A cost-effective building in the Mediterranean area: 
Passivhaus design and energy modelling

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Abstract. An actual cost-effective approach to high performances building in the Mediterranean area has been still missing: this project was carried out applying the Passivhaus approach to several building solutions using PHPP 9. Integrated design approach made possible a cost-effective building: all the designers involved were forced to work together and PHPP was used as a design tool, starting in the very first phases of the process. The initial concept was unfortunately far from a simple form and there were a lots of thermal bridges. The majority of those were completely solved, however, we decided not to design a thermal-bridge-free detail in some cases, but simply minimize the impact of the losses and verify internal surface temperatures. Triple-pane for windows would have certainly minimize the heating demand, but a low-e double-pane is cheaper and also maximize the solar heat gains. In summer, solar gains would be a real problem in this climatic zone and for this reason shading systems were optimized to offer protection in summer and large gains in winter. The whole design process was simultaneously followed by real time energy calculations with PHPP as a design tool. A compact unit for each apartment provides ventilation, heating, cooling and hot water production. Really low heating and cooling demands made possible to heat and cool only with a post treatment after the recovery on the airflow.

Keywords: Built, Passivhaus, Design, Cost-effective, Multi-family, MVHR, Compact unit

1. Introduction

In 2021 Italian code will requires NZEB performances for every new building as every other European country [1]. High efficiency buildings are already present nowadays in Southern Italy, but the main obstacle to the spread of this level of performances is still its higher construction cost. A cost-effective approach was the goal in this work of ours. Meeting the tough demands from the Passivhaus certification criteria without no higher costs than other approach respecting easier code limits [2].

For a building to be considered a Passive House, it must meet the following criteria [3]:

- The Space Heating Energy Demand is not to exceed 15 kWh per square meter of net living space (treated floor area) per year or 10 W per square meter peak demand. In climates, as in this case, where active cooling is needed, the Space Cooling Energy Demand requirement roughly matches the heat demand requirements above, with an additional allowance for dehumidification.

- The Renewable Primary Energy Demand, the total energy to be used for all domestic applications (heating, hot water and domestic electricity) must not exceed 60 kWh per square meter of treated floor area per year.

- In terms of Airtightness, a maximum of 0.6 air changes per hour at 50 Pascal pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states).
• Thermal comfort must be met for all living areas during winter as well as in summer, with not more than 10% of the hours in a given year over 25 °C.

Passive House buildings are planned, optimised and verified with the Passive House Planning Package (PHPP). The PHPP based on Excel provides calculation sheets for space heating and cooling balances (annual and monthly methods), and for heat distribution and supply as well as for the electricity and primary energy demand, constitute the main features of this tool. Other important modules for the practical planning of energy efficiency projects include the calculation of characteristic values of windows, shading, heating load and summer behaviour, cooling and dehumidification demand, ventilation.

DesignPH, the modelling tool for the PHPP, provide a 3D model interface for entering building geometry into PHPP. Firstly it will simplify the process of entering data into PHPP, but most important it will provide preliminary feedback on the performance of the design within SketchUp. In fact, meeting the target of a cost-effective high performances building is possible only through an integrated design process and a detailed energy modelling [4]. Real time energy calculation using SketchUp and DesignPH, also during the preliminary architectural design phase, helps a lot to evaluate some important choice about orientation, form (S/V), windows positions and shadings. In the following steps, a more accurate and appropriate calculations let us understand which is the optimal value for each components: not less than what we need to reach the target performance, not more because that would be an extra-cost. Innovativeness in the design process - integrated and well supported by more and more accurate building physics calculations - and the target to meet ZEB and Passivehaus energy performances and indoor air quality, with no higher selling price on the market of these units are some of the most interesting features of our work.

2. Case study building
The building is the first residential Passivhaus building in Apulia region, located in Putignano (Bari), with three levels and eight apartments. Design phase started in early 2016 and the building has been occupied since June 2018.

In order to achieve better performances but not overturn the local typical construction method, the building has the usual reinforced concrete frame but a better envelope and, of course, optimized thermal bridges and airtightness. Accurate building physics calculations allow us to precisely sizing every component, in order to achieve a cost-effective building. So, first thing we needed was a proper and long term climate data set for the precise location. Nowadays it is still difficult to find it and for this reason we had to interpolate and then validate multiple data set from the nearest location available.

