

Hemp-lime buildings: thermo-hygrometric behaviour of two case studies in North and South Italy

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ABSTRACT

In the framework of Circular Economy policies aimed at reducing the consumption of raw materials, shives, an agricultural by-product of hemp cultivation, have gained a renovated life in the construction sector; new building materials, suitable for various executive techniques, have been developed exploiting the excellent thermal insulating properties of shives. When this vegetal material is mixed with a mineral binder such as lime or cement, the mixture is usually referred to as hemp-lime. In Italy, the use of hemp-lime blocks and the development of new production chains dates back only to about the last decade, while other European countries have more long-lasting experiences. In order to assess the potential benefits of hemp-lime blocks in the construction sector, it is necessary to evaluate the performance of these materials in situ, i.e. on the construction site, to obtain fundamental data to ensure that consumers and designers receive trustworthy and relevant information on products and their durability.

This research work aims to be a solid base for the development of future guidelines and/or regulations at national and international level, in order to guarantee the maximum diffusion of this type of product. Then, a study plan has been carried out regarding the functionality of hemp-lime blocks in

masonry, layered with finishing plaster made of fine hemp shives, to evaluate the in situ thermohygrometric building performance. In particular, experimental methods were developed and measurements were carried out on two structures, one in northern Italy and one in southern Italy, and precisely in Sicily, focusing the study on the performances of the walls subjected to warm Mediterranean climates.

1. INTRODUCTION

The building sector has a major impact on the environment, the heating and cooling of buildings constitute 40% of global energy consumption and around the 33% of equivalent carbon dioxide emissions (CO₂eq) [1]. During the last two decades, new materials have been developed to reduce the impact given by the production and utilization of traditional building materials and the natural-based solutions are among the most promising novelties. These are produced introducing by-products of agricultural cultivations (e.g. rice husk [2], flax [3], hemp [4], corn [5]) in traditional binders to obtain products with excellent insulating properties. Also, the utilization of local crop waste and biomasses reduces the transport of raw materials and enhances regional plans for sustainable development. At the end of their service life, the natural-based solutions are completely recyclable and hence their life cycle fully adheres to the principles of circular economy.

This research focusses on hemp-lime that is produced introducing hemp shives, obtained after the scutching of industrial hemp plants, into lime [6]. The result is a carbon negative or carbon neutral material characterized by low density, excellent moisture buffer capability, low thermal conductivity and excellent insulation properties. Regarding the environmental sustainability, few life cycle assessment studies of hemp-lime have been performed: two of them regard the sprayed hemp-lime [7], [8], a study deals with casting in formworks [9] and one focusses on hemp-lime blocks [10]. They confirm that hemp-lime is characterized by lower embodied energy and emissions of carbon dioxide with respect to traditional building materials; significant carbon uptake occurs during the growth of

the plants and through the reaction of carbonation of lime that is typical of the hemp-lime hardening phase. Moreover, a crucial property of hemp-lime is hygroscopicity, it gives an improvement of indoor air salubrity and contribute, together with porosity to hinder the formation proliferation of microorganisms or moulds formation favoured by high humidity conditions [11]. Thus, hemp-lime can store or release moisture giving good response in terms of indoor humidity regulation even when a sudden variation of indoor conditions verifies; this characteristic behaviour has a direct influence on the energy consumption that, for example, are reduced of the 45% with hemp-lime versus cellular concrete application [12], [13]. In addition, the measurement of thermo-hygrometric properties is fundamental to determine the response of the material to variations of temperature or relative humidity. If these tests are performed in situ, the efficacy of the material and of the selected coating can be determined in the climatic conditions of application as well as the effect on the indoor comfort can be evaluated [14–17]. Hence, the modelling of hygrothermal behaviour is crucial to predict the behaviour of the material when different constructive strategies are applied, e.g. application of hygroscopic plaster, external or internal insulating layer [18–20].

When hemp-lime is casted on site it is difficult to control the homogeneity of the mixture; to overcome this issue some producers have initiated the production of prefabricated elements such as panels or blocks. These components are installed as non-loadbearing elements in thermal and acoustic insulation layers of building envelopes or as internal partition walls and the quality of the material is higher than that of the hemp-lime casted in wooden frameworks [21].

This project aims at evaluating the performances of hemp-lime blocks in Mediterranean climate, specifically in Italy, where the application of such materials is increasing despite some technical issues. Actually, industrial hemp is widely cultivated in Italy where there are more than 30 producers of hemp-containing building materials (e.g. insulating panels or blocks), but there are some substantial limitations to the diffusion of these materials in the national building sector [22]. Primarily, specific granulometry range is required to shives for building applications and, at present,

the existing facilities in Italy do not produce shives with controlled granulometry. Hence, the suitable shives for building purposes are imported from France or other European countries lowering the environmental and economic sustainability of the process. In addition, the lack of normative about building with hemp prevents the standardization of these materials in the construction sector and consequently their spread. Regarding prefabricated blocks, their production does not require specific machinery, as it exploits the supply chain of traditional vibro-compressed concrete blocks. Then, the only differences between the recipes of sprayed or casted hemp-lime and prefabricated blocks are the proportion of ingredients and the granulometry of hemp shives, which is finer when spraying is performed. The critical step of the production of blocks is the drying of hemp-lime since it is necessary that a certain level of strength is achieved to install them. During hardening, it is necessary to protect the material from excessively high or low levels of relative humidity to avoid the initiation of biological degradation phenomena that decrease the properties of hemp-lime. Beside the drying step, the type of binder and hemp shives employed have significant influence on the performances of the material and the huge variety of these factors causes difficulties in monitoring the quality of products and their application [23–25]. In France, the association Construire en Chanvre [26] has introduced a standardization and certification procedure for hemp-containing products to be used in buildings and good practice rules have been introduced for the different constructive technologies to grant a correct installation of the material and uniform strategies of application [27 - 28]. In Italy there is only a law related to sustainable materials for the construction sector [29] and authorises the utilization of organic material deriving from crops in building products; however, this recent legislation (2016) is, up to now, the only directive which regulates the installation of building materials containing vegetal fibres [22].

Being the bio-based solutions innovative in the framework of building materials, further studies of their performances aim at developing a complete study of the materials to exploit all the advantages they can introduce in buildings and foster their utilization in the building sector.

2. MATERIALS AND METHODS

Hemp-lime prefabricated blocks analysed in this research are characterized by the following properties:

- dry density: 330 kg/m³;
- thermal conductivity: 0.07 W/mK;
- water vapour diffusion resistance: 4.50;
- specific heat: 1280 J/mK;
- absorption coefficient (acoustic): 0.80;
- fireproof, if plaster is applied.

