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Getting Results in an Historical Dwelling Stock in a Thermal Simulation with EnergyPlus

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Abstract

The invaluable historic dwelling stock of many cities today needs an accurate analysis in order to implement a relevant program of research for its conservation, maintenance, or refurbishment. Additionally, energy efficiency studies are essential in every case to guarantee sustainability. In these situations, a simulation process will be a suitable approach to obtaining results. However, historic dwellings are complicated to simulate. They require a comprehensive study of traditional crafts and techniques as well as of ancient constructions which rely heavily on local builders' design skills and traditions as well as on the regional materials and architectural knowledge. Furthermore, the intricate geometries and the large number of different dwelling cases demand a amplification and a typological definition of representative buildings. In addition, in an energy simulation process, it is indispensable to know what the lifestyle was. In a traditional dwelling, the ancient customs have to be taken into account, studying the occupation, metabolism, activities, and traditional clothing in order to define a reliable computer model. Moreover, an operation usage program has to be defined in order to set other building simulation parameters such as the ventilation, shading, and internal gains. The present work proposes a method using DesignBuilder, an EnergyPlus software package, to generate a model for the energy simulation of historic dwellings through a case study of an historic dwelling stock in the Sistema Central of Spain. How the type was generated from a real case with an architectonic, constructive, and activity definition is described. Guidelines are provided for modeling the building and for setting the simulation parameters necessary to obtain correct results.

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Keywords: building simulation; historic building type; thermal model, model simulation inputs;

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1. Introduction

In many European cities today, the historic dwelling stock is deteriorating and abandoned (European Commission, 2007). For this reason, there are currently under way projects with various objectives including urban regeneration (Vicente et al., [15], recovery of habitability or accessibility of buildings [16], and neighbourhood revitalization [2]. All these studies have to incorporate the added requirement of sustainability and energy efficiency [4] in accordance with the European environmental commitments made in recent years (P. E. & C. of the European U., 2010, 2012).

On these occasions, it is appropriate to have recourse to processes of modelling and simulation of buildings. However, historic dwelling stocks are extensive and complex, and their buildings are difficult to model because a thorough knowledge of traditional materials and construction systems is needed, as well as of the traditional ways of life. The geometrical complexity of the old quarters of towns makes it enormously difficult to generate computer models, and complicates the extrapolation of the results. Moreover, the simulation of dwellings with their original activity and uses requires a definition of those traditional uses and customs.

Therefore, it is necessary right from the start of any project for there to be an orderly analysis of the historic dwelling in its architectonic, constructive, and functional aspects. A typology can then be defined that represents generically the typical constructions of a given zone, to be modelled successfully to get the results needed to define the energy behaviour of historic buildings.

2. Method and case study

To document this methodological approach, we used dwellings of the Jerte Valley (referred to henceforth as "El Valle"), located in the Sistema Central of the Iberian Peninsula. There are some three thousand dwellings in eleven nuclei characterized by traditional construction with high historic and heritage value. These nuclei are deteriorating day by day since the dwellings are being abandoned as no longer providing adequate living conditions. However, these autochthonous buildings have great potential in sustainable rehabilitation and energy efficiency due to their adaptation to the environment, characteristic of popular architecture. Understanding how these dwellings originally functioned will facilitate making decisions on the rehabilitation strategies that must be carried out.

The study of these dwellings as a group and the definition of their representative types allowed them to be simplified and energy-modelled in the EnergyPlus DesignBuilder software package. The results will enable decisions to be made in the search for a future for this set of dwelling stock.

3. Results and discussion

3.1. Study and recognition of the historic dwelling stock

As the first step, one must conduct a survey of the stock of historic dwellings by collecting architectural and construction data through recognized sources of information, i.e., the land registries (Sede Electrónica del Catastro, 2016), the national institutes of statistics (Instituto Nacional de Estadística, 2016), and the existing urban plans. This has to be followed by rigorous fieldwork to confirm the previous theoretical data. The study of sufficient samples of dwellings will make it possible to obtain favourable final results. In the present case study, we prepared information data sheets for some characteristic dwellings of popular construction in El Valle (an example is shown in Figure 1).

