Energy performances of a passive house for Mediterranean climate: a case study

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Abstract

An energetic analysis of an office building located in southern Italy and properly designed to have energy consumption almost zero, has been carried out by means of the Design Builder simulation software. The choices of opaque surfaces, glazed surfaces and appropriate external shading devices have been made to reconcile the different and conflicting needs of the investigated building. Several simulations of different opaque surfaces have allowed the choice of adequate materials for the dispersing walls, to reduce thermal losses and attenuate summer thermal waves. Glazed surfaces have been conveniently selected, to exploit their optical properties both in winter and in summer. Finally, an appropriate sizing of unmovable external shading devices has allowed the optimization of winter solar gain and the reduction of summer solar load. These choices have demonstrated that, in Mediterranean climate conditions, the design process of the building envelope follows a completely different approach compared to the method typically used for the realization of passive houses conceived for continental climates. With reference to the primary energy requirements, simulation results have been used to design a proper generation system coupled with active solar systems in order to obtain a NZEB building.

1. Introduction

The passive house can be defined as a set of technical sizing criteria, focused on the construction of a building in which the energy consumptions are almost "zero" (Gonzalo and Vallentin, 2014). The passive house concept has been developed in the last twenty years, in order to find a solution to the increase in building energy consumptions, by means of the exploitation of particular heating and cooling plants coupled to appropriate building envelopes (Jacobson, 2014). In the Mediterranean region, the energy consumption is high in office buildings, where the summer energy requirements are usually greater than the winter energy requirement (Ferrante, 2012). Moreover, these requirements are continuously increasing due to design criteria that do not take in account the geographic context (Mlakar and Strankar, 2013). Nowadays, with reference to the first prototype built in 1990 (Van Huffelen, 1992), the passive house system has notably improved, offering evident advantages compared to traditional houses. However, designers do not take sufficiently in account that the climate characteristics of the geographical area, where the first model has been built and optimized, are typical of central Europe. Consequently, the realization of the successive passive houses are characterized by building envelopes sized mainly to provide a good behaviour for severe winter weather conditions. This local and geographical aspect results in the development of sizing procedures that considers large south-facing windows and high insulation thickness in the dispersing opaque walls.

These procedures, however, are not an ideal solution in the Mediterranean areas, where the climate conditions are markedly different from those of continental Europe. Moreover, an excessive exposure to solar radiation usually results in an overheating of the indoor environment, also in the heating period, with a correspondent worsening of the thermal comfort. Consequently, the controversies relative to the exploitation of the standard passive houses procedures in the Mediterranean region are still much debated (Ferrante and Cascella, 2011). Nevertheless, the key concept of passive house remains valid also in Mediterranean areas and so the development of new construction techniques for new building systems, which keep the indoor air temperature comfortable both in summer and in winter, with a minimal contribution of the air conditioning plants, is requested.

In this paper, the results provided by the dynamic simulation code Design Builder have been used to evaluate the most suitable construction procedures of passive houses in Mediterranean climate conditions. With reference to an office building, a parametric study of the properties of walls and transparent surfaces and of unmovable shading systems has been carried out. Heating energy requirements are calculated supposing a 24-hour plant operation, according to the Italian regulations (DPR 59/09, 2009; DL 102/2014, 2014; EN ISO 13790, 2008).

This study has allowed the most appropriate choice of the main components, the criteria for choosing transparent surfaces and type and size of the correspondent shading systems. Finally, the energy labelling of the investigated building has been carried out, considering a generation system of the air-conditioned plant coupled with active solar systems.

2. The reference building

The investigated building is shown in Fig. 1; it consists of an air-conditioned ground floor, with rooms having a net height of 2.7 m, and a correspondent gross volume of 291 m³. Large glazed surfaces are located on the south-facing wall, while the west façade is equipped with more limited transparent surfaces. The space under the pitched roof, oriented toward south with 10° tilt to allow a suitable installation of active solar systems, is not conditioned. The lightweight roof is made of two metallic frames to interpose a compact high density insulation layer (polyurethane, λ=0.032 W/mK), with a global heat loss coefficient (U_{roof}) of 0.265 W/m²K and a periodic thermal transmittance Y_{IE} of 0.12 W/m² K. The inner volume is conditioned by means of a suspended radiant celling system, with an active surface made of plasterboard and insulated by a polyurethane layer, with pipes located in parallel. The ground floor is insulated by 6 cm of polystyrene with a bottom layer made of 50 cm of gravel to limit the water rise by capillarity. The correspondent heat loss coefficient (U_{floor}) is 0.360 W/m²K.

