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Simulating specific bioclimatic strategies to recover valuable designs in vernacular architecture. Case study: thermal inertia in El Valle

Simulación de estrategias bioclimáticas concretas con el objetivo de poner en valor los diseños de la arquitectura tradicional. Caso de estudio: la inercia térmica en El Valle

Beatriz Montalbán Pozas (*), Francisco Serrano (**)

ABSTRACT

This article provides a method to analyse energy efficiency in existing bioclimatic strategy in vernacular dwellings. It has been tested in the Jerte Valley in Cáceres, Spain, that holds a stock of about three thousand historical housing. First, three building models have been defined. Furthermore, the energy behaviour of the thermal inertia strategy, provided by the large masses of stone walls of the building envelopes, and by the earth in direct contact with the ground floor, has been specifically simulated. Simulations were conducted in which the massive elements were eliminated to allow the differences in hygrothermal conditions and energy exchanges to be estimated, either heating or cooling energy. The findings indicate that this strategy is advantageous, affording indoor temperatures stabilization in relation to the outdoor oscillation, which close them to the more pleasant daytime averages. Identifying the bioclimatic strategies enables to propose the valorisation of vernacular designs.

Keywords: methodology; bioclimatic strategy; energy simulation; thermal inertia; vernacular architecture.

RESUMEN

En este artículo se aporta una metodología para evaluar la eficiencia energética que aportan las estrategias bioclimáticas de las viviendas vernáculas. El caso de estudio ha sido el Valle del Jerte (Cáceres) con unas tres mil viviendas tradicionales. En primer lugar, se han definido tres tipologías constructivas, y posteriormente se ha simulado específicamente el comportamiento energético de la estrategia de la inercia térmica, proporcionada por los muros de piedra de la envolvente de los edificios, y por la tierra en contacto con la planta baja. En las simulaciones fueron eliminados los elementos masivos para analizar las diferencias en las condiciones higrotérmicas y los intercambios energéticos, tanto de calentamiento como de enfriamiento. Los resultados indican que esta estrategia es beneficiosa, ya que estabiliza las temperaturas interiores respecto a las oscilaciones exteriores, acercándolas a las medias diurnas, más agradables. Identificar las estrategias bioclimáticas permite proponer la valorización de elementos vernáculos.

Palabras clave*: metodología; estrategia bioclimática; simulación energética; inercia térmica; arquitectura tradicional.*

(*) Arquitecta. Profesora contratada doctor. Universidad de Extremadura, Cáceres (España).
(**) Arquitecto. Profesor colaborador. Universidad de Extremadura, Cáceres (España).
Persona de contacto/*Corresponding author*: bmpozas@unex.es (B. Montalbán Pozas)
ORCID: https://orcid.org/0000-0002-1065-0969 (B. Montalbán Pozas); https://orcid.org/0000-0001-8910-6837 (F. Serrano)

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1. INTRODUCTION

Vernacular architecture displays bioclimatic behaviour, given that it is designed in response to the immediate setting, adapted to the environment and thus, linked to geographical factors including climate (1). As such, these native constructions take the shape of architectural models that feature construction techniques and aesthetic results which are unique to each region and climate of the world. A wide review of bioclimatic architecture construction strategies are examined in some climate zones in Manzano (2); subsequently, other relevant research should be highlighted in (3-7). This kind of adaptation has been lost in the construction process today and therefore, in light of the concern raised about high greenhouse gas emissions in the sector, numerous research works (8) are being conducted in order to recover local bioclimatic strategies (9-11). Energy retrofits in historic buildings are seen both as a way to reduce energy demand and improve thermal comfort (12-13), and further, as a means of reusing and preserving them for future generations (14).

A literature review of energy efficiency and conservation measures for building energy systems in simulation is incorporated in Harish and Kumar (15); however, in ancient constructions thermal comfort is specifically achieved by passive strategies.These passive strategies are solved in vernacular architecture by the application of different energy conservation mechanisms (16).

The thermal issues of current buildings are solved by controlling the thermophysical characteristics of the envelope (mainly, the thermal transmittance); however, in old buildings, made of high density and thickness materials, and subsequently with heat storage, thermal inertia should also be considered (17). In this way one of the most widely used strategy is thermal inertia, dependent on the thermal storage capacity of local materials (18-20). Among solid sensible heat storage materials of traditional buildings (21) are rocks or massive stones in heavy walls (22), (23, 24), clay walls (25) in timber buildings (26), sand and gravel (21), and further the ground effect (27, 28).

Several authors provide some considerations about thermal inertia in both periods of the year. Various studies show that the synergistic combination of natural ventilation and thermal inertia avoids overheating phenomena during summer periods, nevertheless this fact depends on the influence of layer distribution and relative thickness of the insulation/masonry in the envelope (17). Additionally, thermal inertia in walls can be properly combined with thermal insulation throughout the year (29). Thermal inertia could be responsible for up to 70% of energy savings (30). Regardless of whether high thermal mass constructions are clearly effective in hot climates (31), they can cause an increase in final energy use in cold climates (32).

A wide range about thermal inertia in buildings research has been registered in Verbeke and Audenaert review (33). Regarding methodologies some researches have used real models with monitoring surveys in experimental spaces (18), other authors have opted for simulating conceptual and theoretical models (34), or for implementing prediction models thanks to machine learning techniques (35). Research carried out without the current potential of energy simulation estimates different optimum properties that define thermal inertia (thermal conductivity, specific heat capacity, and density) maintaining indoor temperature within the thermal comfort range climates (36); however, there is a need to address vernacular buildings with uncommon materials.

Regarding traditional houses methods, they also vary from using monitoring in a field test (24, 37), (however in these cases it is impossible to distinguish the impact of the thermal inertia with respect other influencing strategies); to simulating to support the latter (23, 38-40) (although some authors state about the specific limitations in simulation models related to the geometric features and peculiarities of the heritage buildings (41, 42).

Furthermore, retrofit interventions in the cultural heritage should maintain those valuable constructive elements that characterize the buildings, solving the complex balance between energy efficiency and heritage conservation (43). This fact points to the need to analyse and simulate rigorously these elements in order to promote their maintenance and conservation in a faithful and respectful way.

Thereby the final contribution of this paper is to emphasise the importance of identifying the bioclimatic strategies of vernacular architecture to propose their preservation in rehabilitation projects.

