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Timber houses in the Mediterranean area: a challenge to face

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Abstract. About 40% of European energy consumption and most of the environmental impacts are related to the construction sector. A key role in decarbonising the construction sector play the timber buildings. Wood is a sustainable resource and has excellent thermo-physical and acoustic characteristics compared to traditional building materials, with short production times that affect not only the construction phase but also costs. Although wooden houses are very common in the countries of northern Europe, in Italy and in general in the Mediterranean countries, this type of building is not very widespread today. The hot climate, characterized by a long cooling season, has always directed builders to build massive buildings. Because today building a timber house means creating energy-efficient buildings, it is proposed to study the energy-environmental performance of timber buildings in a Mediterranean climate. In this work, the performance of a building made with traditional construction will be compared with a simulated wooden building at different latitudes and climatic conditions. At the same time, a simplified assessment of the economic aspects will be carried out. For each model, the main thermophysical and geometric characteristics necessary to achieve the energy comfort requirements will be identified using MATLAB. The first results show that a wooden house has an energy saving of around 17% with payback times of 10 years compared to a traditional house.

Keywords: energy saving, comfort indoor, timber house, economic costs

1 Introduction

Improving the energy performance of buildings and increasing the share of renewable energy is one of the three main principles on which the European Green Deal is based on [1]. As a matter of facts, a "Renovation Wave" is planned to decarbonize heating and cooling and improve the performance of public and private buildings[2]. In the European Parliament resolution of the 15th of January 2020 [3], the EU encourages the use of timber and other environmentally sustainable materials in the building sector, indeed the 80% of all the international works published in the literature deal to timber construction in Europe [4]. Application of timber buildings in different European

climate is a hot topic in literature. For example, Stazi et al. [5] verify the performance of a timber residential building located in a hot dry summer climate, and the results showed that, in a hot climate, indoor overheating may occur without smart ventilation strategies, or the interior walls mass is too low. Kosonen et al. in [6], demonstrate how in Finland, a house made entirely of logs, without any insulation, could satisfy the definition of Zero Energy Building (ZEB) thanks to a correct design of the vertical surface and the generation plant. According to Svajlenka et al. [7], the modern methods of timber construction led to indisputable ecological and environmental benefits, using panel wood-based system built off-site. Since timber is a key point on new building materials, its thermophysical qualities must be analyzed, because they contribute to the building needs. The review on thermophysical properties presented by Asdrubali et al. [8] shows that timber is competitive in terms of thermal and structural behavior, but as illustrate in [9-10] the thermal response of wooden walls is highly dependent on the moisture content inside them.

To evaluate how a wooden house can also represent an alternative solution to traditional constructions in a Mediterranean context, the following work proposes a case study in which the performance of a wooden building is compared with that of a building constructed with techniques traditional. In detail, thanks to an analytical model developed in MATLAB [11], the main static and dynamic thermophysical characteristics that affect the thermal balance of the building system will be highlighted. For each model, thanks to a parametric analysis, the main thermophysical and geometric characteristics necessary to achieve the minimum environmental and energy comfort requirements will be identified.

This work and research is organized as follows. In the first section the approach and the physical variables that will be taken into consideration are described; the description of the case study follows, i.e. a traditional residential building typical of the Mediterranean area and the design of the same in timber. These buildings were simulated in different climatic zones, in order to highlight how different climatic conditions influence the design and therefore the performance of a building. Finally, the results compare the energy and economic performance between a traditional and a timber building, where the main results and contents of this work are described in the conclusions.

2 Materials and Methods

Based on the above, the following work proposes an analytical method for the analysis of the performance of timber houses. To be able to identify the best solution to varying climatic conditions, a case study is proposed in which the main thermophysical and dynamic parameters that come into play are evaluated. This approach will allow us to evaluate how a wooden house, unlike a traditional building with a massive structure, can, with a correct design, respond to the needs of indoor comfort even for buildings built in a Mediterranean climatic context. The following work is set up as follows: after identifying a base model, this was designed according to the actual law and simulated for different climate zones and for both the construction techniques. All models are simulated in steady state to calculate the energy consumption of the buildings and have

allowed to evaluate energy consumption and possible economic savings. To complete the study, the behavior of thermophysical characteristics of the walls when one of the fundamental parameters in the energy balance of a building, namely the thickness of the insulation, varies.