The blocks are produced in different dimensions, tailored to the specific application, and their size-dependent properties are listed in Table 1.

Table 1. Hemp-lime block properties as provided by the producer.

Hemp-lime block	B8	B12	B25	B30	B36	B40
Dimensions [cm]	50x8x20	50x12x20	50x25x20	50x30x20	40x36x20	36x40x20
Thermal transmittance [W/m²K]	0.76	0.53	0.27	0.22	0.19	0.17
Sound attenuation index Rw (dB) with 1.5 cm plaster	24.37	36.55	40.11	41.17	42.29	42.96
Thermal lag without plaster	3h 9'	5h 53'	14h 48'	18h 13'	22h 19'	25h 4'

In order to study the functionality of hemp-lime blocks, a methodology was developed and verified through laboratory experiments (thermo-hygrometric and thermo-flow performances) on a test wall introduced in a climatic chamber [30]. Then, the same procedure has been applied in two construction sites to evaluate the performances of hemp-lime in Mediterranean climate. The results of the first in situ experimental campaign are presented in this paper; the experimental data have been collected in two buildings, one in Sicily (South of Italy) and one in Veneto (North of Italy), in which the same hemp-lime blocks had been installed [31].

The methodology consists in monitoring temperature and relative humidity of the indoor and outdoor

environments as well as on the internal and external sides of the walls of the building. The technical characteristic of instruments employed for the tests are summarised in Table 2.

Table 2. Technical characteristic of testing instruments.

Instrument	Technical characteristic
Capetti measuring station	measuring range for temperature: -40 °C – 80 °C, sensitivity 0.2 °C measuring range for wind speed: 0.5 m/s – 70 m/s, sensitivity 0.1 m/s measuring range for direction: 0° - 360°, sensitivity ≤ 1° measuring range for sun radiation: 0 W/m ² – 2000 W/m ² , sensitivity 3 um
Thermographic camera FLIR T 620	measuring range for temperature: -40 °C - 650 °C, thermal sensitivity (N.E.D) from <0,04 °C to 30 °C zoom 4x, automatic or manual focusing
Capetti PT1000 Class A sensors for wall temperature measuring	measuring range for wall temperature: -20 °C-60 °C, 0.01 °C, sensitivity 0,1 °C accuracy in 10% - 90% relative humidity range
Capetti sensors for microclimate measuring	measuring range for temperature: 10 °C - 80 °C, 0.01 °C sensitivity 0.1 °C accuracy in 10% - 90% relative humidity range 0 ppm - 2000 ppm, 10 ppm sensitivity and 1 ppm accuracy
Capetti sensors for surface temperature and relative humidity (CMOSens [®]) measurement	measuring range for temperature: -10 °C - 60 °C, NTC 10K, ±0.2 °C sensitivity measuring range for relative humidity: 0% - 100%, ±2.5% sensitivity in 0% - 90% and sensitivity varies from ±2.5% to ±3.5% in 90% - 100% (validity temperature range 0 °C - 50 °C)
Bosch laser rangefinder GLM 80 Professional	measuring range 0.05 – 80.00 laser diode 635 nm, < 1 mW
TROTEC 3000 hot wire anemometer TS 430 SDI	measuring range for temperature 0 °C - 50 °C accuracy +1.0 °C suitable for measurements up to 2m/s
Microclimate sensors for indoor comfort measuring	CO ₂ range 0ppm-2000ppm, with sensitivity ±10 ppm, accuracy 1 ppm measuring range for temperature: 30-60 °C, sensitivity ±0,2 °C, accuracy 0,01 °C relative humidity range from 0% - 100%; ±2,5% from 0% to 90%,from 90% to 100% vary from ±2,5% to ±3,5% (validity temperature range 0 °C - 50 °C)

When in situ measurements are performed, it is possible to avoid the installation of the meteorological station if data about weather conditions are available. In this project, the data recorded in the two buildings have been compared with the information from Meteonorm[®] software [34], which provides meteorological time series - e.g. temperature, relative humidity, wind speed, wind direction, normal

rain, global horizontal solar irradiance, diffuse solar irradiance, cloud index, atmospheric counter radiation- from more than 8000 weather stations on Earth. Particularly, Meteonorm generates a representative typical year, averaged over three years, with a sampling frequency of one data per hour.

Then, to support and validate experimental analysis, walls have been modelled through the software WUFI® which allows for the numerical simulation of their thermo-hygrometric behaviour [32]. The calculation procedure applied by the software is schematized in Figure 1, it consists in resolving simultaneously, in an iterative way, coupled equations of transport and accumulation of heat and humidity in the wall.

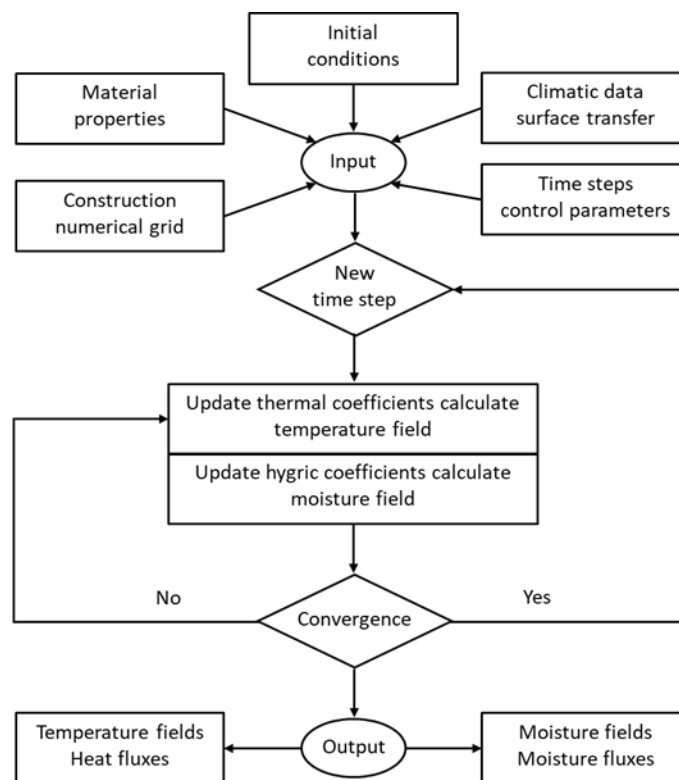


Figure 1. Workflow of WUFI® calculation procedure [32].

