Energy-Efficiency Passive Strategies for Mediterranean Climate

Subjects: Engineering, Civil
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The main objective and function of passive solutions are to contribute to the natural cooling or heating of the building. They are constructive technologies integrated within buildings. The exchange of thermal energy takes place by natural means that, when dimensioned correctly, can significantly reduce a household's energy bills. Several passive strategies, namely natural ventilation, shading devices, overhangs, and daylighting, associated with the building envelope's characteristics are important passive design parameters that should be given particular attention to highlighting the potential of buildings for energy efficiency.

Keywords: buildings ; passive cooling solutions ; passive heating solutions ; energy efficiency ; Mediterranean climate

1. Introduction

The European continent consumes about 1/5 of the energy at the worldwide level, and most of that energy has been imported due to the limited hydrocarbon resources on this continent. The European Union's (EU) energy dependency did not substantially change over the last decade, with a minimum of energy imports of 53.9% in 2013 and a maximum of 60.5% in 2019 [1]. The previous data from 2020 indicate that 57.5% of European energy needs was imported. It is worth mentioning that more than half of the EU's gross available energy was supplied by net imports, and the dependency rate has exceeded half of the needs. The dependency of the EU on energy imports, particularly oil and natural gas, forms the backdrop for policy concerns relating to the security of energy supplies [1].

The most energy-intensive sector in Europe is transport (32%), including road, air, river, sea, and rail transport. The buildings and construction sector follows with 27% while contributing with proportional CO_2 emissions [2]. In third and fourth places are the sectors of industry (25%) and services (13%). Therefore, the construction and buildings sector is the second most energy-intensive sector in Europe. These economic sectors are the ones where significant environmental mitigations can be achieved, as recently stressed in "Fit for 55": delivering the EU's 2030 Climate Target on the way to climate neutrality. Buildings are a major player that can help accelerate the "green transition" to a net-zero future by sustainable use of natural resources, eco-friendly materials, eco-designs, efficient use of the total energy, and valuation of ecosystem impacts [3].

Fuller et al. [4] showed that the location and size of the buildings are the dominant factors that explain the total energy used in the residential sector. Tzikopoulos et al. [5] showed that buildings' energy efficiency decreased by 7% every 1500 degree hours in the Mediterranean climate, while building location also accounted for a variation of about 17%. Du et al. [6] used empirical data to show that the energy footprints are higher in low-rise suburban households than high-rise urban. It must be highlighted that, in 2020, about 14% of European inhabitants lived in a dwelling with a leaking roof, damp walls, floors, or foundation, or rot in the window frames or floor [7]. Besides, European citizens are increasingly spending more time indoors (80–90% on average) [8], and this was further stressed by the pandemic situation, in which remotely working became more common.

Building operational energy consumption has been under scrutiny with the European Commission's agenda, as one of the front actions to promptly alleviate the global energy supply, climate change, and energy poverty [9][10]. The need to control the energy consumption of buildings and greenhouse gas emissions while guaranteeing users' comfort has been constantly accompanied by standards and regulations [9][10]. Particularly, since the beginning of the 20th century, the efforts to promote clean solutions and improve building designs have resulted in the invention of many types of energy-production equipment and efficient heating, cooling, and ventilation.

From this perspective, passive solutions that improve buildings' energy efficiency must be present and reflect upon the project's early stages of development [11]. The main objective and function of these solutions are to contribute to the natural cooling or heating of the building, called passive solutions. Passive solutions are constructive technologies integrated within buildings. The exchange of thermal energy takes place by natural means that, when dimensioned correctly, can significantly reduce a household's energy bills. Several passive strategies, namely natural ventilation, shading devices, overhangs, and daylighting, associated with the building envelope's characteristics are important passive design parameters that should be given particular attention to highlighting the potential of buildings for energy efficiency.