2.1 Building energy balance and simple economic evaluation

In the design of a building, the engineer must evaluate all the exchanges that the thermodynamic system of the building exchanges with the surrounding environment. The goal is to create a comfortable building for the occupants. The building is not an object, but part of an interactive and dynamic system that considers different aspects: natural (earth, water, wind, sun, vegetation) and social (identity and belonging to places), technical (materials, elements) and geometric (position with respect to the sun, size of the glazed surface). Generally, energy requirements of a building are influenced by the transmission losses through the envelope, the energy gains due to solar radiation and the presence of people and strongly correlated to the climate context and the thermophysical parameters. About the thermophysical parameters, it is important to underline how the thermal transmittance and the dynamic thermal transmittance of the envelope are fundamental in the evaluation of transmission losses and in the choice of the best air conditioning system both in summer and in winter [12]. Simultaneously the weather is one of the main factors to consider when designing a building because it represents the most important boundary condition that affect the behavior of a building.

Closely linked to the energy needs of a building are the costs related to the use of the heating and / or cooling system and the production of DHW. If a building requires the consumption of electricity only to achieve indoor comfort it is possible to convert $PE_{g,nr}$, the global primary energy non produced by local renewable energy sources (RES) required by the building, into an annual operating cost A , according to Equation (1):

$$A = \frac{PE_{g,nr}}{f_{p,tot}} \cdot S_{floor} \cdot E_{e,price} \quad (1)$$

where S_{floor} is the floor building surface [m²], $f_{p,tot}$ is the total primary energy conversion factor which is 2.42 for Italy [13], and $E_{e,price}$ the price assumed for 1 kWh of electric energy [€/kWh] which is assumed 39,6 c€/kWh as the mean price of 2022 in Italy [14]. Considering different interest rate i the net present value (NPV) and the discounted payback time (DPT) can be calculated.

2.2 Thermophysical qualities

Since the building envelope is responsible for the thermal heating and cooling energy needs, it is important to deepen the knowledge of the properties of building materials, analyzing how the quantity or geometry of these affect the quality of the building envelope. For this type of analysis, a code has been developed in a MATLAB environment. For a given stratigraphy of the wall, depending on the climatic zone, the model generates a curve that allows to identify the thickness of the insulation necessary to

meet the legal limits in terms of stationary thermal transmittance U , periodic thermal transmittance Y , surface of the mass M_s and displacement time Δt . This analysis was developed for both classic brick and cross-laminated timber (CLT), keeping the thickness of the load-bearing structure constant.

3 Case Study

To highlight how energy consumption is closely linked to the type of building that is designed and used, the following paper analyses the energy performance based on the following steps:

1. the performance of a residential building designed according to the traditional typology of masonry houses located in the south of Italy, will be analyzed;
2. the same building will be redesigned in wood, to evaluate how this type of building has a great benefit on consumption and therefore on the environment;
3. to assess how the climate plays an important role in these assessments, the performance of the same building at different latitudes and climate context will be analyzed and compared;
4. to assess how the thermophysical parameters are fundamental in the energy and economic evaluation, a focus on the envelope quality will be described;
5. analysis of the results: consumption analysis and economic investigation.

3.1 Brick House

It is assumed to consider a residential house of simple geometry, built with traditional materials, that is with reinforced concrete structure, external walls in perforated bricks, wood frames and double glazing, insulated attic with simple sheath, with an uninhabited attic and ending with a double pitched roof with tiles (see Fig.1).

