

DESIGNING A PASSIVHAUS USING CERAMIC MATERIALS WITH HIGH THERMAL INERTIA

COMPUTER MODELLING IN TRANSIENT REGIME

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1. INTRODUCTION

Energy saving is a significant factor to be taken into consideration in housing design because of both the cost of energy expenditure and the quest for responsible usage of resources. The use of design tools is increasingly common as a means of quantifying energy demand in a building depending on the design and materials used.

There are many examples of homes designed with the Passivhaus standard that aims to reduce the building's energy demand in both hot and cold temperature regimes, thus improving indoor thermal comfort conditions (UNE-EN 15603, 2008; Serra & Coch, 2001).

This paper follows on from earlier research on the design of homes in the planning stage and for which the tool used for modelling was a software application called TRNSYS 17. The criterion used by the authors (Aparicio et al., 2013) was to achieve the Passivhaus standard for low energy demand, developed in Germany in the 1990s (Pagliarini et al., 2012). These comfort criteria are:

- Limiting energy demands for heating in winter and cooling in summer, without compromising the conditions of indoor thermal comfort.
- Renewing indoor air by means of thermal conditioning, thus ensuring that hygiene and cleanliness are maintained.
- Maximising the compactness of the building in order to reduce the thermal envelope and consequently the inner surface in contact with the outside environment.
- Limiting and controlling all thermal bridges in the envelope. Thermal bridges should be avoided as far as possible in order to prevent condensation on indoor surfaces.
- Controlling the temperature of interior surfaces in order to prevent internal discomfort.
- Avoiding draughts or high air velocities that may have a negative effect.
- Restricting the infiltration of air by ensuring high airtightness of the envelope, thus limiting and controlling energy losses. This criterion calls for the tightness of the building to be tested.
- Curbing the building's primary energy demand.

On the basis of that earlier research, the objective of this paper is to quantify how much energy demand can be reduced in a certain type of house by means of different construction solutions that use both ceramic materials with high thermal capacity and materials with low thermal inertia, in order to assess the contribution made by such materials in different climate conditions.

2. METHODOLOGY

The methodology used to achieve the above objectives is amply covered by the TRNSYS tool, which calculates energy demands in housing. To do so, the following steps were taken:

Firstly, the type of house to be studied was plotted in 3D and its geometrics entered into the programme.

Secondly, each of the parameters for calculation considered in the afore-mentioned research was set up, i.e. both the thermal envelope obtained from the study by Aparicio et al., 2013 and the HVAC systems provided for in the Passivhaus model design.

Thirdly, meteorological data from 4 different climates were defined.

Finally, an assessment was made of different construction solutions that use both ceramic materials with high thermal capacity and materials with low thermal inertia, thus providing a view of how these materials perform in different climate zones.

The TRNSYS program was used to calculate and optimise house energy demand. The program enables the model of a building's energy demand to be calculated over a period of one year. Those data in turn allow the same model to be compared when different construction items are changed in order to gauge how energy demand varies over a whole year.