Specifically, the method followed for the case studies described in this paper consists in comparing temperature and relative humidity, experimentally measured for a certain period on the two faces of a wall, with the same physical quantities determined through numerical simulations. Data regarding

the conditioning systems inside the room and outside meteorological conditions, together with the thermo-hygrometric properties of the wall, are given as input to the software.

3. EXPERIMENTAL CAMPAIGN

In this study two reinforced concrete buildings having infill walls realised with the same kind of hemp-lime blocks (Table 1) were monitored. In order to evaluate their thermo-hygrometric performances under different climatic conditions, they have been chosen in two distinct areas of Italy (Veneto and Sicily respectively).

3.1. CASE STUDY 1: BUILDING SITE SONA (VR), NORTHERN ITALY

3.1.1. Generality

The first case study is a building in reinforced concrete with masonry wall system which has been turned into multipurpose use: residential and restaurant. The structure is located in Sona which is included in climatic zone E [33]. The tests were performed in autumn over almost one month, namely between November and December.

The measurements have been carried out in a dining room, open to the public, obtained as recovery of an arcade after a constructive action. This is an open space with a mezzanine, and then a double height, having not isolated roof with solid wood kerbs; the heating system consists of traditional radiators. The perimeter infill walls, accomplished in various intervention, present different types of materials: Poroton (12 cm thick) and hemp-lime blocks (25 cm thick) for north and south exposure and hemp-lime blocks (30 cm thick) for west exposure. The latter wall, positioned at the ground floor, was selected for the thermo-hygrometric measurements; it is constituted by hemp-lime blocks and masonry pillars as schematized in Figure 2. The transversal section of the same wall as modelled for numerical simulations through the software WUFI® Pro 6.3 is reported in Figure 3.

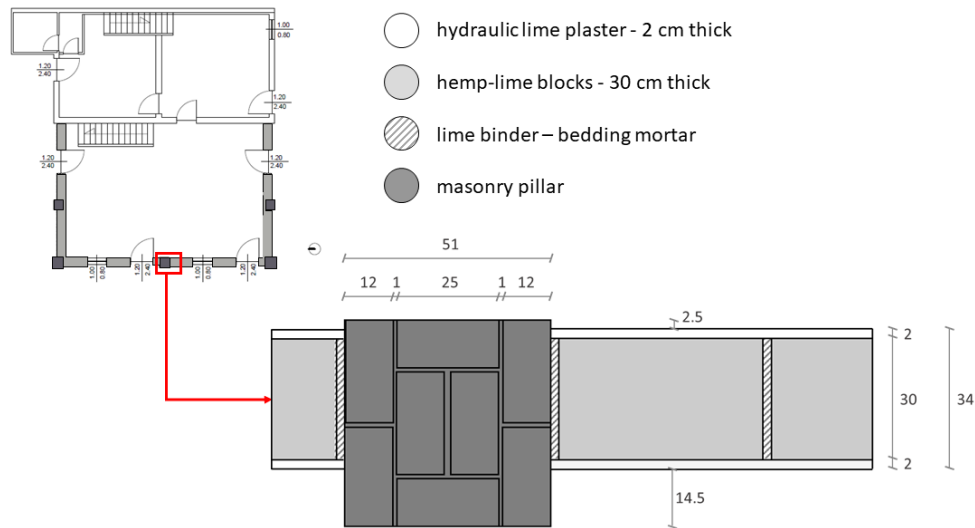


Figure 2. Horizontal section of the analysed wall including material sheets.

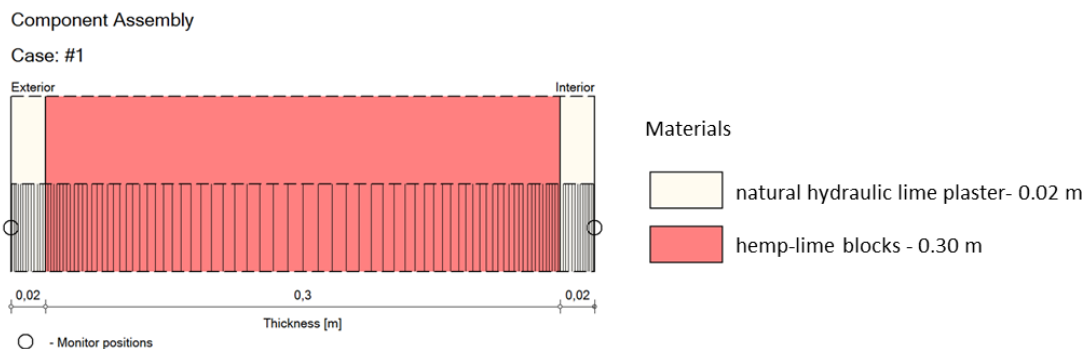


Figure 3. Numerical model of the transversal section of the analysed wall (WUFI® Pro 6.3).

3.1.2. In situ testing set up

The map of the ground floor and the positions of the sensors are reported in Figure 4: the meteorological station for temperature, humidity wind and sun irradiation measuring has been installed in position 1; position 2 corresponds to room sensors for temperature, humidity and CO₂ measuring; position 3 and position 4 indicate the location of indoor and outdoor wall mounted sensors respectively, applied for surface temperature and humidity measurement. The installation of the instruments has been carried out after thermographic survey on the wall [31].