3.2. Definition of construction type

Analysis of a building stock allows the subsequent definition of its building types [4. 7. 13]. These types represent the general characteristics of historic dwellings in the area in question. The example of Figure 2 defines one of the types existing in El Valle, with its architectural, constructive, and usage variables. This data will later be required to define the computer model. The type is described in a brief form as a small dwelling, with a single façade, of two floors, and a roofed space, built with thick, stone walls, wooden frames and sloping roof, and vertical adobe partitions. On the ground floor are the stable, storage cellar, and passage way. On the first floor are the kitchen, bedroom, and living room ground floor roofed space.

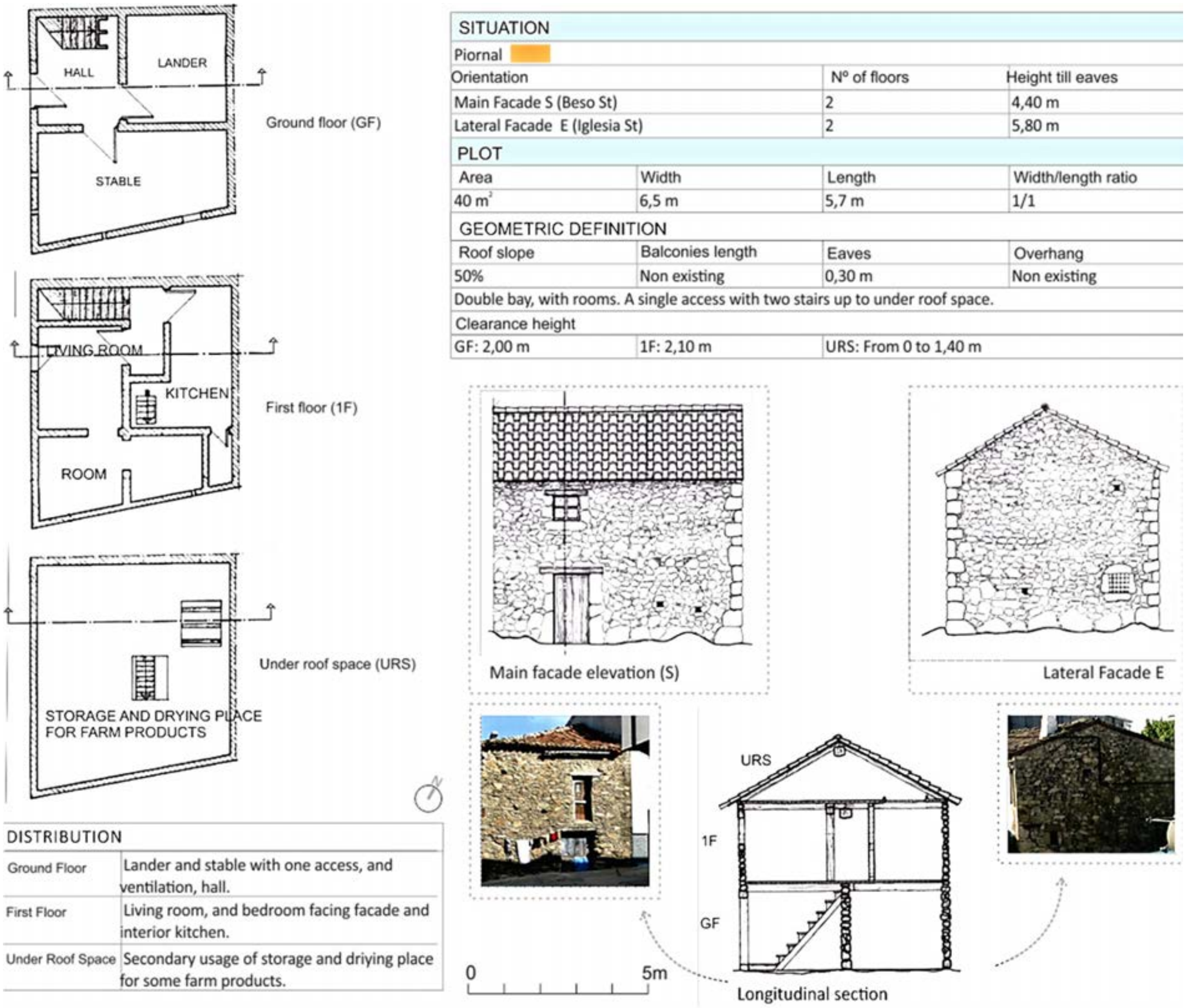

Fig. 1. Example of an information sheet for an historic dwelling in El Valle (drawings from Valverde, [14].

3.3. Creating the computational models in DesignBuilder

To perform the energy simulations, we created computer models with data corresponding to the original state of the dwellings, i.e., with the traditional lifestyles and customs. In particular, this included the animals in the stable on the ground floor, a wood fire in the kitchen, grain stacked up under the roof of the deck, etc. Account was always taken of the different tasks corresponding to each season [1]. No data were included introduced for hot water, lighting, or thermal conditioning systems. The most relevant data input under the different tabs of the software program were as follows:

- Site details: One must select a suitable climate record. In particular, the corresponding template to input must correspond to the closest available climate record geographically and with a climate similar to that of the place in question. In this case, we used a record that belongs to one of the most representative towns of El Valle. A characteristic orientation has to be defined. In the case study, the orientation simulated was southwest, 225°, as being the direction of valley's orientation, and therefore of most of its buildings. Any other orientations, if they exist, should implemented as variations in the model.