2. METHODOLOGY AND CASE STUDY

The research is based on the thermal inertia strategy, and therefore, energy model simulation has been used to come up with findings that could prove suitable in a specific setting. In this case, the architecture of traditional dwellings in the Sistema Central of the Iberian Peninsula has been chosen to carry out the research, represented by eleven villages in the Jerte Valley (henceforth referred to herein as “El Valle”) (Figure 1) of great value in terms of history and heritage. Thermal inertia could be beneficial in both of the separate seasons in this climate, so it can be used as a strategy in winter as well as in summer. These houses comprise thick granite stonemasonry walls on the ground floor, which sometimes rise to the upper floor featuring small openings to the exterior, and other times are replaced by half-timbered walls on the upper levels with bigger openings. Furthermore, wood joists and ventilated roofs are used, and the floor on the lower level is built in direct contact with the ground. These historical centres have grown old and are gradually being abandoned so it is urgent to propose refurbishment projects that are at once mindful of the heritage and also energy efficient.

The bioclimatic strategy of thermal inertia in the massive components of these dwellings (stone walls and floors in contact with the ground) has been probed using building models. Thereby energy simulations were conducted in which the massive elements were eliminated to allow the differences in hygrothermal conditions and energy exchanges to be estimated, either heating or cooling energy. Anyway this method can be extrapolated to check any other bioclimatic strategy or constructive elements both existing and in the project.

Stepwise procedure for forward approach modeling is given by Harish and Kumar (15): acquire building geographical characteristic, climate and building construction data, and operation schedules. In vernacular architecture, HVAC sys-

Figure 1. Situation of the 11 villages in El Valle (Sistema Central, Spain) and images of some houses in some of its villages: Piornal (1), Rebollar (2), Cabezuela del Valle, and Navaconcejo (4).

tems do not exist but it is necessary to properly define the ventilation values: buildings opening percentage, infiltration rates, and local winds, which are much more relevant than the climate conditions (44, 45).

2.1. Architectural model data

Architectural models for simulations representing the main building types were defined based on a morphological and construction study of some three thousand vernacular dwellings present in the eleven municipalities of El Valle. In addition to the field work done, information sources included the Land Registry, National Statistics Institute and urban planning documents have been checked. Thus, compact, dense, enclosed blocks, plots with little façade space and low building heights can be discerned in vernacular urban design. Due to the large number of dwellings present, and the geometric complexity of historical houses the dwelling shapes have been simplified into patterns. Thereby, three models have been defined: model 1: half-timbered house, two floors, one facade, and medium size; model 2: half-timbered house, two floors, one facade, and small size; and model 3: masonry house, two floors, one facade, and small size. As regards the typical floorplan, the entrance and spaces for livestock and produce storage (hall, stable and cellar) are located on the ground floor, the upper floor contains the dwelling itself (kitchen, bedrooms, and living room), and the attic level is not a living space but rather is used for storage and drying harvests (Figure 2).

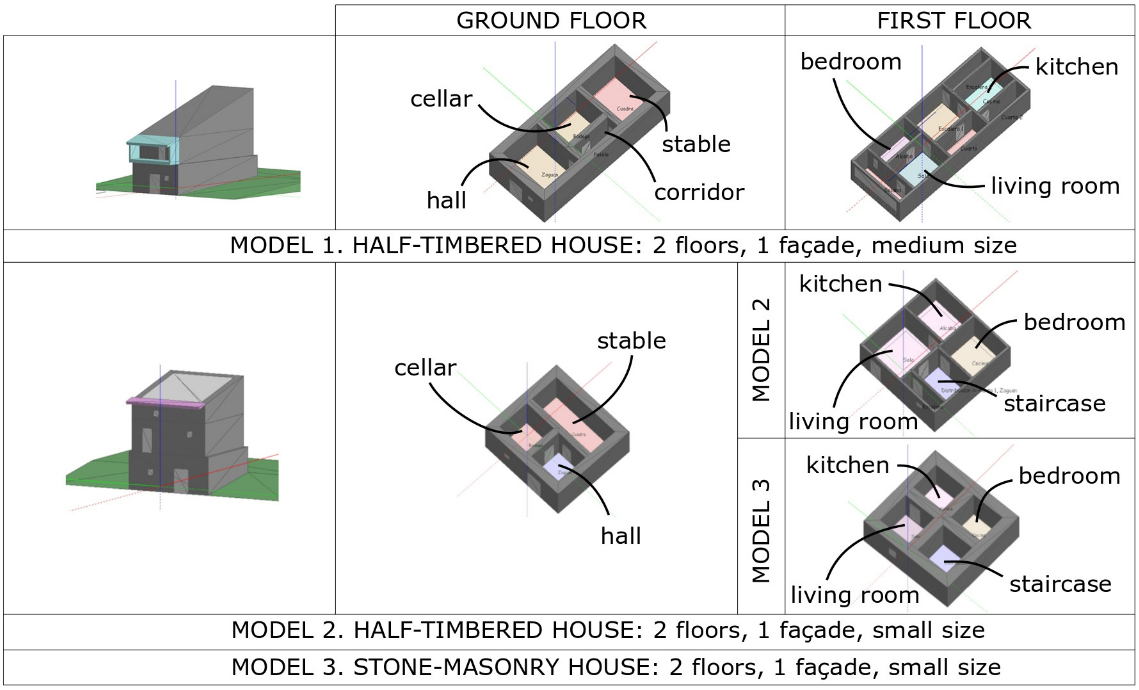


Figure 2. Main building typologies models of half-timbered and stonemasonry architecture in El Valle in DesignBuilder software.

Table 1. Thermal parameters of the construction materials and elements in vernacular architecture in El Valle.