Although there is already an increase in the concern with sustainable construction and solutions that can reduce energy consumption, passive solutions are still quite reduced in some countries, such as Portugal. The main passive solutions are direct gains, such as the orientation of the glazed openings to the south or the adoption of double/triple glazing and external protections [12].

The passive solar technologies are more important and efficient for buildings in Mediterranean climates. The Mediterranean climate is a particular variety of subtropical climates, with an average temperature above 10 °C in their warmest months (warm and dry summers) and an average in the coldest months between 18 °C and −3 °C. The European countries within the Mediterranean present 300 days of sunshine per year and an annual average air temperature of 16.3 °C, precipitation of about 726 mm/year, and relative humidity of approximately 63.2% [13], and they are excellent places to exploit bioclimatic concepts. They also have many natural and renewable resources, such as cork, whose insulating characteristics can be exploited. In the literature, it is possible to find a considerable number of research about the design optimisation of passive solar strategies, multiple passive technologies, or more focus on a target of a specific technology, such as glazing, sun shading, and Trombe walls. However, the application of solar passive strategies or technologies in Mediterranean countries, such as Portugal, is still lacking.

2. Passivhaus Concept

The Passivhaus concept was drawn back in 1988 and developed by Professor Bo Adamson and Doctor Wolfgang Feist due to the low-energy construction required in the 1980s for new buildings in Sweden and Denmark. The Passivhaus concept is based on three pillars: (i) the energy requirements are limited, corresponding to heating, cooling, hot water production, and electricity; (ii) the thermal quality requirement of the building; (iii) the construction of the building must be based on passive solutions to satisfy energy requirements at a profitable cost [14].

Afterwards, several projects were developed within the Passivhaus concept, such as Darmstadt (1990) and GroßUmstadt (1995), in Germany. In both cases, they were houses where the main objective was to achieve low energy consumption at reasonable costs for the German climate. Due to the success of the first building, the Passive House Institute was founded [15]. Since then, this institution has been dedicated to studying and developing energy-efficient buildings.

Over than 40,000 passive houses were built worldwide and 20,000 in Germany alone. The concept is gaining popularity due to the outstanding advantages it offers, but this is also due to its flexibility [16][17]. In fact, there are no restrictions on the type of construction, type of building, or specific climate. It can be adopted in solid wood construction, prefabricated or reinforced concrete construction, and residential, administrative, school, or hotel buildings, proving that the concept is suitable for any construction system, regardless of the function of the building. The Passivhausse standard is based only on physical principles [15]. The requirements to be applied in the design and construction phase of a building to verify the Passivhaus concept are:

- Heating and cooling needs.
- Primary energy consumption.
- Building water tightness.
- Thermal comfort for its users.

The limit for energy requirements for both heating and cooling is 15 kWh/(m^2·year). The energy value is verified with the help of passive house planning package (PHPP), a tool used in the design of passive houses where the energy balance is calculated, as well as the planning of windows, the ventilation project, and the water heating project, determining the amount of energy for heating and cooling the building and estimating comfort in summer [15].

The primary energy consumption, such as water heating, electrical equipment, and indoor heating and cooling, should not exceed 120 kWh/(m^2·year). The airtightness must be verified through the blower door pressurisation test at 50 Pa, whose limit of the hourly renewal rate of the indoor air must be equal to or less than 0.6 renewals per hour. The thermal comfort of the building requires that, during winter, the indoor temperature should not be lower than 17 °C in all rooms. On the other hand, the indoor temperature must not exceed 26 °C for 10% of the summer. Along with those requirements, it is important to consider the continuity of the thermal insulation of the building envelope. The value of the thermal transmission coefficient, U, must be limited to 0.15 $W/(m^2·K)$ in the entire environment, whether in cold or hot climates. Only 0.15 watts horizontally across the walls, slabs, and coverings of the envelope when they are subject to a temperature difference between the environments that each element separates in each square meter of surface. Besides, the thermal transmission coefficient of the windows, including the frames, must not exceed 0.8 $W/(m^2·K)$ for cold climates. Regarding the solar factor of the glazing, g, it should admit the highest possible value, around 0.5, on a scale from zero to one, which means that gains of approximately 50% would be obtained [16].