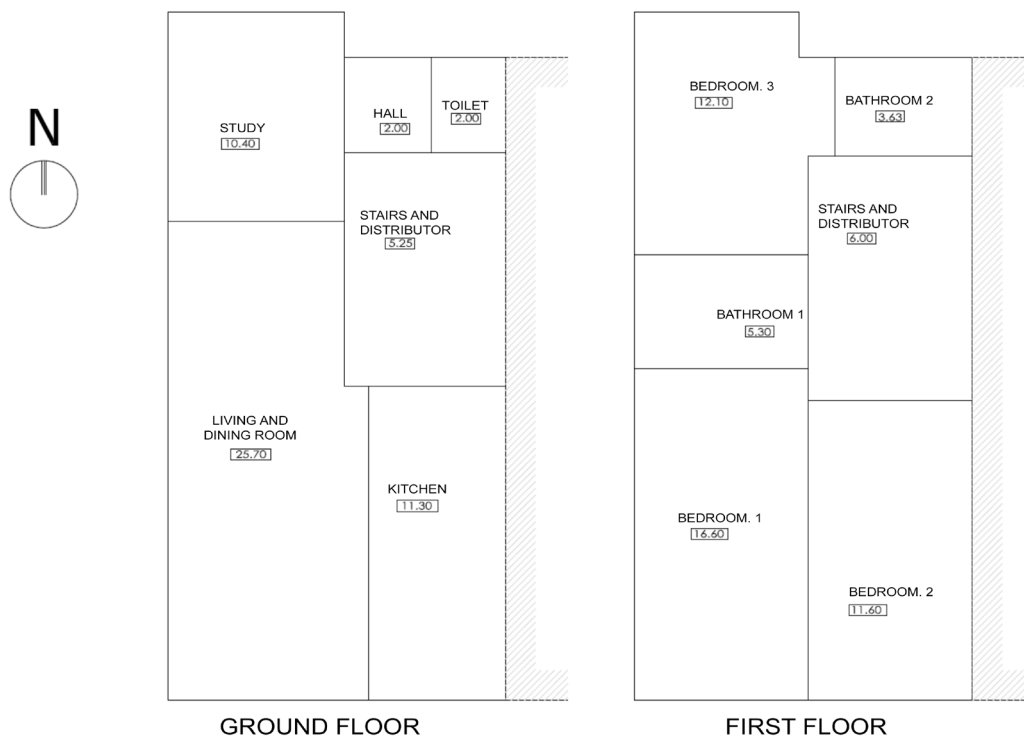
Hereafter is a detailed explanation of each step:

2.1 BUILDING GEOMETRICS

The house under analysis is part of a row of townhouses. The study was made of the end house, which is oriented as follows:

- North façade. Front door main entry.
- South façade. Exit to rear terrace.
- West façade. Faces side garden.
- The eastern side is the party wall with the neighbouring house.

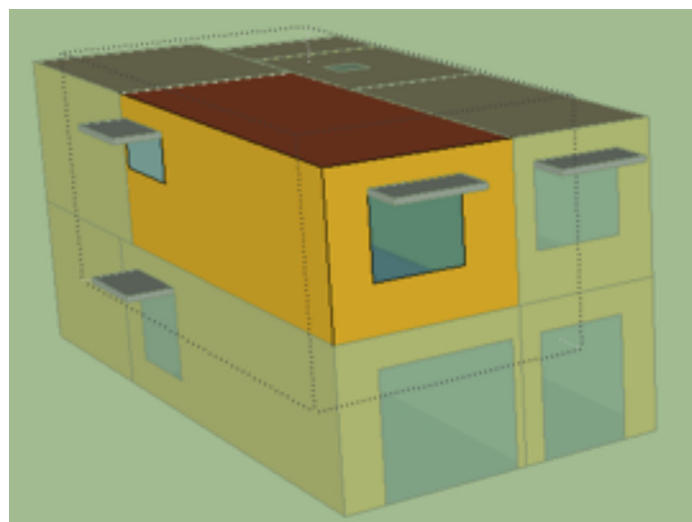
It is a compact house with a useful surface area of 55 sq. metres per floor. Main access to the property is via the north façade and from a terrace on the south facing wall. A scheme of the house is presented below (Illus. 1). Daytime activities take place on the ground floor, while the first floor is for the nighttime programme.



Illus. 1 - House layout.

The house was plotted using Google SketchUp, while a plug-in enabled the model to be imported from TRNSYS. The property was modelled using the Multizone Building model that allows the sketch of the house to be imported from Google Sketchup. The building is inserted using Type56 in TRNBuild. The model can subsequently be modified in the program by editing.

Nine different thermal areas were considered in the design of the house, grouped according to use and thermal conditioning requirements (4 areas on the ground floor and 5 areas on the first floor). The total volume of the house is the volume of air inside that needs to be reckoned with for its conditioning.



Illus. 2 - House model using Sketch Up.