CONSTRUCTION MATERIAL AND ELEMENT	e (m)	ρ (kg/m^3)	ʎ (W/m K)	r (K/W)	Cp (J/kg K)	α $(m^2/s). 10^{-6}$	b $(J\ s^{1/2}/m^2\ K)$
MASONRY WALL U=1.713 W/m^2K Ordinary granite masonry bound with mud and lime mortar and coated with the same mortar on the interior side							
Granite stone	-	2750	2.900	-	1000	1.055	2824
Mud and lime mortar	-	1400	0.748	-	1000	0.534	1023
Granite and mortar (30%)	0.70	2345	2.035	0.344	1000	0.868	2185
Coating	0.05	1400	0.748	0.067	1000	0.534	1,023
HALF-TIMBERED WALL U=1.924 W/m^2K **Adobe block bricks and chestnut wood beams coated with mud and lime mortar on the inside**							
Adobe brick	-	1510	0.581	-	850	0.453	864
Wood nogging	-	700	0.174	-	1610	0.154	443
Brick and 10% nogging	0.15	1429	0.532	0.282	926	0.402	839
Coating	0.05	1400	0.748	0.067	1000	0.534	1,023
FLOOR U=1.954 W/m^2K **Fill made of sandy soil and granite pebbles bound with lime mortar**							
Sandy soil	0.30	1700	1.204	0.249	920	0.770	1372
Straw	0.20	75	0.030	6.667	1600	0.250	60
Granite pebbles	-	2750	2.900	-	1000	1.055	2824
Mud and lime mortar	-	1400	0.748	-	1000	0.534	1023
Granite pebbles and lime (30%)	0.10	2345	1.961	0.051	1000	0.836	2144
CARPENTRY Doors U= 1.169 W/m^2K Windows U = 5.894 W/m^2K							
Chestnut wood Plain glass	0.10 0.003	700 2230	0.174 1.160	0.575 2.586	1610 1000	0.154 0.46	443 1703

e: thickness ρ: density ʎ: conductivity r: thermal resistance (r=e/ʎ) Cp: specific heat
α: thermal diffusivity α=ʎ/(ρ.Ce) b: thermal effusivity (b=√ρ.Ce.ʎ) U: thermal transmittance: (U = 1/(1/he + Σʎ/e +1/hi)
1/he+1/hi: surface thermal resistance (0.20 in horizontal flow, 0.17 in ascending vertical flow)

2.2. Climate data

The climate in this zone is categorised as “Csa” by Köppen-Geiger classification: temperate, dry and hot summer. With mild temperatures in this mountainous area, this climate displays quite different seasonal periods: a hot, dry one (with an average maximum temperature in July of 31.8ºC), a cold, rainy one (with an average minimum temperature in January of 1.6ºC) and two other mild seasons. Furthermore, to understand the lags in the thermal waves through the massive elements, hourly hygrothermal data (46) including day-night performance was used in the simulation.

2.3. Building materials analysis

The values provided for thermal properties in the construction materials and elements are theoretical for this zone, and were gathered from the following sources: CTE Lider (DesignBuilder data for calculations), material characterisation tables (37, 47, 48) and direct calculations in Table 1. Subsequently, based on the materials data, average compositions for each construction system were estimated through field work and on-site data collection: the stone and bonding mortar composing masonry walls and the wood used for half-timbered walls.

In addition to the heat conductivity displayed by the thermal transmittance property, the thermal data also indicate the inertia or thermal capacity of the material. Thus, thick granite masonry walls with average diffusivity and high effusivity (due to their high density, high thermal conductivity and great thickness) should provide thermal inertia. However, half-timbered walls with slower diffusivity than stone and average effusivity (due to lower density and low conductivity, and to their reduced thickness) should provide little inertia. In turn, dirt floors with average diffusivity and high effusivity due to their high density, high thermal conductivity and great thickness, should provide high thermal inertia (6).

In many cases theoretical values, not validated by tests, are adopted for the characterization of the materials in the simulations using Design Builder, (36, 49); however the results are useful as long as they are obtained by comparing global results between different construction solutions, in order to measure the variation among them, minimizing possible inconsistencies or mismatches in the simulation model with respect to reality.

2.4. Computational model

The energy analysis was conducted by means of simulation using DesignBuilder software by EnergyPlus (v.5.5.0.007). The computational model was defined by taking the metabolic activity and occupancy of the historical dwelling into account, as well as significant variables such as the animals housed in the stable on the ground floor, the wood fire burning in the kitchen and the harvest products (grain, straw, chestnuts, etc.) spread out to dry in winter over the attic level floor structure. The following parameters have been observed:

Table 2. Example of the estimation of the basal metabolism of two activities in the vernacular dwellings of El Valle.

COOKING OR WEAVING		CLEANING THE STABLE OR FEEDING THE LIVESTOCK	
By basal metabolism	42.5 W/m²	By basal metabolism	42.5 W/m²
By body part used	85.0 W/m²	By body part used	190.0 W/m²
By static position	10.0 W/m²	By static position	30.0 W/m²
By displacement	0.0 W/m²	By displacement	0.0 W/m²
TOTAL	137.5 W/m²	TOTAL	262.5 W/m²
Body surface area	1.70 m²	Body surface area	1.70 m²
TOTAL	233.7 W	TOTAL	446.2 W

2.4.1. Metabolic activity and occupancy, building energy models should represent accurately the occupants behaviour on energy models because this parameter is considered very influential (50). The data were assigned to each room taking into account the basal metabolism in every activity (some activities examples in Table 2) (47), and the density of occupation by the default value provided by the software according to specific use and area, as follows:

a. Unoccupied spaces dedicated to storage (cellar and deck) have null occupation, and none internal gains.
b. Occupied or habitable spaces:
    - Spaces for animals (stable): internal gains should be considered in the period in which the animals are kept stabled, it is considered a certain metabolic rate (51) and an occupation depending on the size of this space (e.g. in a small stable, it is estimated 670 W corresponding to a cow, and 150 W to a pig). On the other hand, the metabolic rate of the persons assigned to this space is 263 W/m².
    - Circulation spaces: the daytime occupation is estimated from 7 h to 21 h in the corridor and the stairs. The metabolic rate is 180 W/m² (corresponding to a standing position and walking on a horizontal plane), except for the stairs for which it rises to 700 W/m² (ascending a steeply inclined plane), and a density of 0.155 persons/m².
    - Living spaces: they are occupied from 13 h to 14 h and from 19 h to 21 h in the living room. These spaces correspond to light work, seated, using both arms, with a final metabolic rate of 110 W/m² and a density of occupation of 0.0188 persons/m².
    - Sleeping areas: the use of bedrooms is considered from 23 h to 7 h, with a metabolism rate of 90 W/m² and a density of occupation of 0.02 persons/m².
    - Cooking and eating spaces: the kitchen is the most used space along with the corridor, with a variable occupation from 7 h to 21 h depending on the work corresponding to each season. The metabolism data is 210 W/m² corresponding to light work, seated, with the use of both arms, and 0.0237 persons/m² density. The heat generated by the fire is considered as an important internal gain. This is considered alight all day in the cold months, and maintained all night with its embers.