The Passivhaus concept also introduced heat recovery ventilation. With the help of a high-performance heat exchanger, this technology allows at least 75% of the heat that comes from heat recovery to be renewed, contributing to better indoor air quality and lower energy consumption. In addition to this factor, these systems must have a low acoustic level, below 25 dB. Another ventilation characteristic is that all building compartments must have an opening to provide natural airflow in summer.

It is estimated that the Passivhaus concept can save about 90% of energy compared to existing construction in Europe and 75% compared to new construction. This saving occurs in cold climates and hot climates during the cooling season [16].

3. nZEB Concept

The Energy Performance of Buildings Directive 2010/31/EU introduced the concept of nearly zero-energy buildings (nZEB) to promote buildings that are more efficient at fulfilling the current minimum energy performance requirements. According to this directive, a building with zero or almost zero energy balance represents a high-energy performance building. A large portion of its nearly zero energy needs is covered by locally produced energy. It was defined that all member states must take the necessary measures and create conditions so that, from 2020, all-new buildings constructed will be nZEBs. During the project phase, the building principles for an nZEB are:

- Reduction of energy consumption.
- Use of renewable energies.
- Reduction of greenhouse gas emissions.

In turn, it is essential to consider some other aspects such as solar orientation, local characteristics and constructive solutions, more specifically, the glazed spans of the materials to be used, among others. Traditionally, an nZEB uses electricity and natural gas sources only when its own production cannot meet its energy needs. The building uses renewable, non-polluting, and low-cost sources of energy. When the production of this energy exceeds consumption, excess production is exported to the public grid for later use.

Regarding energy production from renewable sources, technologies available during the building service life and with the lowest environmental impact must be preferred. These same technologies must have high availability and easy recurring resources, as with photovoltaic and solar water heating systems. When the aforementioned measures used in a Passivhaus (insulation, high-performance windows, ventilation with heat recovery, sustainable architecture) are combined with local renewable energy sources and with an energy consumption practically equal to the energy produced, it turns into a “near-net-zero energy”, “net-zero-energy”, or even “positive energy building”.

An nZEB building can be defined differently depending on the project objectives, the energy values desired by the design team, or the maximum costs intended by the building owner. In other words, there are nZEB buildings with different energy consumption, consumption that must be compensated with the corresponding production of renewable energy. These different perspectives are:

- Nearly zero-energy building (nZEB): the annual energy consumption should approximate the energy production by renewable energy sources.
- Net-zero-energy building (nZEB): annual energy consumption must be equal to or less than the energy produced by renewable energy sources.
- Net-zero site energy: annual energy consumption equals the building’s yearly own energy production from renewable sources, excluding nearby sources.
- Net-zero source energy: the annual energy consumption is at least equal to the production, considering the primary energy source used in the production and supply of energy to the building.
- Net-zero energy cost: the annual amount that the public grid pays for the supply of energy produced and exported by the building is, at least, equal to the annual amount that was paid to the grid for the annual energy consumption of the

building. Building energy is zero or negative.

- Net-zero energy emissions: the amount of emission-free renewable energy produced annually is at least equal to the amount of annual energy consumed from renewable sources.

The choices made regarding solutions during the design phase are directly linked to the definition of the nZEB perspective indicated above. Although there is no standard approach to the design of nZEB, there is consensus that one should choose to start the project by introducing a passive sustainable design to reduce energy needs. In this way, passive solutions represent crucial elements in constructing an nZEB, since they are directly related to the heating, cooling, ventilation, and lighting needs.