2.2 CALCULATION PARAMETERS CONSIDERED

The property is calculated in order to be considered as a Passivhaus in Madrid. On the basis of that model, the following characteristics of the house were obtained for subsequent simulations. The calculation parameters thus obtained in order to attain the standard of a Passivhaus in Madrid (and which constitute the data used in this paper) are summarised and discussed below:

- The **windows** have a solar factor g_L of 0.298 for a 4/16/6 double-glazed pane. The thermal transmittance value of the window frame, $1.3 \text{ W/m}^2\text{K}$, corresponds to the ID 3302 type used in the programme.
- **Shading** of empty areas. Roller blinds are activated when solar gains become excessive, i.e. they are activated when room temperature rises above 25°C .
- **Air infiltration** through the walls of each room is modelled on the basis of an air renewal rate of 0.06 of the volume per hour in normal atmospheric pressure conditions. This infiltration rate is very low and means that, if the results of the simulation are to be applicable, an infiltration rate of this value needs to be achieved. This value was set a priori - however, it should be confirmed by means of a Blower Door test.
- **Ventilation** or air renewal is simulated on the basis of an initial reference value of 0.84 volumes per hour. Ventilation is one of the parameters that are modified in order to optimise the calculation so that the values adopted in this study are justified in the relevant section. A heat exchanger with an efficiency of 83% is used.
- **Increased ventilation flow** is considered for the summer months, when the outdoor temperature is below 25°C and the inside temperature is higher.
- A **by-pass system** has also been included, which prevents air from entering the house through the heat exchanger. It is only activated when the air inside the house is above 25°C .
- A **comfort temperature** of over 20°C for heating and below 26°C for cooling is maintained in each room at all times.
- The remaining **energy gains** are 2.1 W/m^2 according to the Passivhaus standard, including lighting, people, and appliances.
- **Energy demand**. We calculate the energy supplied to heat and cool the house with the above characteristics, expressed in kWh/m^2 per year.
- We have considered that the south façade has window eaves protruding 80cm from the wall and rising 50cm above the lintel.

- The party walls between houses are considered to be adiabatic walls, as they belong to an indivisible construction, all built at the same time as a single construction unit.
- The building's thermal envelope. The building has the following outer surfaces:
 - **Façade.** The proposed façade consists of non-hydrophilic thermal insulation made of expanded polystyrene (EPS) panels and rockwool (RW) on the inner side, as it is protected from outside moisture. The values for total Thermal Resistance (tR) and overall Thermal Transmittance (U) of the outer wall are:

$$tR \text{ (m}^2\text{K/W)} = 4.5$$

$$U \text{ (m}^2\text{K/W)} = 0.22$$

- **Roof.** The projected roof is a flat roof with a roof garden. Total thermal resistance (tR) and overall thermal transmittance (U) for the roof are:

$$tR \text{ (m}^2\text{K/W)} = 5.67$$

$$U \text{ (m}^2\text{K/W)} = 0.18$$

- **Floor slab.** The house stands on a slab resting directly on the ground and with an XPS thermal insulation layer of 4 cm across the entire surface. The results below were obtained on the basis of current regulations and the detailed project design. The house is designed to have underfloor heating on the ground floor and first floor, so that floor insulation should be continuous in order to reduce losses:

$$tR \text{ (m}^2\text{K/W)} = 2.23$$

$$U \text{ (m}^2\text{K/W)} = 0.45$$

2.3 METEOROLOGICAL DATA

When creating a new building with TRNBuild, the program inserts what is known as Type109, a weather file whose extension is tm2. The data in the file can be changed by taking different locations into consideration. This enables analysis of the same building model in different climate zones, which was precisely the aim of our research.