2.4.2. Data for opened windows and doors: a schedule is designed for the operation of doors and windows which will subsequently influence the external infiltrations and natural ventilation. The doors of the unoccupied storage spaces remain closed, the bedrooms are closed by a curtain between them and the living room, the door of the corridor is evaluated partially open except for the coldest months when it remains closed. While the ground floor staircase has no door, the one that goes up to the deck does. External shading was situated on windows facing the street in the summer from 9 h to 18 h. The time chosen for opening for ventilation is minimal in winter in cold weather and in summer at the hottest times of day. However, for cooling in the hottest months, a broader time of opening during the cooler hours of the night is designed.

2.4.3. Options of the model: the calculated natural ventilation has been adjusted, e.g., the natural ventilation and infiltration are calculated based on the dimensions of the openings and cracks, the stack or chimney effect, and wind pressure. The internal gain data are simplified, i.e., they are divided into various categories (occupation, kitchen, solar collection, etc.). Synchronization is through scheduling, and is defined using the scheduling and profiles mechanism.

2.4.4. Other relevant details were:

- the earth temperature was estimated at 14°C, as the average temperature of the ground in this zone on the Peninsula
- the prevailing orientation of El Valle, 225°N Southeast, has been used for the dwellings
- the degree of infiltration through windows and doors has been deemed high due to the traditional construction process
- the party walls have been modelled as adiabatic
- thermal bridges have not been considered due to the fact that there is no discontinuity in the construction process.
- the internal heat gains are 5437 kWh in the cold period and 2135 kWh in the warm one (including cooking, occupancy, latent, and solar gains) (52, 53).

3. RESULTS

Once the energy simulation was attained, an analysis of the thermal inertia strategy of the exterior walls and floor (as parts of the building envelope) was conducted in terms of cooling in the summer and heating in winter. The difference between energy exchange and hygrothermal conditions should demonstrate if this strategy exists, or not. That question was checked on the different levels. In this way, the heat exchange findings (positive for thermal gains and negative for heat losses) for each face of the envelope (windows/doors, exterior walls, ceilings, floors and partitions) have been compared in each room. It has been distinguished between the two main periods of the year (warm: from 1 May to 30 September, and cold: from 1 October to 30 April). Furthermore, it has also been included the hygrothermal performance of each room during the harshest two weeks of the year (in winter: from 11 to 17 January and in summer: 11 to 17 July). One architectural model or another has been used, as appropriate, to verify the strategy. The results show mainly the wall's inertia, since the transmittance of both types is quite similar (Table 1).

3.1. Inertia performance of upper floor walls

In this section, Simulation No 1 compare the inertia of half-timbered walls and stone walls among architectural models 2 and 3. The analysis was conducted on the upper floor (which is where depending on the model, the wall type changes) and on exterior walls (the interior walls show that they are not affected because, on the one hand, the party walls are considered adiabatic and, on the other, in most of the rooms there are no internal gains that could be transferred). Therefore, the differences are primarily seen in external rooms: in this case, the living room and staircase. The results, by period of the year, are as follows:

3.1.1. Cold period: the heat in the two external rooms (the living room and staircase) of the half-timbered model flows from the interior partitions (both horizontal and vertical: floor, ceiling and partition walls (living room: 72, 28 and 287 kWh; staircase 10, 10, and 352 kWh respectively)) and is lost toward the exterior wall (-37 and -73 kWh, in each room). In the stone wall dwelling, the flow starts in adjacent rooms through vertical partition walls (152 and 283 kWh) and flows toward the other faces, including exterior walls (living room: -277, -72 and -66 kWh; staircase -379, -68, and -94 kWh). However, the exchanges through the exterior wall in the stonemasonry dwelling are much greater, from 5 to 8 times greater, than in the half-timbered dwelling (as an example, the wall -37 and -277, -73 and -379 kWh) (Figure 3).

This difference is noticed in the indoor operative temperatures in the two models for the coldest week of the year. Thus, while the outdoor temperature ranges from -3 to 10ºC, with an average of 7ºC, the indoor temperature of the stone wall dwelling remains at 14ºC (the thermal wave lag is 9ºC above average), whereas the temperature of the half-timbered