The building investigated is located in Cosenza (southern Italy, latitude of 39.3°N) characterized by climatic conditions which consist in warm winters and hot summers. The main weather parameters are listed in Tab. 1 at monthly average daily level.

Nowadays, in accordance with the accepted standards, the investigated building can be considered passive if an energy performance index of the air conditioned volume, equal to 5.55 kWh/m³, evaluated with reference to the thermal energy requirements, is reached both in winter and in summer (Wienke, 2002).

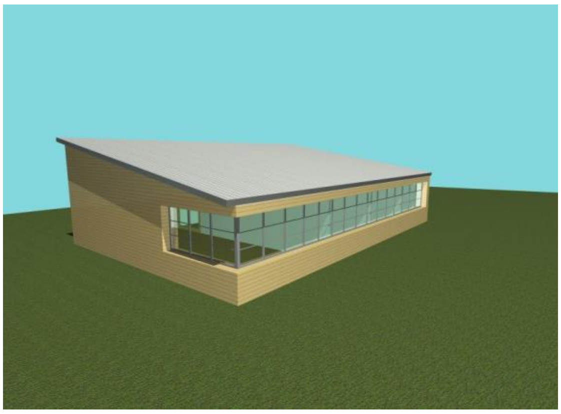


Fig. 1 – The investigated building

3. Opaque surface simulation

Four different typologies of opaque dispersing walls have been considered.

• Traditional wall with hollow bricks, representative of a typical constructive solution diffused in the Mediterranean area: the masonry envelope is made of solid or perforated brick, depending on the structural function of the wall. The thermal insulation is located on the external side to attenuate thermal bridges, therefore the thermal mass is concentrated towards the inside. Figure 2 shows the stratigraphy of the brick wall used in the simulation. Tables 2 and 3 summarize the main layer thermal properties and the wall thermal performance indexes. In particular, in Tab. 3 the values of overall loss coefficient U, surface mass SM, thermal periodic transmittance Y_{IE}, phase shift PS and attenuation factor AF of the thermal wave are reported. The overall loss thermal coefficient has been calculated considering external and internal surface resistances respectively equal to 0.04 m²K/W and 0.13 m²K/W. The surface mass was calculated without considering the thickness of internal and external plaster layers, in accordance to the Italian normative (Italian Decree DPR 59/09, 2009). The dynamic parameters have been determined in accordance to the standard EN ISO 13786 (EN ISO 13786, 2008).

Table 4 – Cosenza: monthly average daily values for outdoor air temperature (T_{oa}), total solar radiation incident on a south vertical surface (SR_{90}) ad on a 10° tilted surface (SR_{10})

Months	T_{oa} [°C]	SR_{90} [MJ/m²]	SR_{10} [MJ/m²]
Jan	8.1	12.5	9.5
Feb	8.8	15.4	13.8
Mar	11.3	15.7	19.1
Apr	14.4	12.6	22.7
May	18.1	10.5	25.8
Jun	23.1	9.8	29.2
Jul	26.0	10.3	28.7
Aug	25.8	12.7	26.7
Sep	22.7	15.4	28.5
Oct	17.8	14.9	14.7
Nov	13.4	15.2	11.5
Dec	9.4	13.8	9.8

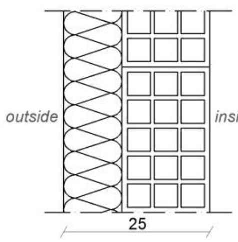


Fig. 2 – Section of hollow bricks wall with external insulation layer

Table 5 – Thermal properties of the wall layers

Material	Thickness [m]	Thermal resistance [m²K/W]	Density [kg/m³]	Heat capacity [J/kgK]
Polyurethane	0.10	3.125	40	1400
Brick	0.15	0.333	1800	840

Table 6 – Thermal performance indexes of the considered wall

U_{wall} [W/m²K]	SM [kg/m²]	Y_{IE} [W/m²K]	PS [h]	AF [-]
0.275	274	0.064	8.57	0.234

● Wall made of precast materials, built by assembling concrete panels, with an internal insulation layer, usually employed for fast and standardized installations (Fig. 3).