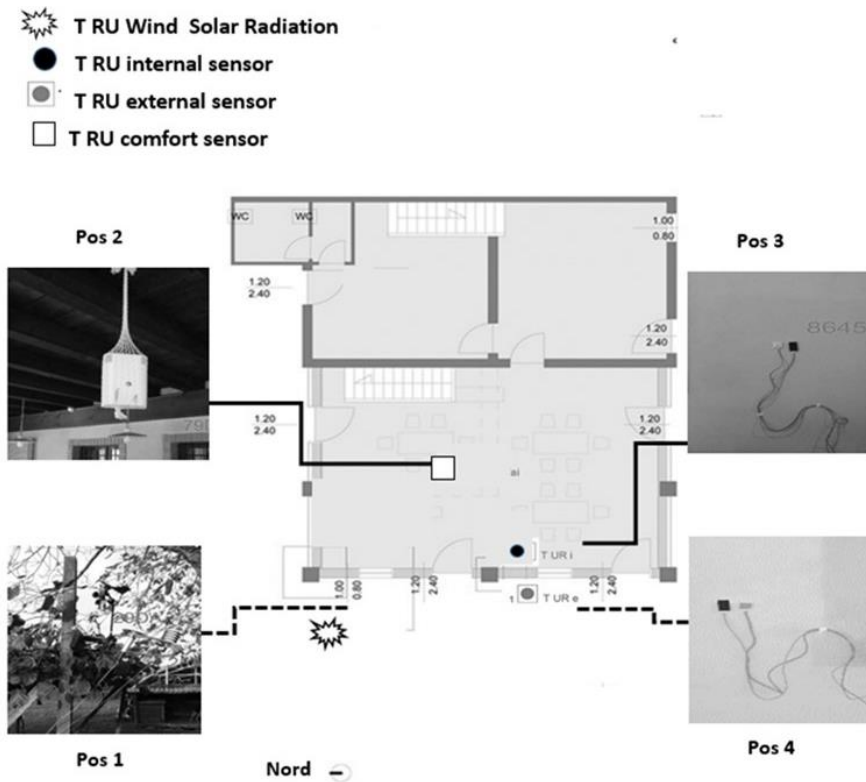


Figure 4. Ground floor map and positions of sensors.

3.1.3. Test results

First of all, temperature and humidity measured through meteorological station were compared with the corresponding data taken from Meteonorm for Verona site. Since the data given by Meteonorm represent a typical year (as the average of three years) and are discrete on the Italian territory (i.e. they are not available for the particular site under study), an approximation error could be introduced into the methodology, specifically regarding the implementation of the numerical model in WUFI® which is used to validate experimental results. The time graphs of temperature and relative humidity between 23rd November and 11th December, superimposed in Figure 5, show some significant differences. Particularly, the maximum difference in terms of daily peaks of temperature, recorded on 24th of November, is equal to 10°C whereas the minimum values differ by more than 8°C on 27th of November. As far as the relative humidity is concerned, the maximum difference in terms of daily peaks is equal to 15% on 6th of December and the minimum values differ by more than 35% on 11th of December.

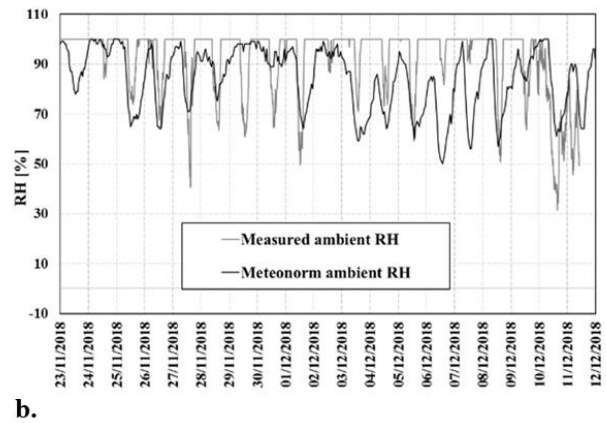
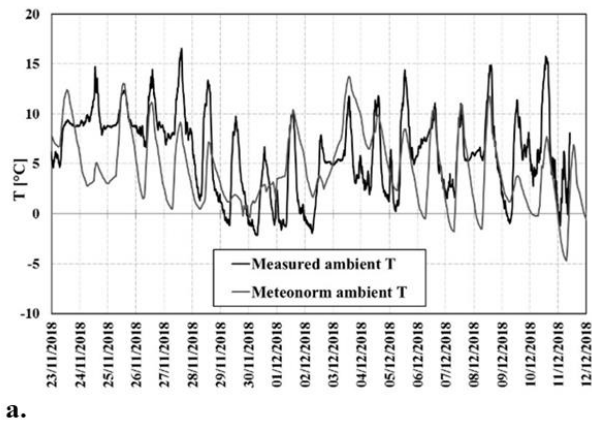


Figure 5. Environmental conditions Experimental vs Meteonorm: a) Temperature (T); b) Relative Humidity (RH).

The temperature and relative humidity measured by sensors in positions 3 and 4 are reported in Figure 6, the comparison between the behaviour of internal and external faces gives direct indication of the infill wall performance.

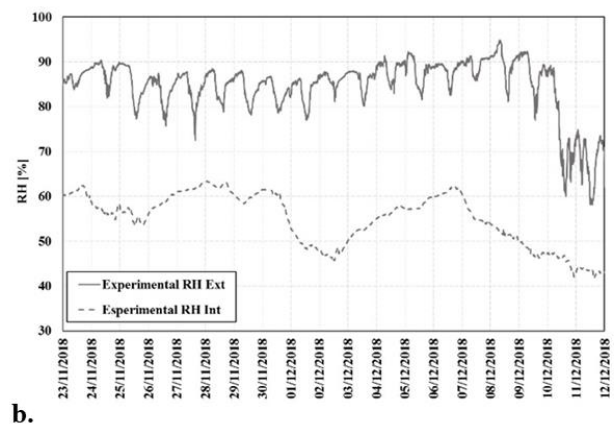
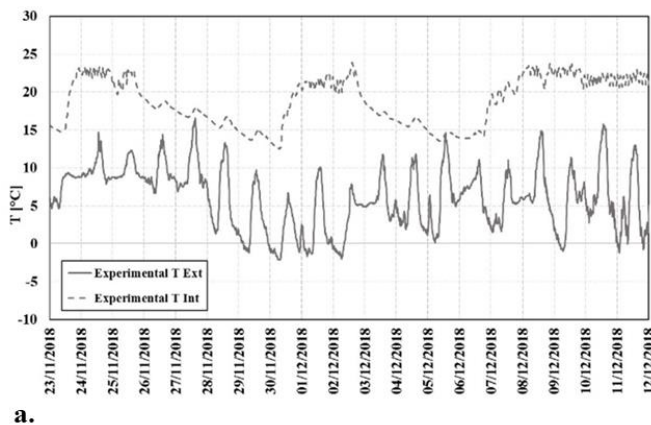


Figure 6. Experimental measuring of surface conditions, internal vs external wall faces: a) Temperature (T); b) Relative Humidity (RH).

In order to analyse Figure 6, it is worth noting that the heating system is set at a temperature of 19 °C only during weekends (23rd - 25th November, 30th November – 2nd December) and between 7th – 12th December, when restaurant is open and people are present in the room; on the other days heating system is not in function. It is evident that the temperature on internal face of the wall is almost constant during heating functioning (with an average value of 19.6 °C) and decreases of almost 8 °C between two consecutive operations without significant variations between day and night. Moreover, the presence of the people slightly increases the temperature with respect to the value set through the

heating system. Meanwhile, the daily temperature ranges from -2 °C to 10 °C on external face of the wall. As expected, the relative humidity on the internal face of the wall oscillates in opposition of phase with temperature, reaching a maximum value of 63% and a minimum value of 45% during the functioning of the heating system and external humidity varies between 80% and 90%.