4. Building Implementation

4.1. Buiding Integration and Orientation

The first energy-efficiency passive measure is an integration building study within the environment. Within the scope of bioclimatic architecture, the design and planning of a building consider all the environmental constraints in the vicinity [5]. This aspect, however, cannot be standardised and applied consistently, as numerous factors change depending on location, dwelling type, and specific climatic factors.

Housing orientation is one of the factors that can and should be controlled in the early planning stages, i.e., the positioning of the building considering the sun exposure, to allow efficient and effective use of the sun's energy as a source of comfort (light and thermal). The difference in the sun's angle of incidence in the different seasons allows a differentiated use of solar energy. The proper choice of orientation that the house will take can translate into solar gains that will reduce the nominal heating needs during the winter season; in addition, the proper and correct exposure of photovoltaic panels, eventually placed on the roof, could translate into a contribution to the reduction of annual energy needs, in line with the nZEB concept.

During the heating season, the height of the sun is lower, so a vertical surface facing south receives solar radiation longer than one facing in any other direction. During the cooling season, the sun has a higher position, causing the variation of the angle of incidence of radiation. Therefore, a vertical surface facing south will receive more energy, with the roofs of buildings registering the highest energy capture in this period.

Any surface facing north does not receive direct incidence of solar radiation, thus making it a less preferential orientation when it is necessary to decide the direction of exposure of spaces with greater permanence. The best solution is an orientation facing south, since it provides the space with the most significant time of exposure to solar radiation.

Therefore, solar radiation, especially in sunny countries such as Mediterranean countries, and the study of the sun's trajectories are key factors during the design phase, being responsible for the natural lighting of the building and for heating the interior environment.

4.2. Building Shape

The volumetric impact on a building has a key role during its life cycle, reducing energy and natural resource consumption [18][19]. Compactness is a characteristic of the building volume; it is used to adjust the exposed envelope, depending on the useful area, as much as possible. This geometric relationship is represented by the shape factor (SFv), which is the ratio between the exposed building area and indoor volume. Buildings with a high shape factor are less compact, i.e., they have a large, exposed area for a given interior volume. This type of construction allows more significant heat losses. The exposed areas of the building must be reduced as much as possible since thermal losses through the exterior envelope are proportional to the product of the areas of the exposed surfaces and the thermal coefficient of the respective element. This means that two buildings with identical glazing characteristics and thermal coefficients, but different shape factors, also differ in the internal heat retention capacity. The impact of SFv varies considerably for buildings with varying properties in the thermal envelope and weather conditions [20]. A study of the impact of different thermal envelopes in buildings showed that more benefits are obtained by using materials with better thermal quality in the envelope when there is more exposed surface per m^2 [21]. However, many variables such as orientation, wind, and lighting must be considered for a correct architectural design.

4.3. Exposure to Prevailing Winds

Another feature to consider during the planning phase is the orientation of the building considering the prevailing winds of the place, since, with proper conditions, it may be used for energy production.

When the area over which its movement is made is restricted, the air changes velocity. The decrease in this area implies a considerable increase in its speed, which causes a certain degree of discomfort. However, it is possible to use this process to carry out ventilation operations, which makes the correct direction of the building or passive devices according to the prevailing wind direction, as depicted in **Figure 1**.