- Geometric data: Each floor previously defined in the typology data sheets (Figure 2) is input, as also are the rooms and dimensions. In addition, we defined the volume of the buildings that make up the street to take into account the effect of shading. The existence of gaps or holes that may affect the natural inside ventilation or outside infiltration has to be specified. In this case, we input the openings in the kitchen ceiling to vent smoke to the wattle of the low roof, and the gaps between roof tiles.
- Activity data: We input a template of activity, occupation, and metabolism in each room, considering a density of persons per unit area, a schedule of use, and a metabolic rate. These data were estimated from knowledge of the functioning of the dwellings. For these historic dwellings we did not consider holidays since there exist no long periods that might affect the overall results. It has to be borne in mind that in many cases the historic dwelling formed part of economic activity and that animals often shared space with people [1]. Considering an initial value of 42.50 W/m² [9], we corrected this for the body part used, the level of work, the position, and the type of displacement involved in the activity. By way of example, we rated two main activities. The first was lighter, using both arms, mid-level, seated, without displacement (such as cooking or weaving). The second was heavier, using the whole body, mid-level, inclined standing position, without displacement (such as cleaning the stable or feeding the livestock). For the final metabolic rate, we took into account the average body surface area of an individual (Table 1).

Table 1. Example of the calculation of the basal metabolism of two activities in the popular architecture of El Valle.

ACTIVITY 1 (Cooking or weaving)		ACTIVITY 2 (Cleaning the stable or feeding the livestock)	
By basal metabolism	42.50 W/m²	By basal metabolism	42.50 W/m²
By body part used	85.00 W/m²	By body part used	190.00 W/m²
By static position	10.00 W/m²	By static position	30.00 W/m²
By displacement	0.00 W/m²	By displacement	0.00 W/m²
TOTAL	137.50 W/m²	TOTAL	262.50 W/m²
Body surface area	1.70 m²	Body surface area	1.70 m²
TOTAL	233.75 W	TOTAL	446.25 W