Following the same approach of laboratory tests [32], experimental and numerical results have been compared. In Figure 7, the temperature measured during the experimental campaign on the internal and external faces of the wall are superimposed to the results obtained by the two numerical simulations. Similarly, in Figure 8, time graphs of measured and computed relative humidity are shown.

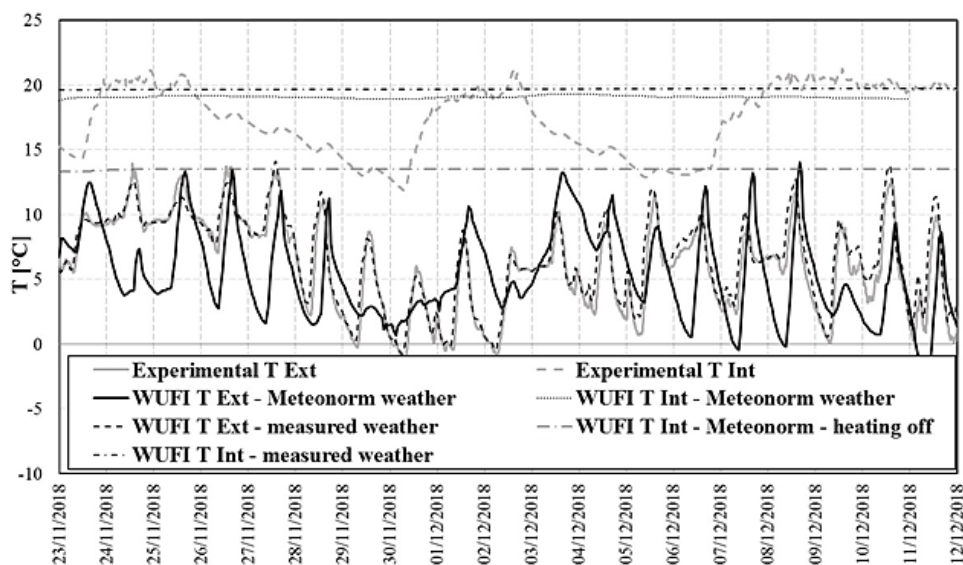


Figure 7. Temperature (T) on the wall internal and external faces Experimental vs Numerical.

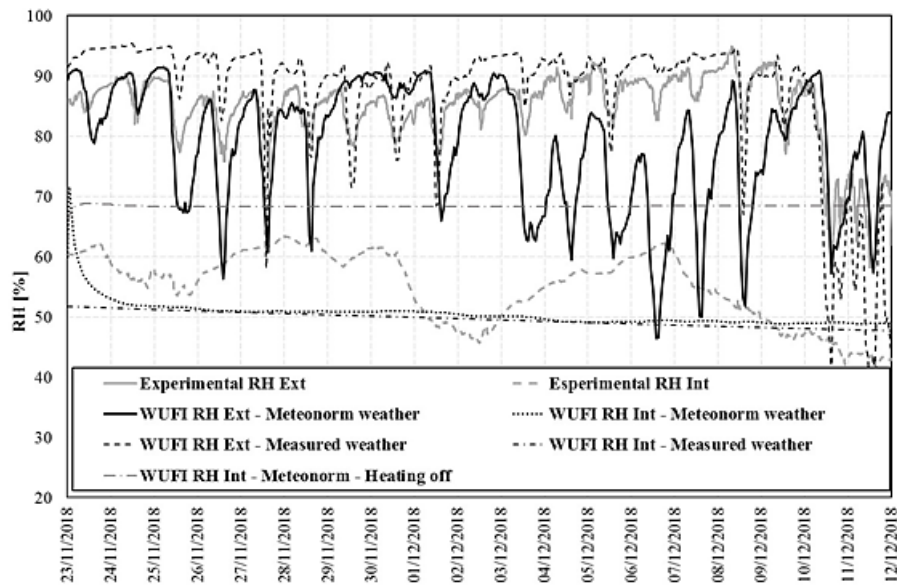


Figure 8. Relative Humidity (RH) on the wall internal and external faces Experimental vs Numerical.

The results for the external face, obtained by numerical simulations using data taken from Meteorom as input, are plotted in darker solid lines. Significant differences were recorded with respect to the experimental results, plotted in lighter solid lines, as expected from plots in Figure 5. It is noteworthy that a difference of almost 7°C , in terms of daily peaks of temperature, is recorded on 24th of November, and similarly on 27th of November the minimum values differ by more than 7°C . The offset values are more evident in terms of relative humidity, on 6th of December the maximum daily peaks differ of almost 13% and the minimum ones of almost 35%. This indicates that the data from outdoor environment monitoring of temperature and humidity for the specific site, Sona, differ from data provided by Meteorom for Verona site. For this reason, the numerical analysis was repeated, introducing as input the environmental meteorological conditions directly measured by instruments in the construction site. In this case a good agreement between experimental and numerical results has been obtained for external face, especially in terms of temperature as shown by darker dotted lines in Figures 7 and 8. The curves are almost coincident except for some point deviations that, however, do not exceed 2°C (e.g 26th of November and 5th of December). As far as the relative

humidity is concerned, an offset of almost 5-7% is recorded in terms of peaks whereas, in some punctual cases, the minimum values differ of 10-15%. Regarding the internal face of the wall, even if results obtained using Meteonorm and measured environmental meteorological data are very close, they differ from experimental ones, both in terms of temperature (up to 10%) and humidity (up to 20%). These differences are due to the introduction of a constant value for indoor temperature (20 °C) as input for the numerical simulations, hence the variation due to the switching off of the heating system is not taken into account. The latter condition is represented by the dotted line almost constant at about 15 °C in Figure 7. On the other hand, numerical and experimental results are almost coincident in the time intervals when heating system is in operation. The small oscillations recorded in the measured temperature can be attributed to the presence of the people, not considered by the software.

It is worth noting that, despite the differences in terms of temperature on the external face of the wall obtained through numerical simulation using as an input data taken from Meteonorm or measured, the numerical results in terms of temperature on the internal face are almost coincident. Hence, the response of the wall is almost independent from external climate giving an additional evidence of the good performances of hemp-lime blocks in these climatic conditions.