In this paper, we have chosen very different climate zones, to allow us to analyse behaviour in warm and cold climates. The selected climate zones, listed below, enable the results to be viewed and suitably analysed:

Mild continental climate. MADRID. D3

Average temperature: January (6.2°C / 71%). July (24.4°C/ 37%)

U_{lim}=0.66W/m²K U_{max}=0.86W/m²K

Warm coastal climate. SEVILLE. B4

Average temperature: January (10.7°C/79%). August (26.8°C/ 52%)

U_{lim}=0.82W/m²K U_{max}=1.07W/m²K

Very severe continental climate. BERLIN

Average temperature: Av. annual temp = 12°C Jan 0°C / 72% June 20°C 75%

Cold Coastal Climate. HELSINKI

Average temperature: January -3°C 84% July 18°C 77%

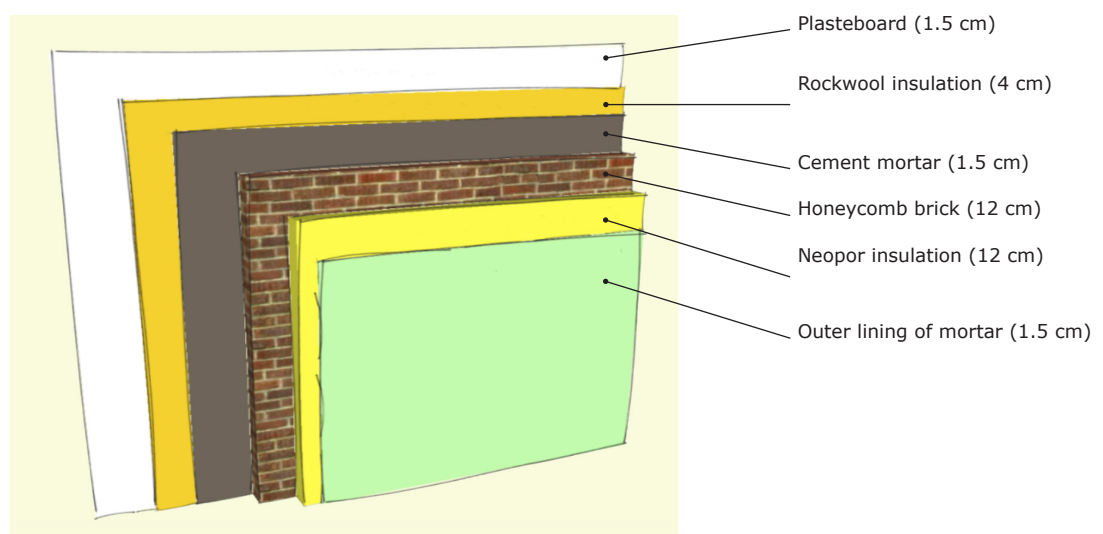
The average temperature and relative humidity for the four climate zones are shown. Meteorological data is entered into the Type109 file every 10 minutes over a year. These data allow the building's thermal performance to be calculated in transient regime.

Working with transient programs has numerous benefits, given that the behaviour of a house varies greatly over a 24-hour period. The next step is to analyse how houses perform during an entire day and assess the advantages.

2.4. PROPOSED CONSTRUCTION SOLUTIONS

Apart from changing the climate zones, the composition of the thermal envelope was also modified and thus five different study cases set up for analysis:

Case 0 is the project model. Thermal resistance and wall thickness are set according to the project data. Details of the walls and the values for total thermal resistance (tR) and total thermal transmittance (U) of the exterior walls in the project are:



CASE 0. $tR(m^2K/W) = 45$ $U (m^2K/W) = 0.22$

The thermal insulation is on the outer wall of the envelope so no thermal bridges occur where they join other walls or building elements.

Case 1 entails using a honeycomb brick with no heat insulation in order to see clearly how the various construction proposals differ in behaviour. The enclosing wall comprises an outer coating of cement mortar, a honeycomb brick, and an inner lining of plaster.

Total thermal resistance (tR) and overall thermal transmittance (U) for such a wall are: $tR \text{ (m}^2\text{K/W)} = 0.446$ $U \text{ (m}^2\text{K/W)} = 2.242$

Although this solution does not meet current building regulations, it is used here to compare results.