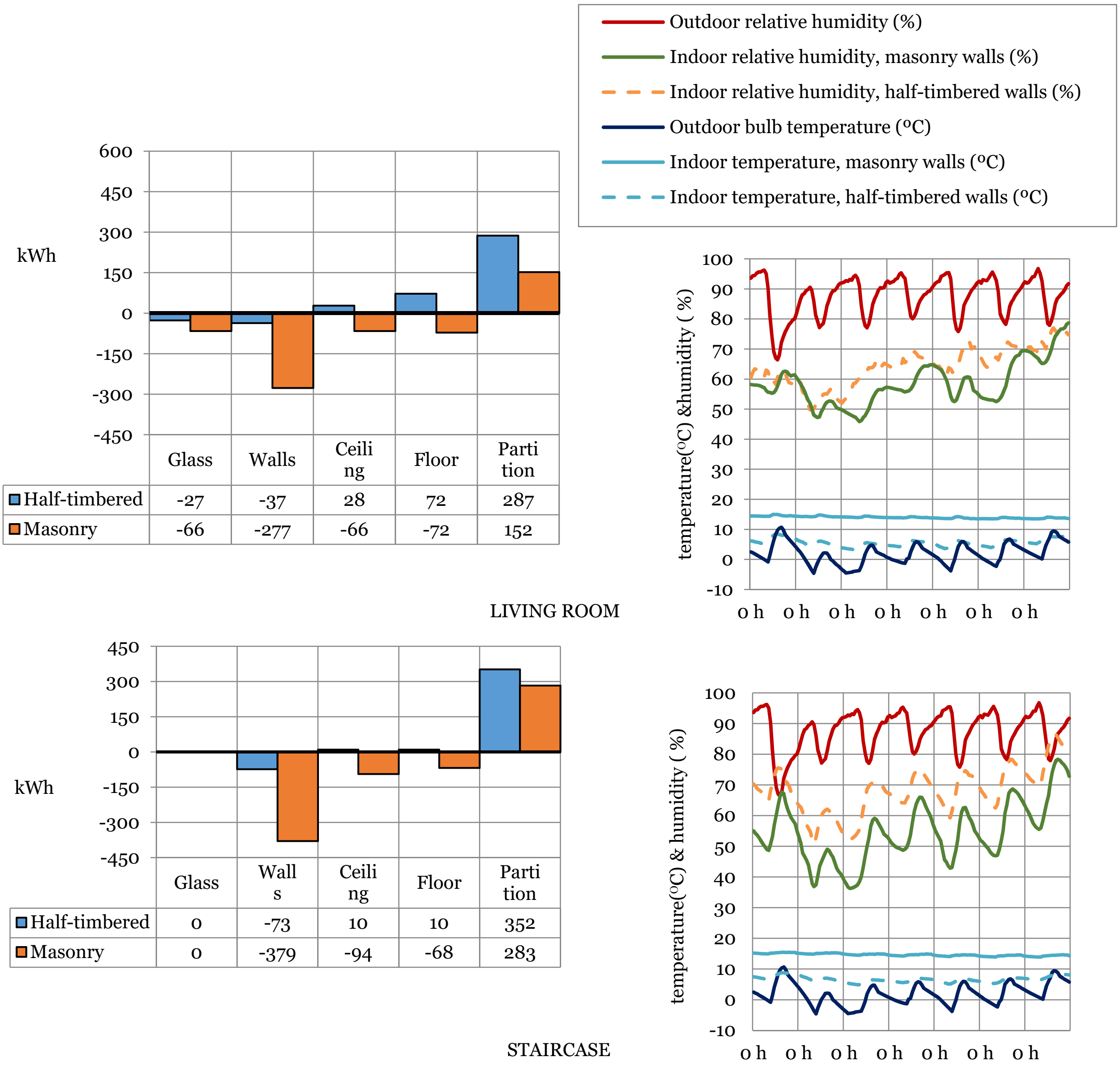


Figure 3. Simulation No 1. Heat exchanges in the cold period and hygrothermal performance in the harshest week of the winter in the living room and hall, model 2 and 3.

dwelling is between 1º and 7ºC, much closer to the outdoor temperatures.

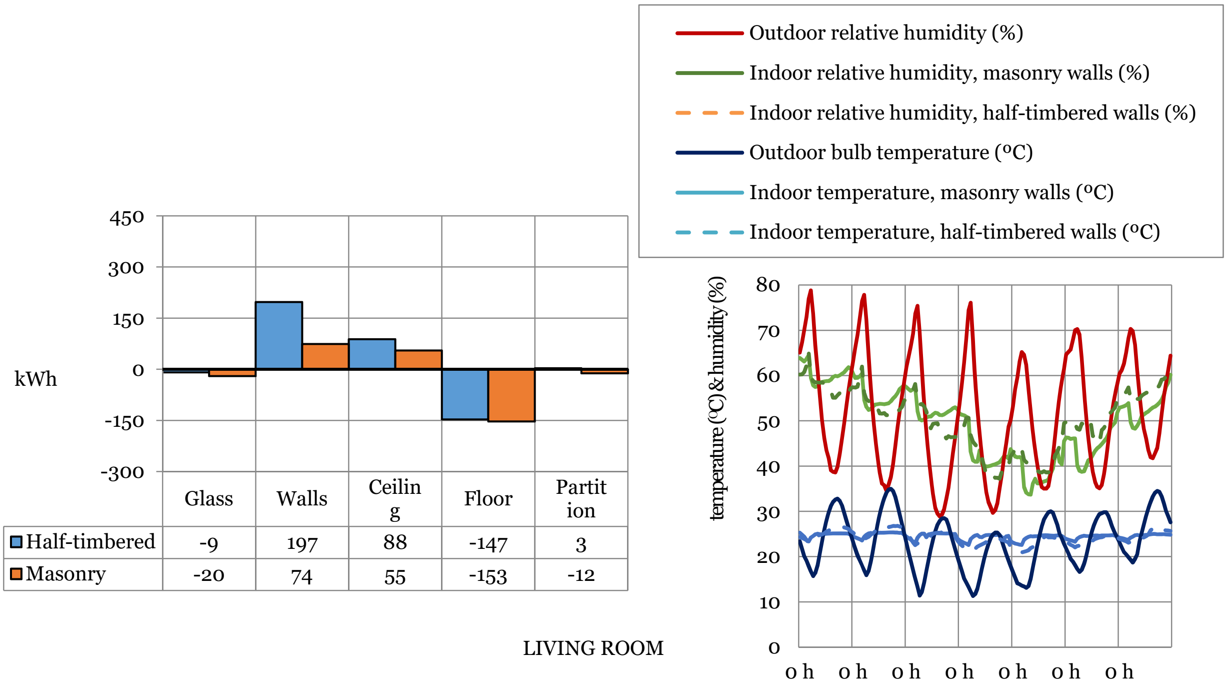
The same fact is checked in winter humidity levels, which are up to 20% lower inside the stone dwelling than outside, whereas the half-timbered dwelling is just 10% lower (Figure 3).

3.1.2. Warm period: the heat in both external rooms (living room and staircase) flows as gains in both models from the exterior walls and ceiling (living room: 197 and 74, 88 and 55; staircase 173 and 71, 66 and 45 kWh, respectively and in both models: half-timbered and stonemasonry), and is lost through the floor (-147 and -153, and -57 and -104 kWh in each room), which acts as a heat sink. The exchanges through the exterior wall in the stonemasonry dwelling are three times greater than in the half-timbered dwelling (197 and 74, 173 and 71 kWh) (Figure 4). This fact is seen in the hygrothermal performance; in the harshest week of summer, with temperatures fluctuating from 12 to 35 ºC between night and day, the half-timbered dwelling displays operative temperatures that range from 21ºC (at 4 AM) to 27 ºC (at 4 PM), whereas the stone dwelling remains at 24 ºC, which is the average for daily outdoor temperatures (at 2 AM it matches to 24ºC for a couple hours). Humidity in both cases is quite similar (Figure 4).