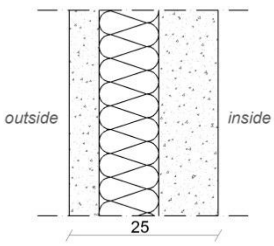


Fig. 3 – Section of wall with precast concrete panels

Table 4 – Thermal properties of the wall layers

Material	Thickness [m]	Thermal resistance [m²K/W]	Density [kg/m³]	Heat capacity [J/kgK]
Concrete	0.05	0.033	2800	1000
Polyurethane	0.10	3.125	40	1400
Concrete	0.10	0.066	2800	1000

Table 5 – Thermal performance indexes of the considered wall

U_{wall} [W/m²K]	SM [kg/m²]	Y_{IE} [W/m²K]	PS [h]	AF [-]
0.294	424	0.082	8.41	0.277

• Wall made of *Gasbeton* blocks, with better thermal insulation properties than traditional bricks, equipped with an additional insulation layer on the external side to attenuate the effects of thermal bridges.

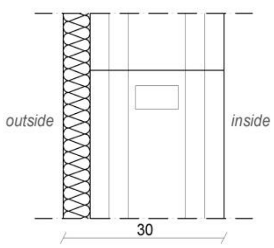


Fig. 4 – Section of wall made of *Gasbeton* blocksl

Table 6 – Thermal properties of the wall layers

\Material	Thickness [m]	Thermal resistance [m²K/W]	Density [kg/m³]	Heat capacity [J/kgK]
Polyurethane	0.05	1.563	40	1400
Gasbeton	0.25	2.174	400	1000

Table 7 – Thermal performance indexes of the considered wall

U_{wall} [W/m²K]	SM [kg/m²]	Y_{IE} [W/m²K]	PS [h]	AF [-]
0.256	102	0.050	10.82	0.194

- On site dry assembled wall, equipped with two wood panels containing a massive sand layer, to combine requirements of demountability, reversibility, reusability and energy savings, allowing the reuse of involved materials. A self-supporting frame is used to fix the panels, whereas the thermal insulation is located on the external side, so that the sand layer can play the function of heat storage system.

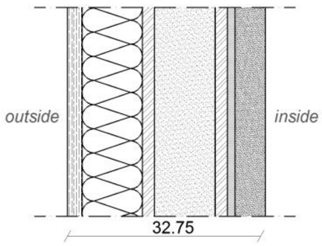


Fig. 5 – Section of the investigated massive drywall

Table 8 – Thermal properties of the wall layers

Material	Thickness [m]	Thermal resistance [m²K/W]	Density [kg/m³]	Heat capacity [J/kgK]
Wood coating	0.024	0.185	500	1600
Polyurethane	0.10	3.125	40	1400
OSB panel	0.02	0.154	650	1030
Sand layer	0.10	0.167	1700	910
Aluminium foil	0.001	0.000	2800	896
OSB panel	0.02	0.154	650	1030
Plasterboard	0.0125	0.042	900	1000
Plaster	0.05	0.063	1600	1000

Table 9 – Thermal performance indexes of the considered wall

U_{wall} [W/m²K]	SM [kg/m²]	Y_{IE} [W/m²K]	PS [h]	AF [-]
0.246	226	0.037	11.00	0.149

A first building simulation campaign has been addressed by using the base slab, the roof and the geometrical characteristics of the building envelope described in the prior section. Moreover, glazed system with double clear glass (U_{WIN}=2.8 W/m²K, g=0.75) and the absence of external shading devices have been initially imposed. Using alternatively the investigated vertical wall, the energy performance index evaluated in function of the thermal energy requirement has been determined. The results of Fig. 6 show that all the investigated walls allow the respect of the winter limit value (5.55 kWh/m³). In particular, the dry assembled wall presents performances slightly better than the other solutions. With reference to the summer performances, the choice of the vertical wall is not sufficient to decrease substantially the energy requirements. In addition, the dry assembled wall presents performances slightly better than the other investigated walls, and the achievement of the best dynamic parameters suggest the choice of this wall. Moreover, it does not lead to a worsening of the winter indexes and it presents the advantage to be more sustainable than the other walls.