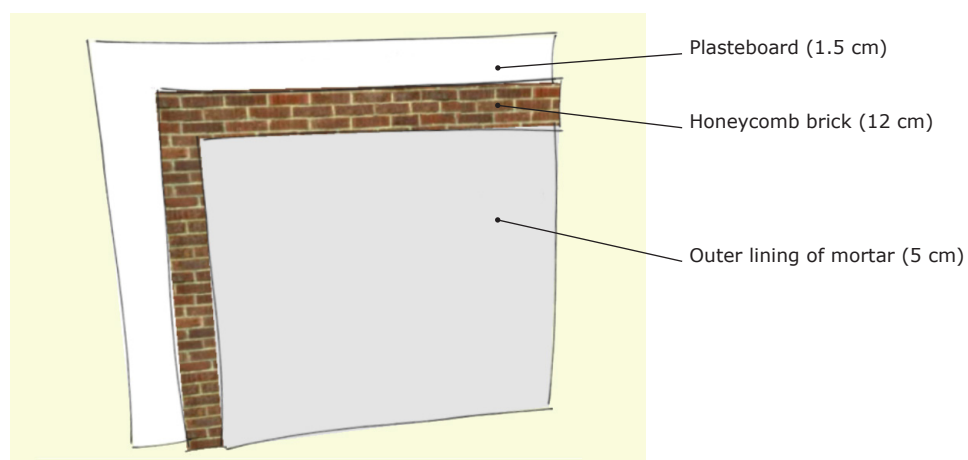
Case 2 comprises (from the outside inwards): a layer of cement mortar, 6cm of rockwool insulation, honeycomb brick, and an interior plasterboard wall with plastic paint finish.

Case 3 has the same components as in the previous case but on this occasion, the thermal insulation is reversed to see how the results thus obtained differ.

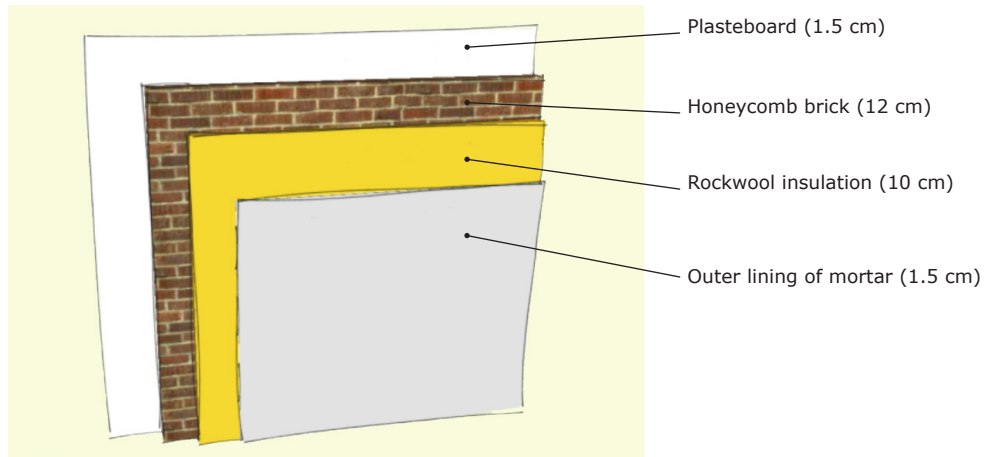
Thermal transmittance is the same as in Case 2 but the thermal insulation has been set in reverse order with regard to the honeycomb brick.

To compare the results properly, it was decided to set up **Case 4**, a light enclosure wall that consists exclusively of material with very low thermal inertia. In this case, the rockwool insulation is 20cm thick.

