# Validation of Energy Simulations of a Sustainable Wooden House in a Mediterranean Climate

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## Abstract

Wood has become an appealing solution in the building sector compared with traditional materials such as stone, steel, concrete, and brick for several reasons: it is more sustainable, it provides good thermal properties, and allows for fast construction processes in dry-assembled applications. However, wooden buildings in the Mediterranean area are still not very widespread , mainly due to social prejudices about their resistance to seismic events and doubts concerning durability and fire resistance. The paper focuses on the validation of an energy model of a sustainable wooden building that is the prototype of a research project aiming at producing advancement in the development of residential settlement models with solutions to implement in new single or multi-story buildings. The single-family building is located in the province of Cosenza (South Italy). The building was equipped with a monitoring system for the acquisition of quantities of interest for thermal analysis and was subject to an experimental campaign conducted in the summer of 2021. The building was then modeled in the TRNSYS environment accounting for the detailed modeling of solar radiation. Simulations were performed in free-floating conditions, allowing the thermal model to be validated. Then, further energy simulation allowed an evaluation of the thermal performances of building in different Italian localities, allowing the viability of wooded solution in a Mediterranean climate to be demonstrated.

## 1. Introduction

Sustainability has become a major concern nowadays where worldwide policies aim at achieving the sustainable development of society, with minimal depletion of material and energy (Shushunova et al., 2020). The building sector is an important field where lots of efforts have been made to reduce the energy consumption associated with annual operation and enhance the sustainability of construction (Korol et al., 2018). Wood has been used in the past as the main construction element, especially in cold climates (Arumägi & Kalamees, 2014), but then disregarded in favor of materials such as steel, concrete, and brick rendered more available by the strong industrialization of manufacturing.

Recently, wood has been rediscovered thanks to its appealing characteristics (Slávik et al., 2019) since it is recyclable, reusable, and naturally renewable. Moreover, it has excellent strength-to-weight ratios, thermal insulating and acoustical properties (Caniato et al., 2022) that make it appropriate for different kinds of applications in buildings (Asdrubali et al., 2017). A comparison of the sustainability impacts of both wood- and concrete-based building materials (Žemaitis et al., 2021) shows that that glue-laminated timber and sawn timber value chains have more positive sustainability impacts, especially when referred to environmental indicators. The study also highlighted the socio-economic advantage of wood, which could increase the competitiveness of the regions and contributes to their sustainable development.

Despite the growth and numerous advantages of timber construction, the global scale of multi-story timber construction is still relatively low (Leskovar & Premrov, 2021) compared to reinforced concrete

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2023. Building simulation applications BSA 2022. bu,press.
https://doi.org/10.13124/9788860461919

and steel construction. One of the reasons lies in the complexity of their design, whereby the architectural design, the selection of a suitable structural system, and the energy efficiency concept heavily depend on the specific features of the location, particularly climate conditions, wind exposure, and seismic hazard. An interesting construction solution combining a timber frame with a precise layout of cross-laminated timber panels for a multistory building has been proposed (Bruno et al., 2019). Such a building was capable of attaining both seismic safety and nZEB requirements.

An experimental research study on a wooden frame house was conducted in France to better understand hygrothermal phenomena, and to allow the validation of numerical models for heat, air, and moisture transfers in wooden frame buildings (Piot et al., 2011). Another study in France focused on the desorption and adsorption behavior of exotic wood, then modeled heat and mass transfer through a wooden wall (Simo-Tagne et al., 2021).

This paper focuses on the energy performance of a single-story wooden building in the Mediterranean area. The prototype was built as part of a research project aiming at producing advancement in the development of residential settlement models. A monitoring campaign was conducted in the summer and the thermal model developed in TRNSYS environment was validated thanks to the experimental data. Finally, a series of simulations showed the thermal behavior and winter and summer energy consumption of the proposed building in different Italian localities.

## 2. Methodology

### 2.1 The Building Prototype

The demonstrator is a single-family building, classified as a single-story /insulated house, located in Zumpano, a town in the province of Cosenza (South Italy), in the climatic zone D with 1647 degree-days. The building is the output of a regional research project and has a gross surface area of 96 $m^2$ including the patios on the main front and back, and an inter-floor height of 2.70 m. The building presents a platform frame constructive system.