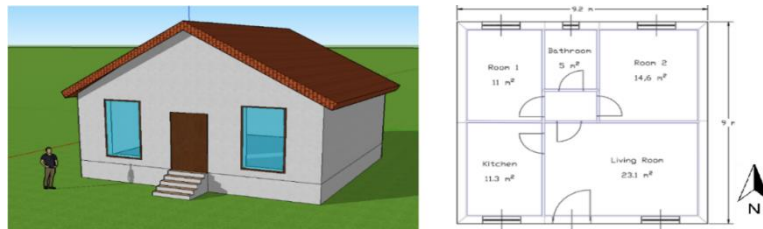


Fig. 1. 3D render and schema of the building

The heating system is composed by a hydronic heat pump and radiators, the cooling system is composed by a split system. The domestic hot water is provided by heat pump and flat plate collectors. A thermal storage is installed too to increase the efficiency of the system. To achieve the maximum rate of renewable energy there is also a photovoltaic system (PV) of 5,6 kWp and a battery with a capacity of 9.8 kWh. The energy performance of this house it was evaluated in 6 different cities of the Southern Italy; in

the Table 1 are indicated the 6 cities, the Heating Degree Days (HDD) values and the thermal transmittance limits of the envelope respectively.

Table 1. Italian cities and parameters

Cities	Porto Empedocle	Palermo	Ragusa	Caltanissetta	Enna	Floresta
Climatic Zone	A	B	C	D	E	F
HDD [$^{\circ}\text{C}/\text{day}$]	579	751	1050	1550	2248	3309
$U_{\text{limit, wall}}$ [$\text{W}/\text{m}^2\text{K}$]	0.4	0.4	0.36	0.32	0.28	0.26
$U_{\text{limit, roof}}$ [$\text{W}/\text{m}^2\text{K}$]	0.32	0.32	0.32	0.26	0.24	0.22
$U_{\text{limit, floor}}$ [$\text{W}/\text{m}^2\text{K}$]	0.42	0.42	0.38	0.32	0.29	0.28
$U_{\text{limit, window}}$ [$\text{W}/\text{m}^2\text{K}$]	3	3	2	1.8	1.4	1

According to the Italian national guidelines for buildings energy certification, it was possible to identify different climatic zones that (theoretically) have the same climate [15]. Employing the HDD, it is possible to identify six different climatic zones: zone A represents the hottest one and zone F the coldest. In each location it was implemented a house with the envelope that respect the requirements indicated from the Italian legislation [13]. More in detail, all 6 models (Base Case) have the same construction, the only difference is the insulation thickness which changes for each climate zone, while the same composition was chosen for the roof and the floor, satisfying the legislative limits for the coldest city, Floresta.

3.2 Timber House

To evaluate how the same building, made of wood, allows for a reduction in consumption, leaving the geometry and position with respect to the sun unchanged, it was assumed that the external walls are made of CLT with the presence of rock wool panels. Also in this case, were developed 6 models (Timber Case), one in each Climatic Zone, it was changed the thickness of the insulation layer and were used the same floor and roof that satisfy the limit of transmittance of F Climatic zone. More in detail, the floor is designed with CLT, a vapor barrier and a cork panels of 15 cm. The roof structure is like the brick one, but the slab is substituted with wood beams and the insulation chosen is a recycled extruded polystyrene (XPS).

4 Results

4.1 Energy consumption and comparison

According to the Italian standard procedure and using a dedicated software [16], the energy consumption of the 6 Base Case models and the 6 Timber Case models were analyzed. Fig. 2 shows the energy needs of all simulated models. For both the base case and the Timber case, the maximum primary energy requirement occurs in Caltanissetta, while the minimum is reached in the city of Porto Empedocle. Obviously, the energy required for the heating period decreases for less rigid climates while the need for

cooling increases. An evaluation of the energy savings related to wooden houses shows a reduction that varies from 17.19% for zone F to 0.23% in zone B. In the case in which the thermal energy required is very low, such as the climatic zone A, the global primary energy is higher of a factor 1.038. As explained in Fig. 2, in all cities, the cooling energy required of the timber house is higher than the traditional ones. For instance, in Porto Empedocle PE_h passes from 9.6 kWh/m² for the base case to 5.76 kWh/m² of the timber case while the PE_c increases of 6.2 kWh/m².