Some features like orientation, maximum height and volume were set by urban planning. However, the building has a good S/V value of 0,36 anyway [5].

![Figure 1](image1.png)  
**Figure 1.** South (left) and North elevation (right) of the building.

3. Envelope
External insulation for a reinforced concrete frame building was the easier option to reach high performances and thermal free envelope without major changes in the local construction methods. For the façade, an inner wall of clay hollow bricks (mm 300) and external insulation in EPS (mm 160) allow us to reach U-value of 0,16 W/m²K. Even if the Passivhaus protocol suggests values under 0,15
W/m²K, in this case this kind of transmittance allows us to reach the heating demand anyway. It should be noted that the Italian energy code requires a minimum of only 0.34 W/m²K to meet. On the roof, the insulation layer in rock wool is 180 mm thick and the U value is 0.18 W/m²K. On the basement ceiling the rock wool layer is only 120 mm instead.

4. Airtightness
The low air leakage rates required must be proven by the Blower Door Test, following the European standard UNI EN 13829: 2002 [6]. The air change rate must be below 0.6 ACH under the test conditions (50 Pa pressure difference between inside and outside) during the two test methods, A (test of a building in use) and B (test of the building envelope). The measurement results of the case study building are the following:

- Air change rate at 50 Pa: \( n_{50} = \frac{V_{50}}{V} = 0.31 \text{ h}^{-1} \)
- Air permeability at 50 Pa: \( q_{50} = \frac{V_{50}}{A_E} = 0.421 \frac{\text{m}^3}{\text{h m}^2} \)

The Passive House Institute has introduced a requirement that the \( q_{50} \) must also be less than or equal to 0.6 h\(^{-1}\) for buildings with a volume greater than 1500 m\(^3\).

![Energy balance heating](chart1.png)
![Energy balance cooling](chart2.png)

**Figure 2.** Energy balances for heating and cooling.

5. Windows
In a Passivhaus building, well-insulated, with all the thermal bridges at least minimized ad high airtightness, windows are than a crucial component. Figure 2 shows the impact of the windows in the overall transmission losses: an amount of 17 kWh/m\(^2\)a for all the windows (accounting for the 20% only of the entire surface) and almost the same amount (19 kWh/m\(^2\)a) for all the other opaque surfaces (the other 80%).

Compared to the opaque envelope, per unit area, windows are usually around three times more expensive and also around three times more transmitting. However, in winter, the solar radiation entering in the building through the glass portion, represent in this case an amount of thermal energy not more insignificant, compared to the overall (smaller) heat losses. For this reason, especially in
warm climate, the U value of the glazing is not the only feature to be taken into account. In order to reduce heat losses, triple pane with an $U_g=0.65$ W/m²K would be the best option, although in this case $g$-value is 0.47. On the contrary, a double pane has a worst $U_g$ value (1.10 W/m²K), but a better solar transmittance ($g=0.65$) and it’s cheaper.

The comparison in fig. 3 between the two option considered - triple pane glazing only on the North elevation and double pane glazing on all the others in the first one, and triple pane glazing everywhere in the second one – shows clearly how effective is the first one under every aspect. 4.159 kWh/a represents the transmission losses in winter with double pane for the South elevation only, and 3.111 kWh/a with triple pane glazing. However, 6.590 kWh/a represents solar gains with double and 4.765 kWh/a with triple. To conclude, facing South, double pane glazing had a better impact on the heating period than triple pane for a percentage near 50%.

Comparing the two, also totally, the balance between losses and gains was still better for the double pane glazing option with an amount of -264 kWh/a, instead of -1014 kWh/a for the triple pane glazing. Solar radiation entering the glazing is a gain in winter but would be a load in summer, especially in a warm climate [7]. For this reason, shading systems are really something to take care of, even in the preliminary design phase (fig. 4).

![Figure 3. Transmission losses and solar gains in the heating period with double pane glazing (left) and triple pane glazing (right).](image)

![Figure 4. Transversal section (South-North) with solar radiation on the winter solstice (left) and on the summer solstice (right).](image)

### 6. Thermal bridges

Building regulations and codes are now taking into account accurately thermal bridges [8] and it is required or recommended they are minimised. The Passivhaus Standard recognises the importance of thermal bridges and the significant impact they can have on the high-performance building envelope. The Passivhaus Standard requires a continuous thermal envelope: this means thermal bridge free construction to ensure a robust high-quality building envelope that delivers radical energy efficiency and exceptional comfort.

