m² of windowed surface on North and South exposures, realized by low-emissivity triple-pane 3/13/3/13/3 with Argon ($g_{\perp}$=0.474, U = 0.78 $W \cdot m^{-2} \cdot K^{-1}$) and wooden frame (20%);
- an overhang of 1.5 m South facing;
- a nightly natural ventilation of indoor environment in the summer months starting from 23:00 p.m. to 7:00 a.m;
- absence of internal mobile shading devices;
- external window shutters closed only during night;
- verified absence of interstitial condensation phenomena inside the walls;
- set point air temperature of 20 °C in winter and 26 °C in summer;

Windowed surfaces on the East and West exposures are not present in order to allow the assembly of larger structures (modular building fabric). Regarding the vertical surfaces, the percentage of glazed surface is 10%, the roof solar reflectance is 70% and the solar absorption coefficient of external walls is 35%. The envelope transmission mean loss coefficient is 0.286 $W \cdot m^{-2} \cdot K^{-1}$, about a half of the limit value set by the current Italian legislation. The ratio of the equivalent summer area of glazed surfaces to the useful floor area is slight lower than 0.03, in accordance with the regulations for the containment of summer energy consumptions. The equivalent area was determined with a shading reduction factor due to the overhang of 0.525 for the windows South facing and a correction factor of the incident solar radiation equal to 0.924. The limit values of the thermal energy requirements for heating and cooling, calculated in function of a reference building with the same size and with standardized thermal parameters, are respectively 35.7 $kWh \cdot m^{-2}$ and 6.7 $kWh \cdot m^{-2}$. The latter value is very limited due to the presence of mobile shading devices in the reference building that provide a reduced corrected solar transmittance value (g_{gl+sh}=0.35). Verifications on the plants concerning heating, cooling and DHW have not been carried out because the analysis is limited only to the thermal energy requirements.

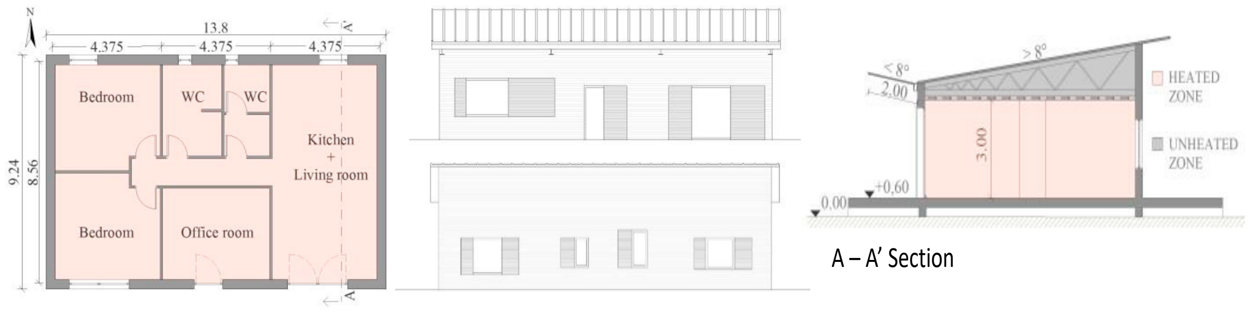


Fig. 5. The reference building considered for energy evaluations.

The results of the several simulations have shown:

- the best wall configuration is W.7, but increasing the thickness of insulation layer to 12 cm and removing the OSB panel in the middle to contain the global thickness, obtaining a thermal transmittance of 0.196 $W \cdot m^{-2} \cdot K^{-1}$, a time shift slightly greater than 17 h and attenuation factor of 0.078;
- the best configuration for the pitched roof is represented by the C.4 solution;
- the best solution for the ground floor is B.4 reducing the insulation thickness to 10 cm because this choice allows for a reduction of cooling requirements that prevails on the heating demand growth, obtaining a thermal transmittance of 0.288 $W \cdot m^{-2} \cdot K^{-1}$and a slight decrement of the superficial mass.

The low value of the normal solar transmittance of glazing allows for a rational exploitation of solar radiation during summer, and the reduced value of the thermal transmittance, that provides limited thermal losses in the same season, is compensated by the exploitation of the nightly free-cooling. The role of the latter is significant, because it allows for the removal of the energy gains stored into the massive layers during the day. The absence of the free-cooling does not allow the achievement of cooling energy requirements lower than 15 kWh/m^2. Finally, the reference building in the analyzed configuration and equipped with the identified solution for the opaque walls is characterized by a seasonal heating energy requirement of 14.5 kWh/m^2 and a seasonal cooling energy requirement of 12.9 kWh/m^2. The latter can be further reduced by exploiting mobile shading device obtaining a seasonal cooling demand lower than the limit value of 6.7 kWh/m^2.

6. Conclusions

The sustainable building involves not only its management, but also its construction, the supply of raw materials, their transportation and the reuse of the same after the building disposal. Therefore, appropriate materials have to be chosen in the design phase in order to attain these objectives. In this paper, a building envelope equipped with dry assembled walls realized by traditional and natural materials, was investigated. The proposed opaque wall configurations combine different aspects concerning technological innovation, energy saving and rational exploitation of resources. Passive house in continental climatic contexts are designed mainly to reduce heating energy demands, by using elevated insulation thickness in the opaque wall and large windowed surfaces toward South. The same approach in warm climatic is inappropriate, because the risk of indoor air overheating is marked, especially in summer. For this reason, dynamic properties of opaque walls assume a significant role. In order to make the building envelope more responsive to the climatic characteristics of the Mediterranean area, the employment of dry loose sand inside the structures, to increase the thermal mass, was considered. Dry sand represents an abundant and cheap material largely available on the construction site. These walls can be modelled in appropriate size directly in the construction site to reduce the material wastage, successively these can be mounted on metallic frame by screw systems reducing the construction time and respecting the seismic standards. Different installation techniques to contrast the thermal bridge effect in the structural nodes have been analysed and appropriate solutions were proposed. Dynamic simulations carried out by Design Builder software have highlighted the good dynamic properties of the investigated opaque walls, and have allowed to identify the best envelope configuration able to minimize the annual thermal energy requirements. The results show the significant role in summer of the combined use of thermal storage located in the internal side of the wall and the nightly free-cooling. For the South exposure, windows with triple panes appear appropriate because they represent a good compromise between the reduction of thermal losses and the exploitation of solar gains. In particular, the decrement of the winter thermal losses prevails on the reduction of the solar gains due to the limited solar transmittance value. In summer, the latter represents an advantage, and the cooling demand growth due to limited thermal losses is compensated by the employment of the nightly free-cooling. A reference building designed applying the identified solutions and located in the South Italy has provided thermal energy requirements lower than 15 kWh/m^2 both in winter and in summer, respecting the limit suggested by the *passivhaus* standard in its extended formulation. The cooling energy requirements value were determined avoiding the use of movable internal or external shading devices, therefore further improvement can be reached.

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