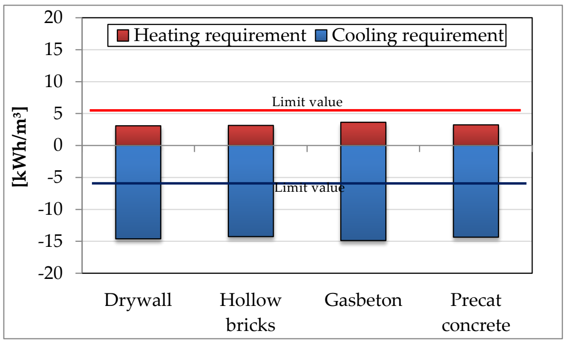


Fig. 6 – Building energy consuption in function of the different opaque walls

4. Windows and external shading devices

To respect the summer performance index, it is extremely important to reduce the solar load, therefore the employment of appropriate strategies in the design process have to be assumed. Appropriate technical solutions have to maximize the solar gain in winter and, at the same time, have to limit the entering solar radiation in summer. The investigated building presents 22 m² south-facing glazed surface, 4.5 m² transparent on the west façade and 7 m² toward north. To improve the thermal energy requirements, the employed glazed surfaces are different in function of the exposure. In fact, to ensure appropriate natural illumination conditions and to limit the thermal losses, the north exposure is equipped with windows mounting triple glass, while south exposure presents double pane windows with a high solar gain coefficient to exploit solar radiation during winter. Finally, to reduce the risk of indoor overheating during the afternoon in winter and in summer, the west-facing room is equipped with a double pane window but with a low solar gain coefficient. The overall heat loss coefficient and the solar gain coefficient of the simulated windows are listed in Tab. 10; all the investigated glazed systems are equipped with air-gap containing argon.

Table 10 – Type of windows and properties

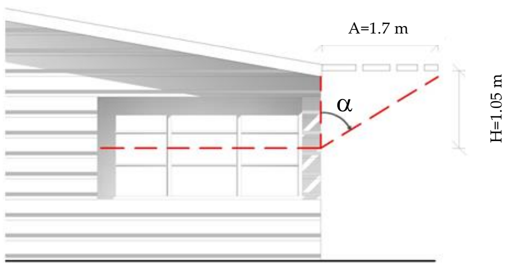
Exposition	Type	U_{WIN} [W/m²K]	g [-]
South	4-12-4	1.61	0.71
North	4-12-4-12-4	0.89	0.71
West	4-12-4	2.53	0.11

A proper positioning and sizing of external unmovable overhangs and sunbreakers, and the employment of mobile internal shading devices, can help the rational use of the solar gains. Therefore, the reference building has been investigated by analyzing three different shading systems in order to identify the more efficient solution in relation to the orientation. The efficiency of the shading devices was evaluated by quantifying the variation of energy requirements for heating and cooling. For each exposure, the investigated shading systems are:

• Horizontal overhangs, sized to reduce solar load in summer, without providing excessive limitation of solar gains in winter. In function of the solar data listed in Tab. 1, the optimal are reported in Fig. 7, obtaining a correspondent yearly average shading factor value of 0.61.

• External sunbreakers, with horizontal louvres width of 10 cm, pitch of 10 cm and 45° tilted.

• Internal light-colored venetian blinds, with horizontal slats width of 2.5 cm and spaced 5 cm from the glass surface.