The project aims at proposing innovative modular solutions for buildings that can be easily assembled and disassembled providing flexibility in the creation of new spaces, and with the use of sustainable materials for their construction.

Fig. 1 – Prototype building of the project Sweethome

The massive employment of wood confers characteristics of celerity of construction and ultimately pushes toward the development of a local production chain of wooden elements, given the abundance of woods in the Calabria. The thermal properties of the layers of the vertical opaque elements are reported in Table 1.

Table 1 – Thermal properties and layers of the opaque vertical envelope

| Material | S [cm] | λ [W $m^{-1}$ $K^{-1}$] | ρ [kg $m^{-3}$] | $c_P$ [kJ $kg^{-1}$ $K^{-1}$] |
|---|---|---|---|---|
| Rock Wool | 5 | 0.035 | 78 | 1.03 |
| OSB panel | 1.5 | 0.130 | 650 | 1.7 |
| Wood beams +Mineral wool | 12 | 0.192* | 105 | 1.3 |
| OSB panel | 1.5 | 0.130 | 650 | 1.7 |
| Air | 5 | 0.28 | 1.23 | 1 |
| OSB panel | 1.5 | 0.130 | 650 | 1.7 |
| Plasterboard panel | 1.2 | 0.210 | 816 | 1 |

* equivalent thermal conductivity

The resultant thermal transmittance is 0.23 W/($m^2$ K), due to the high presence of thermal insulation. The wall facing North presents an additional layer of fir wood, mainly for aesthetic appearance. The ground floor has 6 cm of EPS insulation, reaching an overall U-value of 0.24 W $m^{-2}$ $K^{-1}$. The roof cover has the same value.

Different types of windows were employed in the prototype. In the main room, the East façade has a double-glazed window with lamellar chestnut frames and a U-value of 1.73 W $m^{-2}$ $K^{-1}$, whereas the North and South façades have a glazed window with PVC frame with a U-value of 1.47 W $m^{-2}$ $K^{-1}$ and 1.68 W $m^{-2}$ $K^{-1}$, respectively.

## 2.2 The Experimental Campaign

In order to assess the thermal performance of the proposed solution, a monitoring campaign was performed in the summer of the year 2021. Several thermo-hygrometric quantities have been monitored with the help of a conspicuous number of sensors and probes. In particular, only the central room of the building was monitored, since it has the largest area, and is the most representative space of the house.

Data logger M-log from LSI LASTEM was placed in the middle of the room to measure:

- Air temperature
- Relative humidity
- Air velocity
- Wet-bulb temperature
- Mean radiant temperature

The psychrometer measures the dry bulb temperature with a Pt100 class 1/3 and an accuracy of 0.10 °C at 0 °C. The relative humidity is measured with an accuracy of 2 %.

Furthermore, a series of Resistance Thermal Detectors were placed in correspondence with each opaque and glazed surface to measure the internal surface temperature of each wall and window. In particular, 4-wire Pt100 sensors class 1/3 with an accuracy of 0.10 °C at 0 °C were employed. Such data were acquired by a datalogger Hioki LR8400-20.

Fig. 2 – Sensors and instruments installed in the central room of the building prototype

A further thermohygrometer DELTAOHM HD2101.2 was placed outdoors behind the main entrance, covered by the external patio to avoid direct exposition to solar radiation, to measure external temperature and relative humidity. The probe used is the HP474AC R with an accuracy of ±1.5 % (0…90 % RH) for relative humidity and ± 0.3 °C for temperature. The datalogger has an internal memory allowing the storage of data that can be successively downloaded to a pc.