3.2. Inertia performance of the ground floor walls and the earth

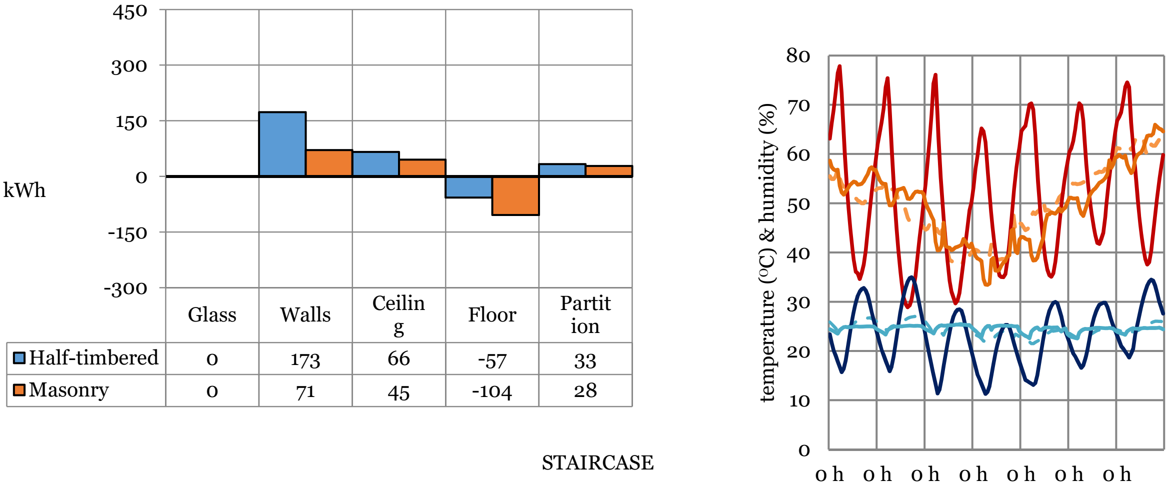
In this section, two changes were executed on the base case of Model 1: Simulation No 2, in which the stone walls on the ground floor (both exterior and partition walls) were replaced with half-timbered ones to verify the inertia of the wall, and Simulation No 3, which combines Simulation No 2 with lifting the ground floor up off the earth with wood joists resting on a stone half-wall, to verify the inertia of the wall and the earth.

3.2.1. Cold period: in the base case, the heat flow enters the external room (hall) in equal proportion from the earth and the stone walls of the adjacent rooms (255 and 291 kWh) and



	Glass	Walls	Ceiling	Floor	Partition
■ Half-timbered	-9	197	88	-147	3
■ Masonry	-20	74	55	-153	-12

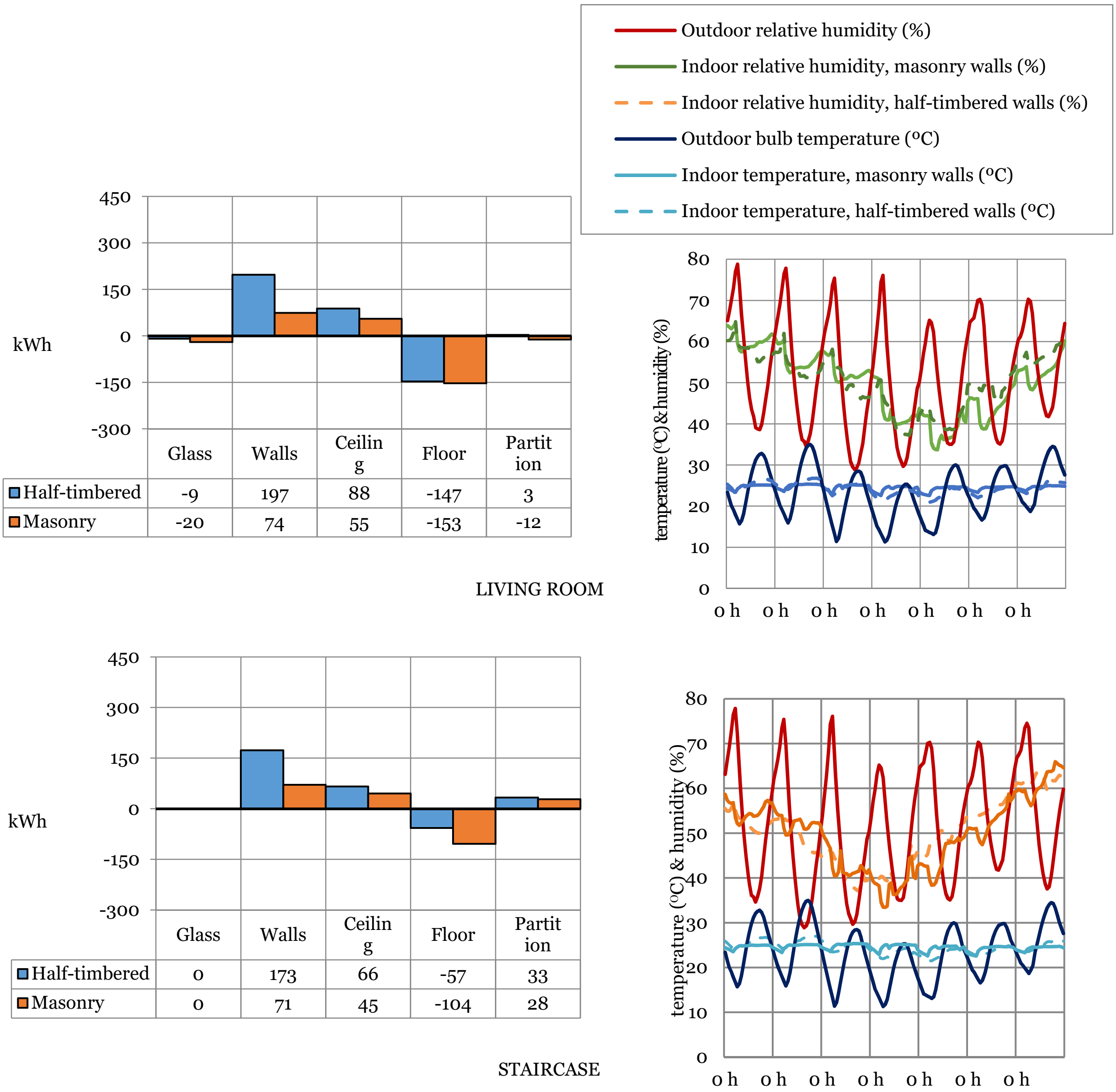
LIVING ROOM



	Glass	Walls	Ceiling	Floor	Partition
■ Half-timbered	0	173	66	-57	33
■ Masonry	0	71	45	-104	28

STAIRCASE

Figure 4. Simulation No 1. Heat exchanges in the warm period and hygrothermal performance in the harshest week of the summer in the living room and hall, model 2 and 3.