α	H[m]	A [m]	F [-]
60°	1.05	1.70	0.61

Fig. 7 – Overhang sizing for the South exposure obtained by simulation results

Assuming an envelope made of dry assembled walls, fig. 8 shows for the south exposure the energy requirements hypothesizing the separated employment of the considered shading devices. Contrary to the case of the opaque vertical walls, the type of shading system produces a more evident variation of the results. All the shading devices provide a considerable reduction of cooling energy requirement, but at the same time an inevitable slight increase in winter due to the reduction of solar gains. Therefore, in Mediterranean areas the choice of appropriate glazed surfaces and shading systems appears more important than opaque surfaces.

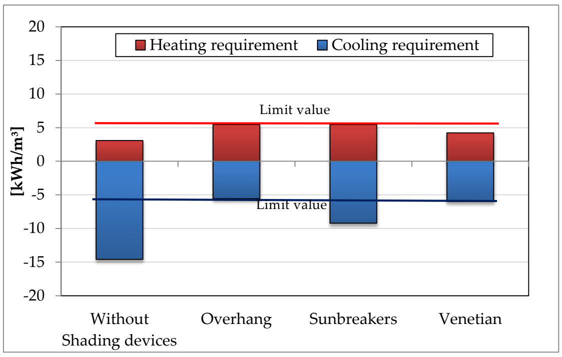


Fig. 8 – Energy performance indexes assuming different types of shading devices on the building south façade

The worst results have been obtained for external sunbreakers devices, as they produce the lowest decrement of cooling demand. In winter, all the shading systems provide a worsening of the heating demand. Nevertheless, the winter performances are respected, but the sunbreakers systems do not allow for the achievement of the summer limit value. On the other hand, horizontal overhangs and internal venetian blinds represent a good compromise for both conditioning seasons. Considering that horizontal overhangs ensure important energy savings and they do not create visual barriers on the glass surfaces, which is completely unobstructed, they seem the best solution for windowed surfaces with a south exposure. Successively, fixing overhangs on the south façade, the same analysis has been carried out for the west orientation, observing that external sunbreakers are the more appropriate devices. In fact, Fig. 9 shows that these systems allow the achievement of appropriate annual energy performance indexes, for both heating and cooling. The contemporary employment of the identified shading systems allow the respect of both seasonal limits. Therefore, with reference to the heating and cooling period, the investigated building can be labeled as passive only if the envelope is made of dry assembled vertical walls and, overall, it is equipped with overhangs on the south exposure and sunbreakers on the west façade. The employment of hollow bricks or a precast concrete wall, however, does not allow for the respect of the winter limit, due to the excessive worsening of the solar gains through the windowed surfaces.

For the detected building envelope, the annual values of the performance indexes for heating and cooling are shown in Tab. 11.

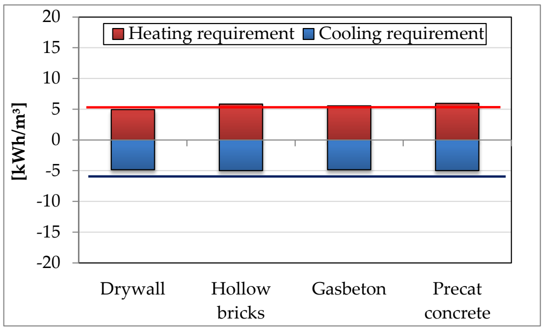


Fig. 9 – Energy performance indexes assuming overhangs on South façade and sunbreakers on West exposure, in function of the vertical wall type

Table 11 – Winter and summer energy performances indexes obtained for the better building configuration

Heating Demand	Cooling Demand
5.15 kWh/m³	-4.91 kWh/m³

5. Renewable sources

To reduce the energy supply from fossil sources, an air-conditioned plant that exploits renewable energy is requested. Therefore, active solar systems have been employed to reduce the exploitation of fossil sources. Since the building has been designed with a suitable pitched roof for solar device installation, the generation system is made of an air-water electric heat pump that interacts with:

- Solar thermal collectors;
- Single effect absorption chiller;
- Photovoltaic modules.