## 2.3 The Simulation Model

The simulation model of the building prototype was developed in a TRNSYS 18 environment. This well-known software allows for dynamic energy simulation of buildings and energy systems in general. The 3D model of the building was realized in Sketchup with the TRNSYS 3D plug-in allowing for a detailed geometry representation. To increase the accuracy of the model and account for the effect of shadings and overhangs, the detailed model for beam radiation and diffuse radiation was set for calculation in TRNBUILD. Likewise, a detailed approach was chosen for the longwave radiation exchange. Internal and external heat transfer coefficients were set to 11 kJ $h^{-1}$ $m^{-2}$ $K^{-1}$ and 64 kJ $h^{-1}$ $m^{-2}$ $K^{-1}$ respectively. The solar absorption coefficient was set to 0.14 for external white surfaces and 0.75 for the north one with a wooden finish. For windows, the g value was assumed to be 0.62 for the window on the north façade and 0.66 for all other windows.

Since during the monitoring campaign there were

no internal loads in the building, the thermal gains were set to 0.
Furthermore, because of the careful construction of the building with a high degree of air tightness, it was possible to exclude infiltration through the envelope.
Type 9 was used to provide hourly data on solar radiation, dry bulb temperature, and relative humidity. Type 16g was then used to evaluate irradiation on different tilted surfaces; Type 69b and 33e were used to evaluate the sky temperature and finally Type 77 provided the ground temperature at different depths.

## 3. Results and Discussion

The validation of the model was performed with data acquired from 01/06/2021 to 16/06/2021 when the building was operating in a free-floating regime. The main quantity considered for validation was the internal air temperature of the zone. The values of simulated and measured temperature are reported in Fig. 3.

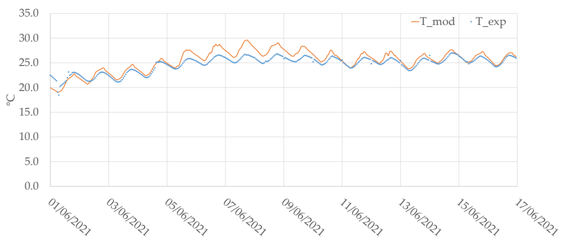


Fig. 3 – Trends of simulated and experimental internal air temperature in the free-floating regime for the period 01/06/2021 – 16/06/2021

The model showed an excellent capability for predicting the internal air temperature variations. Some differences can be observed in the central days of Fig. 3, which are mainly attributed to uncertainty in the values of solar radiation employed for simulation and because of some deviances in the prediction of the temperature of some internal surfaces. Overall, the performance was fairly satisfactory, with an average difference between predicted and measured temperatures of -0.74 °C. The results are further confirmed by Fig. 4, which reports the simulated versus the measured temperature. As can be observed, the data are well aligned along the bisector and a global correlation coefficient $R^2$ of 0.9683 can be obtained.

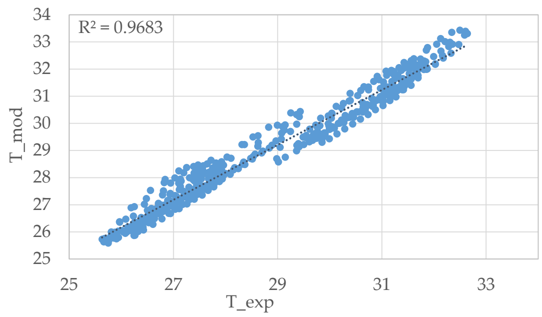


Fig. 4 – Simulated versus experimental internal air temperature in the period 01/06/2021 – 16/06/2021

### 3.1 Thermal Performance of the Prototype Building

In order to obtain more detailed information on the energy performance of the prototype building in different climatic conditions, a series of subsequent simulations have been performed. To describe more realistically the operation of the building, internal gain according to the Italian reference UNI EN TS 11300 was defined and set in the building model. In particular, for the main room of the building, a daily profile as in Fig. 5 was defined, with a maximum load of 20 W m$^{-2}$.

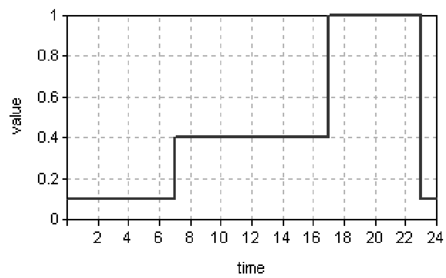


Fig. 5 – Internal gain profile for the main room of the building

Simulations were then performed in different Italian cities, each one representative of a different climatic zone. The heating setpoint temperature was set to 20 °C, whereas the cooling one was set to 26 °C.
In the warm locality of Palermo, with an average yearly temperature of 18.60 °C and global solar horizontal radiation of 1662 kWh m$^{-2}$, the results are reported in Fig. 6.