	Glass	Walls	Ceiling	Floor	Partition
Half-timbered	-9	197	88	-147	3
Masonry	-20	74	55	-153	-12

	Glass	Walls	Ceiling	Floor	Partition
Half-timbered	0	173	66	-57	33
Masonry	0	71	45	-104	28

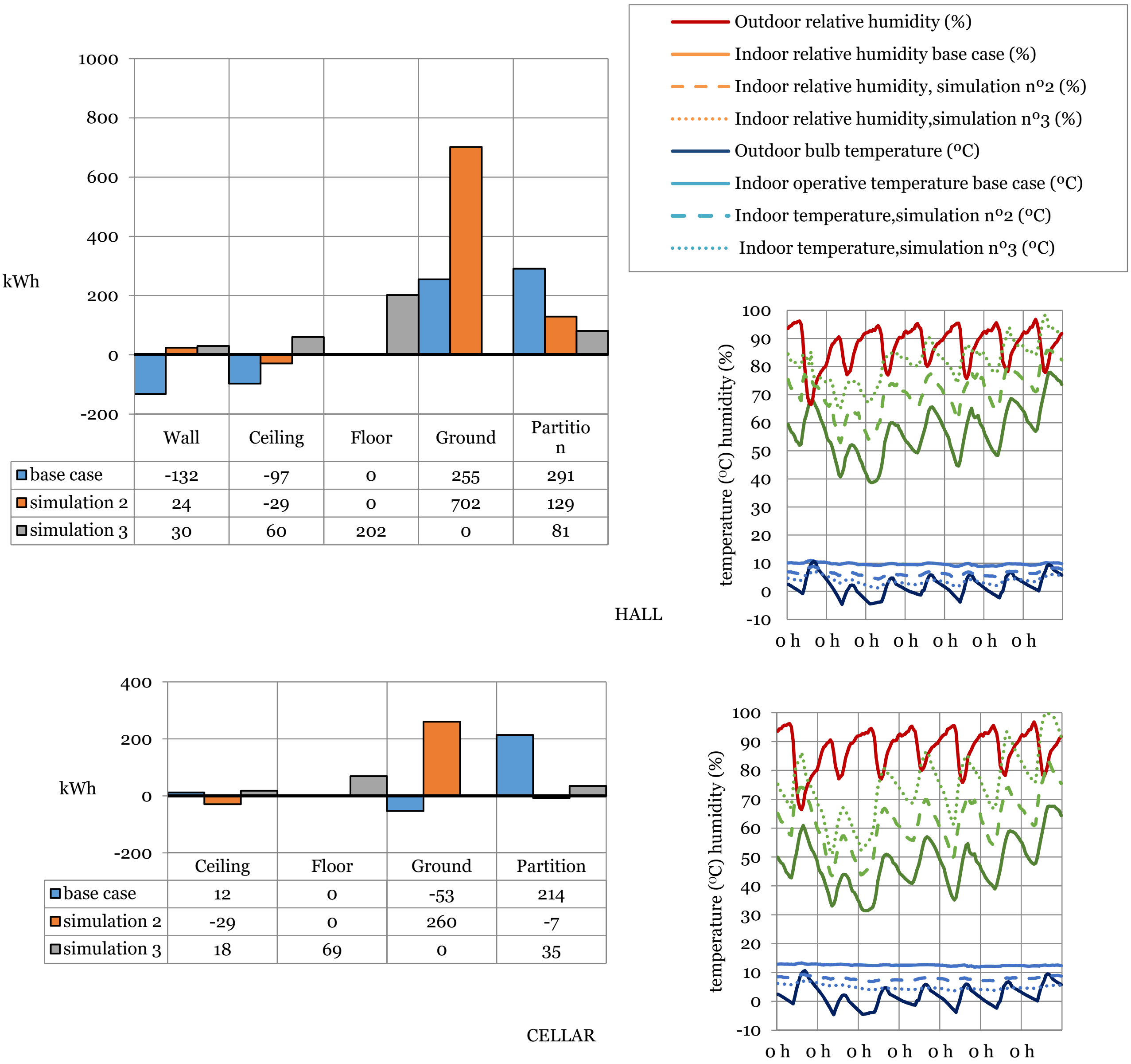
Figure 5. Simulation No 2 and No 3. Heat exchanges in the cold period and hygrothermal performance in the harshest week of the winter in ground floor rooms, model 1.

is lost through the ceiling and exterior walls (-97 and -132 kWh). When the walls are changed to half-timber, Simulation No 2, the exchange through interior faces drops to more than half (291 and 129, -97 and -29 kWh) and through exterior ones, by a sixth (-132 and 24 kWh). Thus, the change in wall type causes the temperature to drop by some 5ºC and humidity to increase by 15% (Figure 5).

In Simulation No 3 the exchanges through the earth reach the elevated floor and drop by more than a third of Simulation No 2 (hall: 702 and 202 kWh, corridor: 192 and 40 kWh, cellar: 260 and 69 kWh). The indoor operative temperatures go from about 12ºC and 40 to 60% humidity to 5ºC and 70 to 90%, and with this, a drop in temperature of some 2ºC and a 15% increase in humidity is seen. The findings are similar in all the rooms, although the hall displays conditions most similar to the exterior and the cellar remains at 13ºC in the stonemasonry dwelling and at 6 to 9ºC in the half-timbered one (Figure 5).

3.2.2. Warm period: in the base case, the heat flow enters the external room (hall) in equal proportion from the ceiling and the exterior stone walls (272 and 258 kWh) and is lost through the earth (-729 kWh), which acts as a heat sink. Thus, the interior conditions on the ground floor remain stable at around 20°C with exterior fluctuations from 12 to 35°C and interior humidity ranging from 50 to 80%, compared to the drier exterior, which ranges from 30 to 70% on average.