3.2. CASE STUDY 2: BUILDING SITE SERRADIFALCO (CT), SOUTHERN ITALY

3.2.1. Generality

The second case study is a building located in Sicily, in climatic zone D [33]. This new construction is made up of reinforced concrete with isolated brick cement floor and it is part of a terraced house of residential purpose. Thermo-hygrometric measures have been carried out in summer over almost one month, namely between July and August. It is worth noting that during this time period air conditioning was not running. All perimeter infill walls are accomplished using hemp-lime blocks (36 cm thick) as schematized in Figure 9. The transversal section of the same wall, as modelled for numerical simulations through the software WUFI® Pro 6.3, is reported in Figure 10.

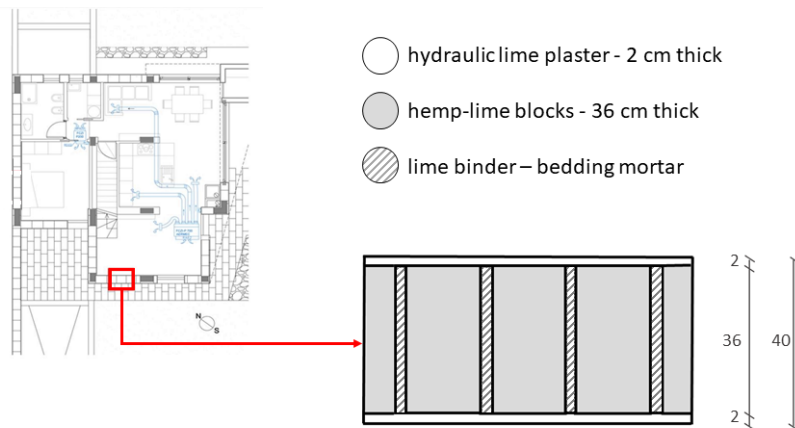


Figure 9. Horizontal section of the analysed wall including material sheets.

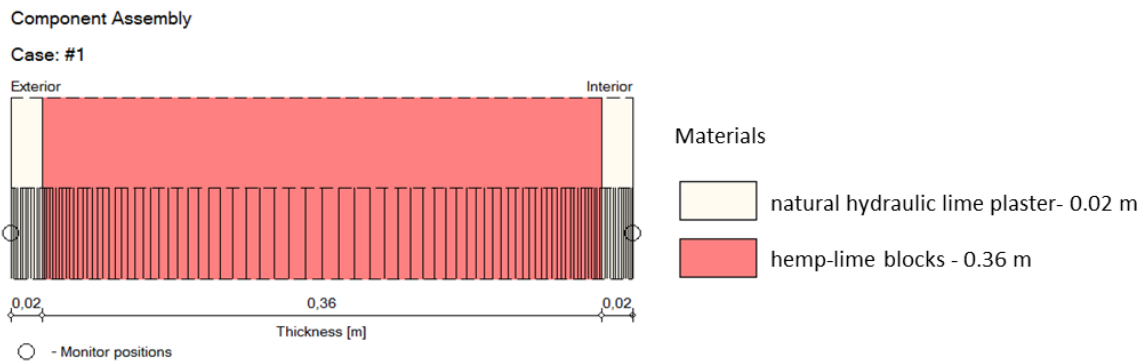


Figure 10. Numerical model of the wall transversal section (WUFI® Pro 6.3)

3.2.2. *In situ testing up*

Two rooms have been monitored in this building: a dining room and a bedroom having respectively north-west (N-W) and south-west (S-W) exposure. The ground floor map of the building together with sensors position are shown in Figure 11: the meteorological station has been installed in position 1; position 2 corresponds to the installation of sensors for temperature, humidity and CO₂ measuring in ground floor room; position 3 and position 4 correspond to location of the inside wall mounted sensors, respectively for N-W and S-W exposure, for surface temperature and humidity measurement, whereas position 5 and position 6 indicate sensors applied on outside wall. As in the previous case, the instruments have been applied after the thermographic survey of the wall [30].

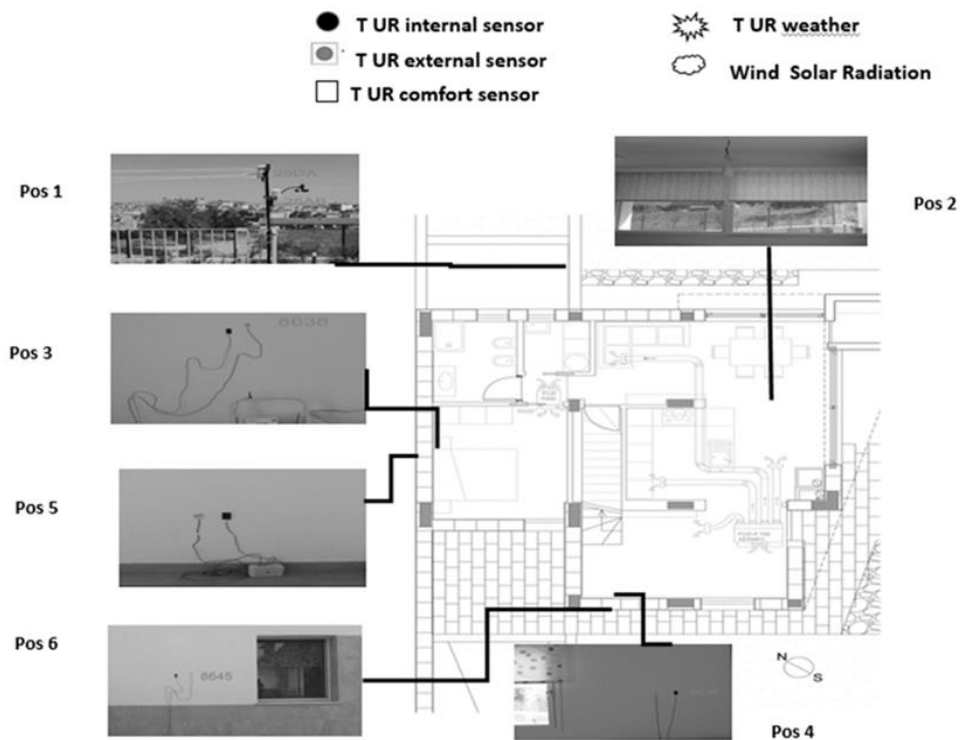


Figure 11. Ground floor map and sensors position.