- Thus, the data assigned to each room were as follows:

a) Unoccupied or uninhabitable spaces: These are considered to have null occupation. They therefore do not generate internal gains, and do not contribute to the metabolic rate. They are spaces dedicated to storage, in this case, the cellar and the deck.

b) Occupied or habitable spaces: These generate gains due to use. In each case, the metabolic activity and the density are taken into account. Among these spaces, one can define:

- Spaces for animals: Internal gains should be considered in the period in which the animals are kept stabled, usually in the coldest months of the year. In the case of El Valle, this was considered to be the months of October to April. Depending on the size of this space, one considers a certain metabolic rate and an occupation. In a small stable, we estimated a cow, 670 W, and a pig, 150 W [3]. The metabolic rate of the persons attending to this space is 263 W/m².

- Circulation spaces: These are of daytime occupation. In El Valle, we estimated from 7 h to 21 h in the passage way and stairs. The data taken are a metabolic rate of 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 which is the default provided by the software.

- Living spaces: In this case, we considered an occupancy of the living room from 13 h to 14 h and from 19 h to 21 h. These are data that correspond to light work, seated, using both arms, with a metabolic rate of 110 W/m² and a density 0.0188 persons/m², the default provided by the software.

- Sleeping areas: The bedrooms were considered as used from 23 h to 7 h, with a default metabolism of 90 W/m² and a density of 0.02 persons/m².

- Cooking and eating spaces: Together with the passage way, the kitchen is the most used space of the dwelling, with a variable occupation from 7 h to 21 h depending on the work corresponding to each season. The data input is a metabolism of 210 W/m² corresponding to light work, seated, with the use of both arms, and 0.0237 persons/m² density. Also considered as an important internal gain is the heat generated by the fire. This is usually alight all day in the cold months, and maintained all night with its embers.

SITUATION			
Zone 2		Street width: 3 m	
Orientation	Nº of facades	Nº of floors (height till eaves)	
Variable	1	2 (5,25 m)	
PLOT			
Area	Width	Length	Width/length ratio
40 m²	6,5 m	6,5 m	1/1
GEOMETRIC DEFINITION			
Roof slope: 20%		Eaves: 0,60 m	
Without balconies		Overhang: Non existing	
Doble bay: corridor and rooms. Single access. One or two stairs (straight directrix)			
Floors	Clearance height	External doors and windows	
Ground floor	2,55 m	Single access door (1,3 x 2 m)	
First floor	2,40 m	One window (0,6 x 0,9 m)	
Under cover floor	From 0,70 to 2,20 m	No doors or windows	
CONSTRUCTION CHARACTERISTICS			
Construction elements		Thickness (cm)	U-value (W/m²K)
M2+R. Granite masonry wall in ground floor rendering lime mortar in the internal face (including internal walls)		70+5	1,713
S1. Dirt floor in the larder		30	2,178
S2. Dirt floor and lime mortar in the hall		30+10	1,954
S3. Dirt floor with straw and dung in the stable		30+30	0,956
F1. Wooden floor structure with chestnut beams		4+4	1,548
F2. Idem with grain on the floor of the under cover floor		4+4+20	0,763
F3. Idem with terracota tiles and lime mortar on kitchen floor		4+4	2,172
F4. Idem with wooden boarding in the kitchen ceiling			
F5. Slope roof with chestnut beams and wooden boarding		2+2,5	3,542
D. External chestnut door (10 cms)		10	1,169
W. Single glazed wooden windows (3 mm)		3	6,257