Solar thermal collectors are employed to cover the limited DHW requirement, part of the heating requirement by direct supply of radiant ceilings and, for the cooling period, the generator requirement of the absorption chiller. For an office building, the annual domestic hot water requirement is determined according to Italian standard (UNI 11300-2, 2014); and in the specific case, an annual value of 825.1 MJ has been obtained. The annual thermal energy required from the absorption chiller generator was determined by dividing the cooling requirement for an average seasonal value of the COP of 0.6. The heating requirements are those determined in function of the configuration detected for the envelope. Tab. 12 lists the monthly values of the thermal energy requirements concerning the production of domestic hot water (Q_{DHW}), heating (Q_h), absorption chiller generator (Q_{cool}) and global requirement (Q_{tot}). By using the solar radiation data of Tab. 1, supposing the use of heat pipes technology, a limited collection surface of 5 m² has been obtained, with a correspondent average annual thermal efficiency of 71.8%. The employment of such collectors allows the achievement of an average annual solar fraction equal to 87 %.

Table 12 – Monthly energy requirements for heating, cooling and domestic hot water production, with solar fraction F.

Month	Q_{DHW} [MJ]	Q_h [MJ]	Q_{cool} [MJ]	Q_{tot} [MJ]	F [%]
January	70.1	1693.3	0	1873.7	44.9
February	63.3	1279.0	0	1426.3	79.2
March	70.1	993.4	0	1130.1	100.0
April	67.8	321.9	0	414.1	100.0
May	70.1	0	616.2	729.2	100.0
June	67.8	0	1659.7	1835.7	100.0
July	70.1	0	2331.0	2551.4	100.0
August	70.1	0	2266.0	2482.3	89.1
September	67.8	0	1313.2	1467.4	100.0
October	70.1	0	410.4	510.5	100.0
November	67.8	267.2	0	356.0	100.0
December	70.1	1225.1	0	1376.2	64.1
Yearly	**825.1**	**5780.0**	**8596.5**	**16153.0**	**87.0%**

The electric heat pump acts as an auxiliary system both in winter and in summer, absorbing part of the electric load provided by the PV field. It has been sized considering the full coverage of other electric loads such as the office equipment and artificial lightning, and by hypothesizing the employment of polycrystalline modules technology, with nominal efficiency of 15.2 % and peak power of 250 W per module. In function of the data of Tab. 1, a photovoltaic modules surface of 60 m² has been determined (about 10 kW_p). Tab. 13 reports the monthly values concerning the global electric energy requirement, the electric energy provided by the PV field and the electric energy absorbed from the external grid.

Table 13 – Monthly electric energy requirement, electric energy produced by PV field and absorbed from the external grid.

Month	Electric requirement [kWhe/month]	E_{el} from PV [kWh_e/month]	E_{el} from the grid [kWh_e/month]
January	1329.6	717.8	-611.8
February	1142.4	919.1	-223.0
March	1234.0	1347.3	0
April	1194.2	1479.3	0
May	1234.0	1655.2	0
June	1194.2	1723.3	0
July	1234.0	1732.8	0
August	1255.5	1475.5	0
September	1194.2	1367.8	0
October	1234.0	1030.2	-203.8
November	1194.2	815.8	-378.5
December	1279.8	739.9	-539.9

Fig. 10 shows the typical plant configuration during the winter operation. The solar thermal collectors deliver the thermal load to a hot storage system, used to cover the DHW needs and to supply directly the suspended radiant ceilings, by-passing the absorption chiller device. A suitable control system operates on three-way motorized valves to control the temperature level, in order to maintain the indoor air temperature to the set point condition. The temperature level is regulated by using the re-circulation of the water flow rate coming from the outlet of the radiant ceilings. If the temperature level available in the storage system is not sufficient, the thermal load is completely provided by the electric heat pump.