3.2.3. Test results

On the basis of the findings of Case Study 1, where the numerical results on the internal wall face have been proved to be almost coincident regardless of the utilization environmental input data directly measured through sensors or taken from Meeonorm database, for Case Study 2 numerical analyses obtained using only the Meeonorm input data are here presented. In addition, this choice is motivated by the fact that in practical applications, specialists in the sector will mainly use commercial databases for simulations.

Considering N-W exposure, in Figure 12 graphs of surface temperature and relative humidity, measured through sensors in positions 3 and 5, are reported. On the internal wall face the relative humidity initially increases from almost 62% up to 70%, and then it remains constant although on the external wall face it reaches almost 100%, due to the rain, before falling back to 40%; similarly, internal thermal response is not affected by external variations. Indeed, even without air-conditioning system, the temperature measured on the internal wall face is 26 ± 1.5 °C while on the external wall

face it ranges between 15 °C and 35 °C. These make it clear that hemp-lime blocks have a good thermo-hygrometric performance which allows to keep a good comfort inside the building despite external weather conditions.

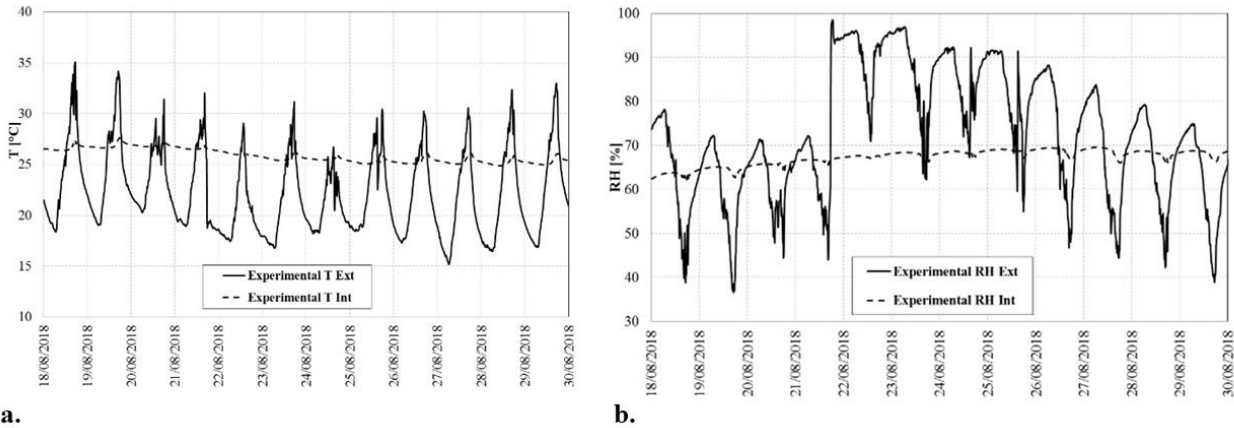


Figure 12. Surface conditions internal vs external wall faces N-W oriented: a) Temperature (T); b) Relative Humidity (RH).

This behaviour is confirmed also by numerical simulations performed by the software WUFI® which give a constant temperature of 26 ± 1 °C on the internal wall face, as shown in Figure 13, where experimental and numerical time plots are superimposed. On the other hand, as shown in Figure 14, a maximum difference of about 8% between measured and simulated results are recorded in terms of relative humidity which, on the basis of numerical model, should not exceed 62%. This difference can be explained considering that input data for simulations refer to the Meteornorm database which does not take into account of the unusual rainfall recorded in those days.

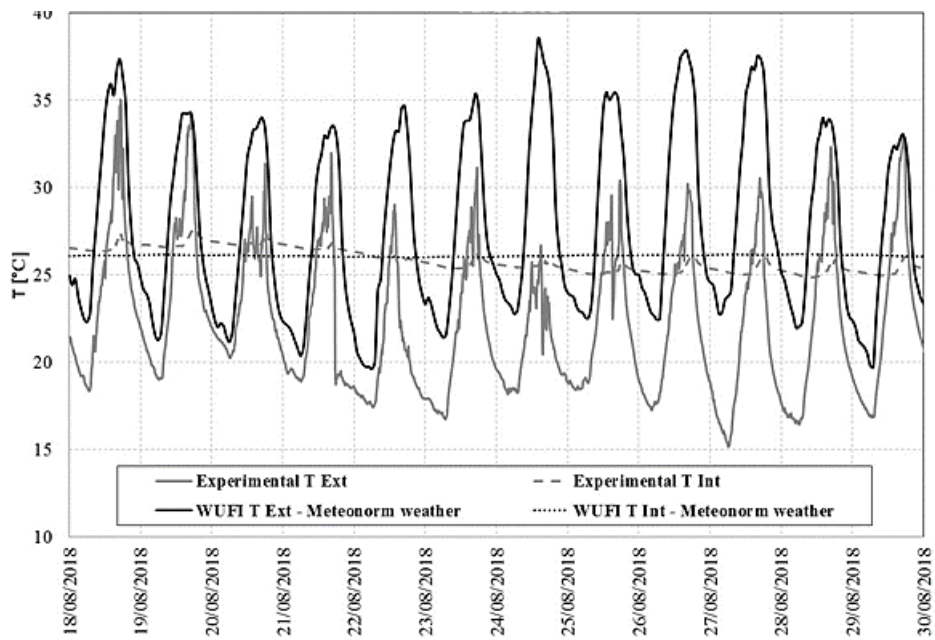


Figure 13. Temperature (T) on the N-W oriented wall at the Internal and external faces Experimental vs Numerical.

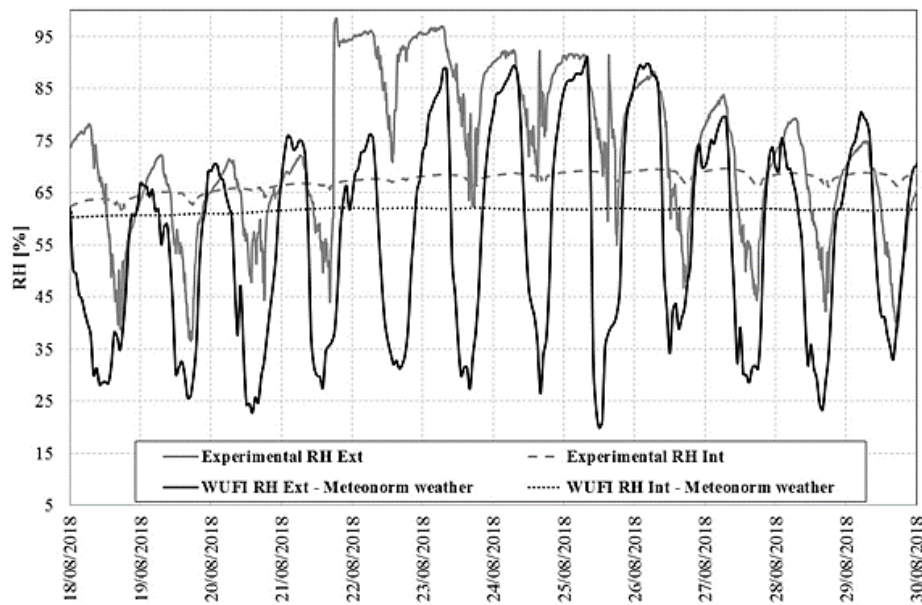


Figure 14. Relative Humidity (RH) on the N-W oriented wall at the Internal and external faces Experimental vs Numerical.