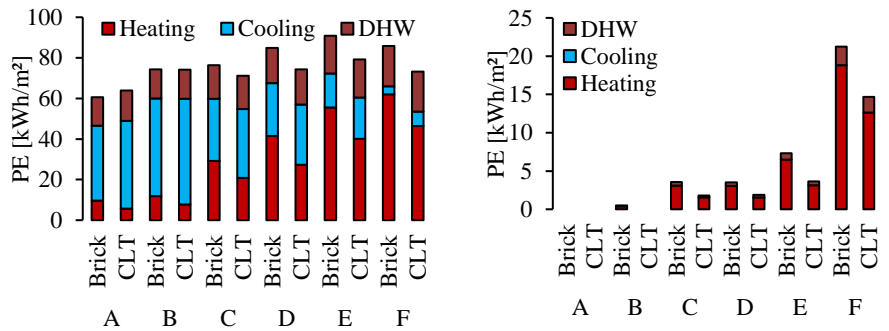


Fig. 2. Primary energy consumption (left) and primary energy not produced by RES (right)

The production of energy for heating and cooling is partially satisfied by the RES on site. The photovoltaic panels power the heat pumps while the solar collectors integrate the production of DHW. The right chart of Fig. 2 shows that the non-renewable energy (NREN) required is lower in the timber house positioned in warm climates. In fact, in zones A and B there is no NREN energy consumption, (PE_{nr}). It is fundamental to highlight that, in all cases, the cooling energy requirement is completely satisfied by the PV system. The reduction of PE_{nr} in the timber houses is between 31% (zone F) and 100% (zone B) so, in general, timber buildings require less PE_{nr} than base case.

4.2 Economic investigation

In general, to date wooden constructions require higher prices based on [17] in general require about 3-8 k€ more. In the coldest cities (Floresta and Enna), the brick walls require a thickness of insulation of 8 cm greater than timber and these are the only cases in which the CLT walls cost 3600 € less. Considering the insulation, costs are generally lower in wooden constructions due to the lower thermal transmittance value, thus requiring a reduced thickness of insulation. As indicated in Table 2 the yearly costs are reduced by a maximum of 100% in Zone B and a minimum of 33.6% in zone E.

Table 2. Yearly costs for electric energy for each model

Climatic Zone	A	B	C	D	E	F
Base Case [€/y]	0	30.15	214.7	211.7	442.6	884.7
Timber Case [€/y]	0	0	109.8	140.5	220.7	397.4

As can be seen in Fig. 3, the differences between the different annual savings and lumber costs, spread over 20 and 40 years, for each model, are considerable. Without considering any interest rate, the two configurations in which the timber is economically more sustainable are in zone E and in zone F. For the climatic zone A-D the investment costs are the same, because in each model the difference between the thickness of the insulation, from the base case to the Timber case, is always the same.

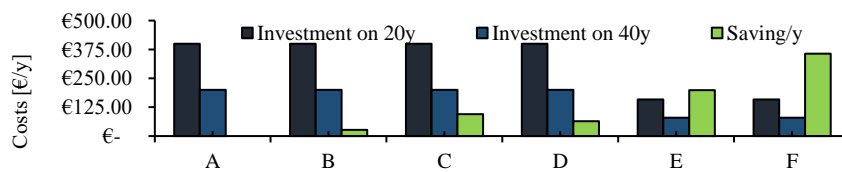


Fig. 3. Investment costs and saving per year

For the climatic zone E and F, a sensitivity analysis was carried out for different interest rates. The results show that using wood, for buildings built in coldest city, will take 20 years to pay back the investment considering an interest rate of 10%. With lower rates, the DPT drops dramatically and becomes just 13 years for a 6% interest rate and only 10 years for an assumed 3% interest rate. In this case, after 40 years, the NPV will be greater than 6,000 €. For Enna, the city that represents the climate zone E, timber house, with an interest rate less than 3%, will be characterized by a NPV after 50 years of only 2000 €, with a DPT that exceeds 20 years.