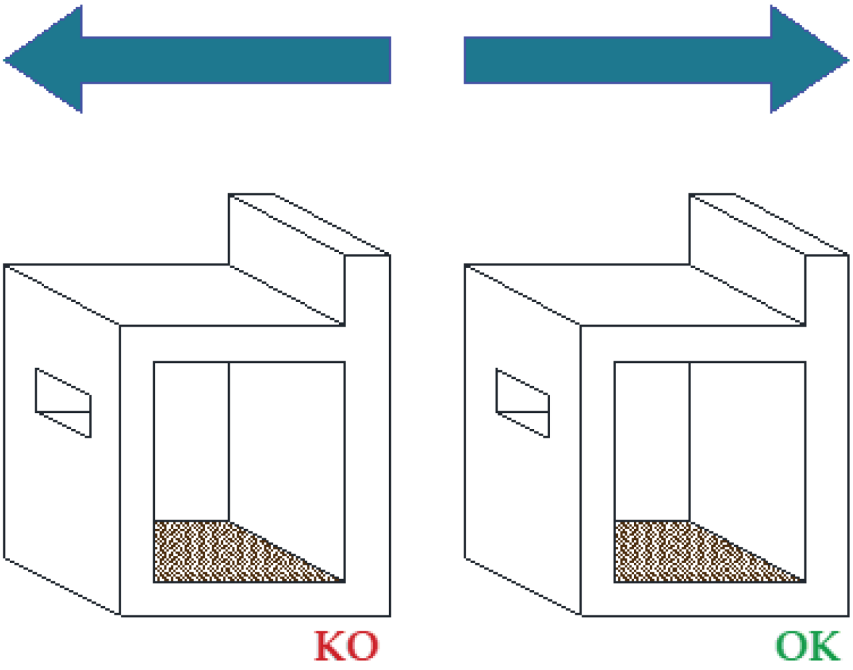

Figure 1. Natural ventilation using prevailing winds [22].

5. Passive Heating Solutions

After the planning phase of the building, taking into account the association of the building with its integration into the environment, it is necessary to consider the strategies to minimise the needing of equipment for maintaining the indoor temperature at acceptable comfort levels.

Passive heating solutions are integral to building structures or housing and can perform as collectors and accumulators of incidental solar energy. Passive heating distributes heat through natural transfer processes, contributing to interior comfort without using active air conditioning systems. They aim to maximise solar gains through well-sized and oriented glazed spans, to which thermal masses can be associated. Mediterranean-climate countries particularly fit those solutions [23][24][25], as this climate is mainly known for its solar availability (solar hours and solar irradiance). Therefore, it is logical that the spaces of permanence in the building must be oriented to the south to obtain greater thermal comfort due to the penetration of the sun. On the other hand, secondary spaces or divisions such as storage rooms, corridors, stairs, garages, etc., should be located in the north's interior space.

It is also important to design the building in such a way that the south-facing side is longer than the east- and west-facing ones, so that this façade is warmer in winter (maximum radiation to the south) and cooler in summer (radiation to the south), with the proper shading [12]. Therefore, solar radiation and the study of the sun's trajectories are key factors during the design phase, responsible for the building's natural lighting and indoor heating.

Different types of passive heating solutions can be adopted, with the possibility of individual or integrated usage, benefiting from the combination of the advantages of each type and reducing or even eliminating the disadvantages that could exist, namely:

- Direct gains solutions.
- Indirect gains solutions.
- Isolated gains solutions.

6. Passive Cooling Solutions

The solutions that prevent and/or mitigate the heat gains, or strategies for heat dissipation, provide a reduction in cooling needs and an improvement in thermal comfort conditions in summer seasons. The application of passive or natural cooling depends on suitable environments that act as cold sources and create temperature differences.

Architectural options can consider preventing or protecting solar gains in all buildings. First, it is necessary to account for the type of glass used and the respective solar control. The best solution may be the use of external shading, as this prevents the entry of solar radiation into the interior of the building. If this is not possible, reflective glass solutions associated with internal shading solutions should be considered [26].

The use of insulation in the building envelope, especially if placed outside the envelope, leads to situations that reduce the thermal demands through the opaque envelope, thus reducing the building's cooling load. Particular attention should be paid to the roofs since they receive solar radiation during the summer. Another aspect to consider is the colour of the building, as light colours translate into lower values for capturing solar radiation, favouring the thermal performance of buildings in summer. The attenuation of heat gains through the building envelope also depends on the building's thermal mass. The passive cooling solutions can be classified as:

- Direct cooling solutions
- Indirect cooling solutions

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