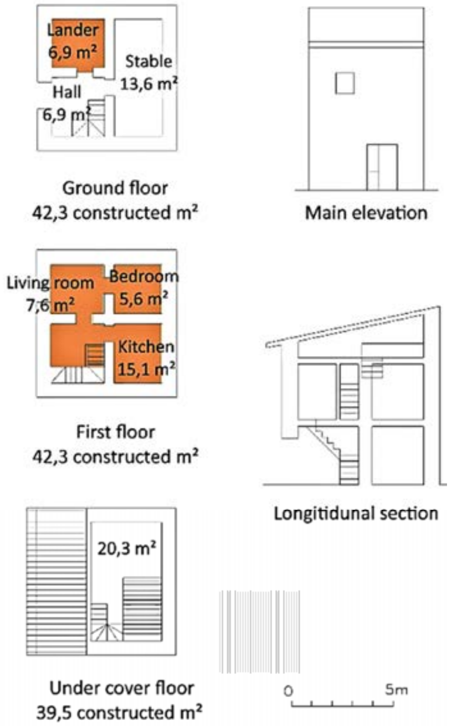

Fig. 2. Construction typology data sheet of a dwelling in El Valle.

- Clothing data: We calculated the value of a person's thermal insulation clothing coefficient in El Valle in each season using Olessen's expression for garments [9] and the study of traditional clothing in El Valle (Flores, 1992). The results indicate that clothing is warmer than currently taken to be usual. We adopted the value of 1.0 clo for spring-autumn, 0.7 clo for summer, and 1.2 clo for winter (Table 2).
- Enclosures data: Data were input corresponding to the structural characteristics indicated in the typology data sheet (Figure 2). In this section, one must estimate the degree of infiltration for each enclosure according to the permeability of the system of construction. Also, the ground floor was assigned contact with the terrain, and the dividing walls separating the dwelling from another building of the same use were assigned the characteristic of adiabaticity, since energy is not interchanged with the surrounding buildings.
- Data for opened windows and doors: We estimated a situation in accordance with the uses and rooms. Thus the doors of the uninhabitable storage spaces (cellar and deck) remain closed, the bedrooms do not have doors but are closed by a curtain between them and the living room, the door of the passage way remains partially open in the less extreme hours of each season 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. Furthermore, we designed a schedule for the operation of doors and windows which will subsequently influence the external infiltrations and natural ventilation. 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, we designed a broader time of opening during the cooler hours of the night.

Table 1. Calculation of the clothing coefficient for men and women in the popular architecture of El Valle.

WOMAN	(1)	(2)	(3)	MAN	(1)	(2)	(3)
Camisole	0.03	0.03	0.03	Long underwear	0.10	0.10	0.10
Petticoat	0.10	0.10	0.10	Long-sleeved shirt	0.12		
Half-sleeved blouse	0.15	0.15	0.15	Long-sleeved shirt	0.25	0.25	0.25
Bodice	0.20	0.20	0.20	Corduroy jacket	0.30	0.30	
Doublet	0.25			Thick trousers	0.28	0.28	0.28
Underskirt	0.25	0.15	0.15	Espadrilles	0.02	0.02	0.02
Panniers, over the underskirt	0.20	0.20					
Shawl	0.10	0.10					
Espadrilles	0.02	0.02	0.02				
Clothing coefficient	1.30	1.00	0.70	Clothing coefficient	1.10	1.00	0.70

(1) Winter (2) Spring and autumn (3) Summer

- Options of the model: In the computer program, the calculated natural ventilation has been adjusted, i.e., 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.

4. Conclusions

With this test of the method on the dwellings of El Valle, one can say that the architectonic and constructive analysis of an historic dwelling stock, and the selection and study of sufficient representative samples, allow building typologies to be defined which represent that stock. Also, to complete the information of a computer model that simulates historic dwellings in terms of energy, it is necessary to define the lifestyles. These in turn enable the allocation of appropriate metabolic rates and thermal insulation clothing coefficients in each zone of the dwelling in question. Other parameters that are necessary to define are the place's climatic characteristics, and the schedules of opening windows and doors so as to understand the indoor movement of air. All this information allows computer models to be generated that contain enough information to provide results that can be conveniently used in subsequent studies.

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