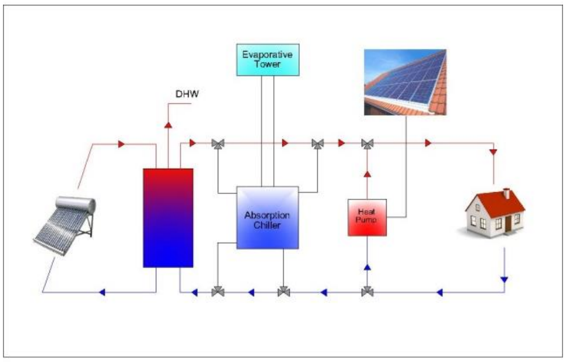


Fig. 10 – Winter functional scheme of the plant

Similarly, in Fig. 11 the scheme concerning the summer plant operation can be seen. In this case, the hot storage system is used to supply the absorption chiller generator. The produced chilled flow rate is sent directly to the radiant ceiling to cool the indoor environment. A cooling tower is provided to reject the heat produced in the condenser/absorber absorption chiller circuits. The temperature level is adjusted by using the same motorized three-way valve system and, if the weather conditions do not allow the absorption chiller operation, the cooling load is entirely covered by the electric heat pump. The results have been obtained supposing the possible exploitation of a small size absorption chiller, which is not commercially available yet.

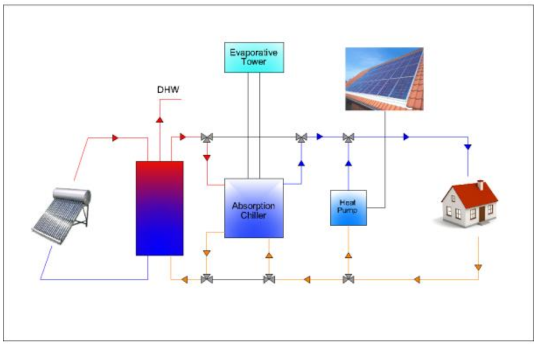


Fig. 11 – Summer functional scheme of the plant

6. Energy label of the building

The building energy class has been determined by the energy performance index concerning the winter heating (EP_i), evaluated in function of the primary energy requirement. To establish the energetic class, a comparison with a correspondent limit value (EP_{lim}) is requested, determined in function of the climatic conditions and of the geometrical characteristics of the air-conditioned envelope. For the investigated building-plant system, a value of 19.87 kWh/m^3 has been obtained (Dlg 192/05). Regarding the domestic hot water, EP_{DHW} is zero because solar thermal collectors are sufficient to cover the thermal energy requirement completely. The energy label of the building has been evaluated by defining two possible scenarios:

- The annual electric energy produced by the PV field is completely employed from the electric heat pump to satisfy the heating requirement and the DHW production. Assuming this plant configuration, the electric energy absorbed from the external grid and employed for heating application is zero, therefore the reference building is completely passive and it can be classified as ZEB (Zero Energy Building).
- Considering part of the electric energy produced by PV field absorbed by internal devices, the auxiliary heat pump requires the absorption of

electric energy from the external grid. In this case, the primary energy for the building heating is represented by the fossil sources involved in the production of the electric energy absorbed from the grid. Considering a national electric system efficiency value of 0.45 (AEEG, Italian Authority for Electric Energy and Gas), a global performance index of 3.47 kWh/m^3 per year has been obtained, allowing to label the reference building as A^+.

7. Conclusions

An energetic analysis of an office building located in southern Italy properly designed to achieve energy consumption almost zero, has been carried out by the Design Builder simulation software. According to the results of different simulations, an appropriate choice of opaque surfaces, glazed surface and external shading devices has been made to meet the climatic conditions of Mediterranean areas. A well-insulated envelope, equipped with large glazed surface toward South, is performing in winter but produce high summer energy requirements, therefore the typology of opaque vertical walls is not sufficient to consider the building passive during the whole year. Regarding the thermal wave delivered through the opaque wall, high values of the attenuation factor and phase shift are achievable by dry assembled walls. To reduce the cooling energy requirements, glazed systems equipped with suitable shading devices, in function to the wall exposition, have to be selected. In the presence of high solar gains, great values of the solar gain coefficient are recommended. To limit solar gains during summer, the simulation results have shown that overhangs with appropriate size south facing, and sunbreakers for East/West exposures appear appropriate. The shading systems produce an inevitable worsening of the winter performances, but the winter limit is still respected. For the detected envelope, the employment of small surfaces of active solar systems, linked to a heat pump generation system, is satisfactory in order to design a ZEB building.

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