4.3 Thermo-physical qualities

The study on the thermophysical quality of the envelope is represented in Fig. 4, in which the value of the transmittance is represented as a function of the thickness of the insulation for the brick building and for the CLT building, respectively. The horizontal lines refer to the legal limit values for the various areas. The results show that Regardless of the climatic zone, CLT panels require less insulation because they are characterized by a lower thermal conductivity than brick ones. In wooden walls, requiring an insulation thickness of about 5-6 cm less.[13] As can be seen in Fig. 4, the traditional walls satisfy the superficial mass requirement without any insulation, while for CLT panels an insulation thickness greater than 50 cm is required. This happens because both CLT and insulation are characterized by low density. In the evaluation of periodic thermal transmittance, the results show that the CLT wall still performs better than the concrete wall, because it requires an insulation thickness of less than 1 cm while for traditional one a thickness of 4 cm is required. To obtain the best summer performance, according to [18], the time shift must be greater than 12 h. This goal is achieved with an insulation thickness greater than 13 cm for traditional walls and lower than 1 cm for CLT ones.

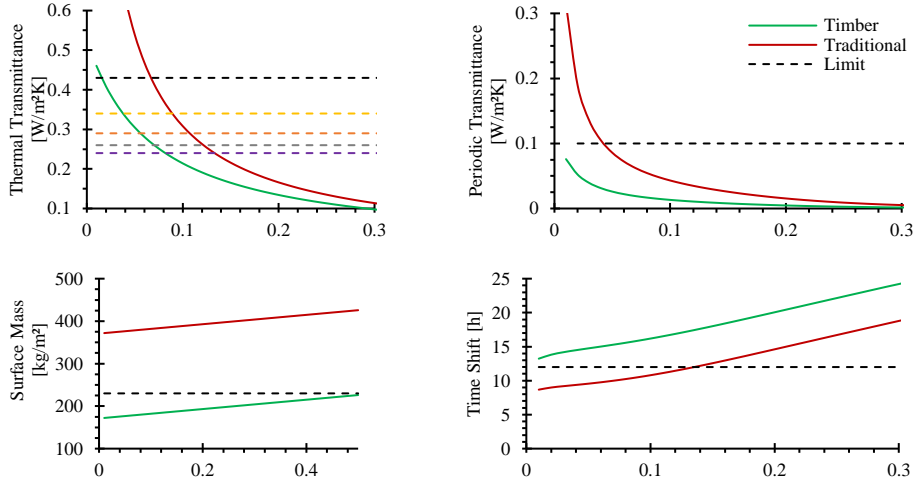


Fig. 4. Thermo-physical variables trend as a function of insulation thickness

5 Conclusions

In this work the authors propose the use of timber houses in the Mediterranean area. This type of building is generally typical of cold climates and Northern Europe, but to meet the needs of reducing consumption and costs, the first results of a case study of houses in wood located in Southern Italy compared to a traditional building is described. Since the climate is an important factor in evaluating the energy consumption of buildings, authors propose the study of the energy consumption of these buildings in six different climatic zone. Furthermore, to evaluate how the energy quality is dependent on a correct design and identification of some furnishing parameters, the fundamental thermal properties have been analysed with a code implemented on MATLAB environment. At the same time a simple economic analysis was carried allowing to evaluate the cost of the investment. The analysis of the first results shows that wooden buildings obtain energy savings ranging from 17.19% to 0.23%, depending on the climatic zone; except the hottest city. Wooden constructions are economically competitive in colder climates, such as Floresta and Caltanissetta. Furthermore, since solar radiation is high in Sicily, the increased demand for cooling in timber buildings could be fully covered by the presence of a PV plant. The model developed on MATLAB showed how a timber house requires less insulation to achieve the standards of periodic and stationary transmittance and time-shift. In conclusion, the research work presented shows that wooden buildings can be attractive solutions even in the Mediterranean climate bringing environmental benefits and cost savings. Despite that, currently, timber buildings are still not economically competitive compared to traditional constructions. This work is only the first result of a research that will be deepened and refined, to represent a guide for the new generation designers who must face complex challenges that consider both energy, environmental and economic aspects at the same time.

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