Thermal bridges make up a small portion of heat loss in a poorly insulated envelope, but if same poor details were used in a Passivhaus, heat loss through thermal bridges would approach really high percentage. $\Psi$ values $\leq 0.01$ W/mK qualify as “thermal bridge free” according to Passive House. Thermal bridges that don’t meet that criteria must be calculated individually using a 2-D
heat flow simulation model (such as THERM in our case), and as with all thermal bridges, minimised as far as possible.

In a warm climate thermal bridges have a different impact on the global performance and it would be too expansive to meet the “thermal bridge free” target. Some can be easily minimised or eliminated through careful detailing, others might require expensive and complex detailing. In the latter case, each thermal bridge needs close consideration in terms of internal surface temperature and danger of mould and condensation, but there is no convenience in reaching every time detailing solutions with $\Psi$ values lower than 0.01 W/mK. The total amount of all the thermal bridges only minimized is still a small part of the overall heat loss in a warm climate, even for a Passivhaus.

In a well-insulated building as ours, the window-to-wall interface can contribute significantly to overall conductive heat losses through the envelope. A slight misalignment of the insulation and window systems as in detailing in fig. 5, determine a value of $\Psi = 0.07$ W/mK, but there is no danger in internal surface temperature and it is a cheaper installation solution. Moreover, in a warm climate, lateral shadings have a positive effect in reducing solar heat load from East and West during summer.

![Figure 5. Window - Temperature.](image)

7. Building services

A compact integrated unit for heating, cooling and mechanical controlled ventilation is a perfect solution for a Passivhaus residential building with so low heating and cooling demands. The Nilan compact system consists of a heat pump capable of recovering the extraction air flow heat to transfer it to the renewal air flow and to a domestic hot water (DHW) tank. In winter conditions, the heat pump partially condensate the refrigerant on the thermal storage tank, so as to dispose the overheating of the refrigerant fluid, and then to complete the condensation on the fresh air flow heat exchanger. The extraction and renewal flows, pass through a high efficiency-recovery heat exchanger, in order to maximize the energy performance of the whole unit.

According to the parameters of the indoor environment, the compact unit has four way to work, automatically managed by the control system, depending on the internal and external parameters of the building:

- passive heat recovery
- active heat recovery
- bypass
- active cooling

A split system unit is used by recirculate the internal air (secondary air) to cover peak loads related to the particular geographical area with hot summer, and to take care of not completely correct user behaviours, like letting in hot or cold external air for a long period of time from the windows. The unit allows a thermal integration function, cooling and dehumidification. The treated supplementary air is delivered to the rooms through a specific distribution. The internal unit is located under the ceiling in a central part of the building.
The air distribution system has polyethylene certified pipes with internal diameter of 74 mm to reduce the air velocity and pressure losses in the channels. The delivery pipes have been insulated with a flexible insulating polyethylene extruded tube with $\lambda$ of 0.035 W/mK to avoid temperature reduction and condensation of the air in the external part of the tubes. The use of air collectors, also under the ceiling, allows a better balance of the distribution system (primary air). The fresh air is picked up and ejected in the façade by insulated pipes with 160 mm internal diameter, in a way to prevent the short-circuiting of flows. The recirculation (secondary air) coming from the split system is delivered in the building coupled with the primary air coming from the mechanical ventilation by a specific double nozzle.

The management of the CompactP and of the split system is integrated. A supervision control unit allows direct setting of temperature, humidity and CO$_2$ set point and switch on the single units to reach the desired values. The sensors included in the Nilan CompactP are used as master control. An RS485 Modbus communication system is used to control the two air conditioning units, involving the split system only if it is needed as an additional booster.

![Figure 6. Air distribution in the apartment n. 8.](image)

8. Conclusions
All the apartments in this building were sold successfully at the same price market (1.800.00 €/sqm) of the others new construction around in that period. However, all the others new construction were far from nZEB and of course from a Passivhaus. Only starting 2021 every new building in Italy has to be nZEB. A more detailed and integrated design, calculations with PHPP and on-site workers training made possible to reach around 3% in extra-construction cost than those buildings, even if they have not the same components, not the same energy performances and also not the same internal comfort.

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