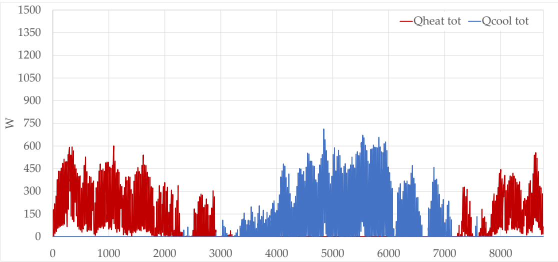


Fig. 6 – Heating and cooling load for the locality of Palermo

The annual energy consumption amounts to 668 kWh for heating and 514 kWh for cooling.
In the milder location of Rome with an average yearly temperature of 15.5 °C and a global solar horizontal radiation of 1559 kWh $m^{-2}$, the results are reported in Fig. 7.

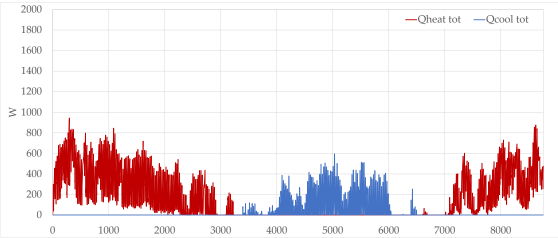


Fig. 7 – Heating and cooling load for the locality of Rome

The annual energy consumption amounts to 1430 kWh for heating and 270 kWh for cooling.
In the colder locality of Bolzano with an average yearly temperature of 12.1 °C and a global solar horizontal radiation of 1250 kWh $m^{-2}$, the results are reported in Fig. 8.

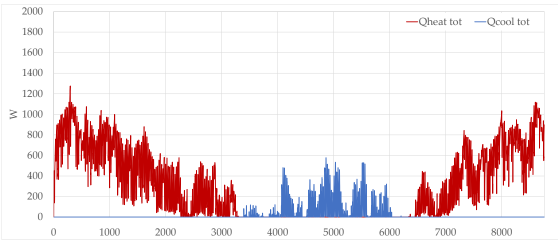


Fig. 8 – Heating and cooling load for the locality of Bolzano

The annual energy consumption amounts to 2563 kWh for heating and 178 kWh for cooling.

## 4. Conclusion

Recently, the use of wood in building construction has increased noticeably since it is recognized that wood is an environmentally friendly material and can contribute to the achievement of sustainable development goals. However, the rate of these construction solutions is still low compared to reinforced concrete and steel constructions, mainly because the selection of a suitable structural system and the energy efficiency strongly depend on the specific location and in particular climate conditions and seismic hazards. The paper presents the validation of the energy model of a single-storey wooden building in the Mediterranean area. The building was equipped with a complete monitoring and data acquisition system, and an experimental campaign was conducted in the summer of 2021. The energy model of the building was developed in TRNSYS environment and was validated thanks to the experimental data acquired. With reference to the internal air temperature of the main room of the building, a correlation index $R^2$ of 0.9683 was obtained for a simulation period of 17 consecutive days.
Then the model was employed to evaluate the energy consumption of the building in winter and summer conditions in different climatic localities in Italy.
The results showed the limited energy needs of the building. Heating requirements ranged from 668 kWh in Palermo to 2563 kWh in Bolzano. In the same two cities, the cooling requirements amounted to 514 kWh and 178 kWh

## Acknowledgment

The paper was partly supported by Regione Calabria POR CALABRIA FERS FSE 2014-2020 ASSE I – promozione della ricerca e dell'innovazione through the grant of project SWEET HOME - Sustainable Wooden and Energy Efficient HOuse in the Mediterranean. CUP J18C17000600006

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