Finally, the results for wall with S-W exposure, obtained through sensors in positions 4 and 6, are summarised in Figure 15. Once again, the comparison between the behaviour of internal and external faces highlights the good thermo-hygrometric performances of hemp-lime blocks.

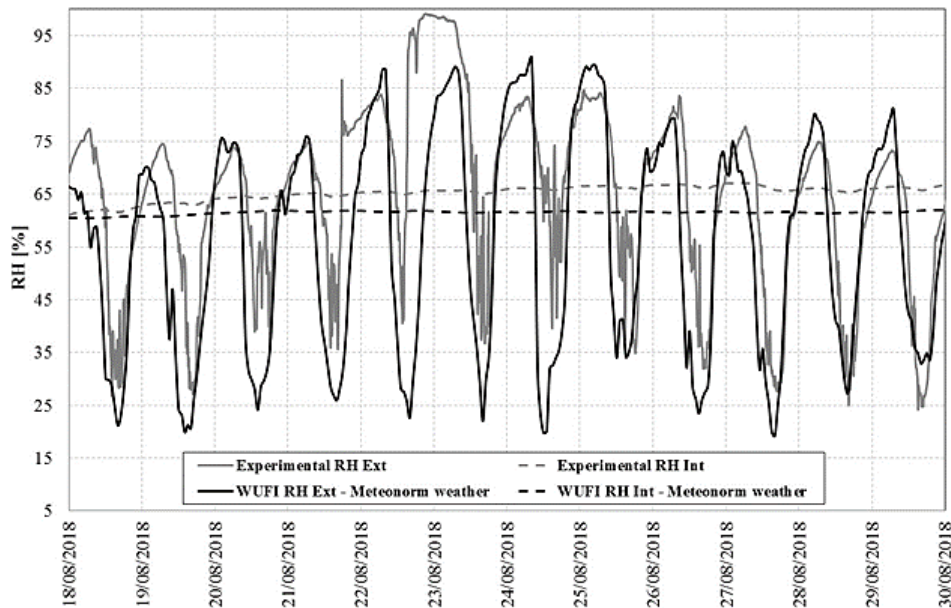


Figure 15. Relative Humidity (RH) on the S-W oriented wall at the Internal and external faces Experimental vs Numerical.

4. CONCLUSIONS

In order to assess the potential benefits of hemp-lime blocks in the construction sector, a study plan has been carried out regarding their functionality in masonry to evaluate the in-situ thermo-hygrometric behaviour. In particular, measurements were carried out on two buildings, one in northern Italy, precisely in Veneto, and one in southern Italy, located in Sicily, focusing the study on the performances of the walls subjected to cold and warm Mediterranean climates, respectively. These two case studies were deemed of particular interest from the research point of view since the two buildings, located in different climatic regions, were monitored in autumn and summer, respectively. Moreover, in the first case the heating system was turned on only during the weekend whereas in the second one the air conditioning system was not running. These two conditions allowed highlighting the performance of hemp-lime blocks in two limit states, cold and warm respectively. In the building in Sona (VR), northern Italy, the temperature on wall internal face has remained steady during heating operation (with an average value of 19.6 °C) and decreased of almost 8 °C in four days, between two consecutive operations, without significant variations between day and night. Since it is a restaurant,

subject to crowding, the presence of the people slightly increases the temperature with respect to the value set through the heating system. Even if the building has not isolated roof and heating system is turned off most of the time, internal temperature never drops below 12 °C despite the fact that on wall external face daily excursions of about 10 °C and a minimum of almost -2 °C occur. As expected, humidity on the wall internal face oscillates in opposition of phase with temperature, reaching a maximum value of 63% and a minimum value of 45% when heating system is tuned on and external humidity changes between 80% and 90%.

Good performance of hemp-lime blocks has also been proved by tests on the building located in the south of Italy, in Serradifalco (CT). Indeed, even if this house is not equipped with air conditioning system, both experimental measuring and numerical analyses have confirmed that temperature on the internal wall face has been at almost 26 °C while on the external wall face it was changing between 15 °C and 35 °C. Moreover, despite the abundant rainfall recorded during monitoring phase, relative humidity on the internal wall face stood at a constant value of almost 70% according to the experimental measuring with a maximum difference of almost 8% with respect to numerical simulations, which give a lower value. This difference can be explained considering that input data for simulations refer to the Meteonorm database which does not take into account of the unusual rainfall recorded in those days.

To summarise, this study allowed reaching the following important results. First of all, the internal wall face response obtained by numerical simulations, performed by means of WUFI® using Meteonorm database as input, has shown a good agreement with experimental measurements. As a consequence, given the fact that for practical application in situ measurement are not generally available, specialists in the sector, which follow an approach exclusively based on the use of numerical models, can reach an evaluation of wall's behaviour very close to the truth.

Then, it has been observed that, when the installation is done in a workmanlike manner, hemp-lime blocks have a good thermo-hygrometric performance which gives a good comfort inside the building

despite very cold or very warm external limit states. Of particular note is the case of south Italy because it refers to climatic conditions poorly investigated in literature and because the building under study is not equipped with an internal conditioning system.

As a consequence, authors consider it important to continue in situ studies and evaluate with greater accuracy the behavior of this kind of materials. Particularly it is necessary to investigate in depth their response when they are subject to sudden change in meteorological conditions and/or situations of persistent high humidity due for example to abundant rainfall.

ACKNOWLEDGEMENTS

This work was supported by PAR2017 Project (D.2 Nearly zero energy buildings (nZEB)) funded by Italian Ministry of Economic Development. The authors thank Salamone and Oliosio families for having made available their houses in Serradifalco (CL) and Sona (VR) on which the measurements were carried out.

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