In Simulation No 2, the gains observed are 50% greater (387 and 364 kWh) and the losses also increase (-813 kWh). The increase in the operative temperature in the wall is 1ºC, and humidity drops by 5%. In Simulation No 3, in which the house is also raised off the earth, the losses that go from the earth to the floor decrease significantly (-194 kWh), which causes a temperature increase of 3ºC and a humidity decrease of 5% (Figure 6). Thus, the hygrothermal conditions in the hall go from 19ºC and 50 to 80% humidity to 23ºC and 40 to 70%



	Wall	Ceiling	Floor	Ground	Partition
▪ base case	-132	-97	0	255	291
▪ simulation 2	24	-29	0	702	129
▪ simulation 3	30	60	202	0	81

	Ceiling	Floor	Ground	Partition
▪ base case	12	0	-53	214
▪ simulation 2	-29	0	260	-7
▪ simulation 3	18	69	0	35

Figure 6. Simulation No 2 and No 3. Heat exchanges in the warm period and hygrothermal performance in the harshest week of the summer in ground floor rooms, model 1.

humidity. The temperature changes in the other rooms on this floor are not relevant (see cellar in figure 5).

4. DISCUSSION OF RESULTS

The energy simulations conducted on vernacular housing in El Valle show some interesting results distinguishing between the two typical time periods. It has been considered a hygrothermal comfort range, for which the PPD (predicted percentage of dissatisfied) is below 10%, between 20ºC and 24ºC in winter, and between 23ºC and 26ºC in summer (54); and regarding relative humidity, optimal values range has been considered between 25% and 60% in both seasons (54). Moreover, comfort values for the intermediate autumn and spring periods have been established between 20ºC and 26ºC (range that include the extreme winter and summer periods).

- In the cold period of the year, the thermal inertia of thick stone exterior walls significantly improves the hygrothermal conditions inside the dwelling, stabilising the maximum and minimum temperatures on both floors to bring them closer to the more pleasant outdoor averages. The inertia provided by the earth also brings the indoor temperature closer to the earth temperature, which is stable. Therefore, we go from extreme outdoor temperatures of -3 to 10ºC during the harshest week of the year to much milder interior operative temperatures such as 14ºC on the ground floor or 10 to 12ºC on the upper floor (it has been proven that specific internal gains in the stables and kitchen are not responsible for these temperatures). In relation to the humidity flow, we can assert that both stone walls and the earth hinder outdoor values in equal proportion by 15 to 20%. Furthermore, in this period, hygrothermal enhancement occurs on both floors despite the roof ventilation. It has to be taking into account that there is an additional layer of grain stacked on the attic floor which may act as thermal insulation. If the stone walls are replaced by half-timbered walls and the foun-

dation is raised off the ground on wood joists, the temperatures would drop by 5 to 10°C.
- In the warm period of the year, the hygrothermal enhancement that is achieved through the inertia of the walls brings the outdoor maximum temperatures down. Therefore, during the harshest week of the summer, with outdoor fluctuations from 12 to 35°C, stabilized average interior operative temperatures of 20°C are achieved on the ground floor with stone walls and temperatures on the upper floor fluctuate from 21°C to 27°C. The influence of infiltrations from the roof in the upper floor is clear during this period, as we must remember that the harvest material stacked on the space under cover floor in winter is no longer there. In turn, humidity increases by 20% with stone walls. In relation to the earth, a slight drop of some 3°C occurs in operative temperatures on the ground floor during this period, and humidity increases by 5%. If there are no massive elements but rather only half-timbered walls and raised wood floor joists on the ground floor, the temperature would fluctuate more from day to night, increasing by some 5°C, and the interior air would be drier, with relative humidity ranging from 10 to 20 % lower.

It has verified that the thermal inertia afforded by the large masses of stone walls or by the earth in direct contact with the ground floor of the building envelopes in El Valle provides hygrothermal improvement throughout the year. During the cold period, the temperatures remain stable at the daytime average and interior humidity drops, while in the warm period maximum temperatures decrease and humidity increases.

In the assessment of the dynamic thermal performance it is observed that the ground acts as a source of constant temperature and the massive elements ensure a damping of the rest of the external conditions so that the effect of that source is not significantly altered, together with a buffer space (stables zone) that avoids an excessive heat transfer with the ground. This heat fluxes have been profusely analyzed in another paper of the authors (52).

5. CONCLUSIONS

This article provides a method to simulate every bioclimatic constructive strategy of vernacular architecture in order to decide preserving them or not in rehabilitation projects. Suppressing the strategy in the analysis process has allowed the results to be isolated, and subsequently compare with the base case.

Further development of this research should provide specific construction parameters for buildings measured on site, while it is also advisable to validate the simulations by checking the hygrothermal conditions monitoring the dwellings. Nevertheless, the proposed method makes it possible to measure the variation between different constructive strategies, minimizing any possible inconsistency or mismatch in the simulation model with respect to reality, by comparing global results.

Furthermore, the study contributes to beneficial data on the hygrothermal improvement provided by thermal inertia, from the stone walls or the ground, in vernacular dwellings, both in summer and winter, affording temperatures stabilization. In addition to this thermal benefit, it should be noted that both materials are considered competitive today: on the one hand affording durability and strength, and on the other, enhancing sustainability because of the local origin and low environment impact. These systems should take into account the energy behavior scheme of the construction process, avoiding conflict with it, both from a functional and formal point of view, thus preserving the architectural heritage and existing energy performance.

The results, on the one hand, prove the benefits of thermal inertia, both from the stone masonry walls, and from the ground, regardless of natural ventilation, or thermal insulation; and on the other hand, they show the improvement in winter period without losing much internal heat. In this case, the internal loads (kitchen, animals) can be assimilated to those generated actually by lighting, HVAC systems and other equipment. It should be taken into account that it has been considered continuous occupation in buildings, and intermittent occupations such as in rural accommodation buildings on short vacation periods have not been demostrated. Likewise, the requirements for guaranteeing thermal comfort must be established and simulated with the heating and cooling systems needed in this case.

Finally, a typology definition in each heritage stock dwellings should be accurately identified. Thus, the strategies mechanism depends on specific variables as climate, occupation behavior, compactness requirements (adiabatic partitions, under roof performance, openings, etc.). Energy simulations must be adapted to bring them up to date with current customs and the occupancy needs that arise in the refurbishing designs to guarantee habitability, ventilation and minimum lighting requirements not currently available in the houses.

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