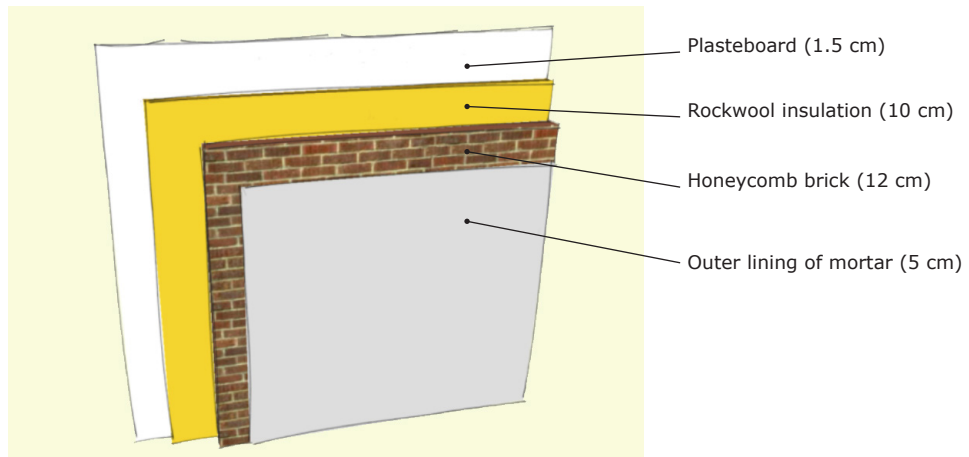
Total thermal resistance (tR) and overall thermal transmittance (U) of the four cases cited is shown below:



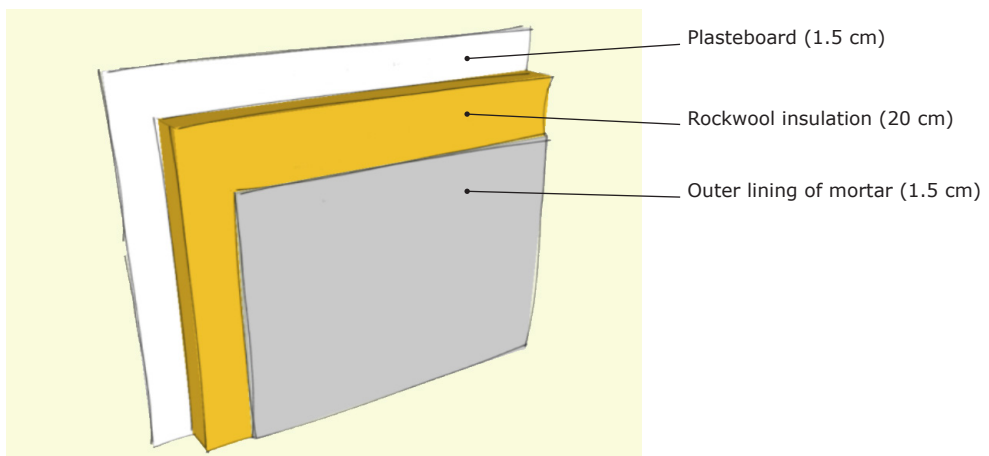
CASE 1. $tR \text{ (m}^2\text{K/W)} = 0.446$ $U \text{ (m}^2\text{K/W)} = 2.242$



CASE 2. $tR \text{ (m}^2\text{K/W)} = 1.457$ $U \text{ (m}^2\text{K/W)} = 0.686$



CASE 3. $tR \text{ (m}^2\text{K/W)} = 1.457$ $U \text{ (m}^2\text{K/W)} = 0.686$



CASE 4. $tR \text{ (m}^2\text{K/W)} = 1.067$ $U \text{ (m}^2\text{K/W)} = 0.94$

Finally, **Case 5** contemplates an inner cavity of hollow brick covered on both sides with ceramic tiles set on cement mortar, rather than the plasterboard arrangement on both sides with rockwool in the middle.

3. RESULTS

The resulting Energy Demand over the course of one year can now be discussed on the basis of this initial data. By only taking energy demand into consideration, the entire HVAC system with its corresponding power supply, energy losses, voltages, performance,... or any other parameter involved in thermal conditioning is omitted, so that the results can be compared objectively. Maximum energy demand can thus be determined, which will help to gauge the power rating required of the HVAC system.

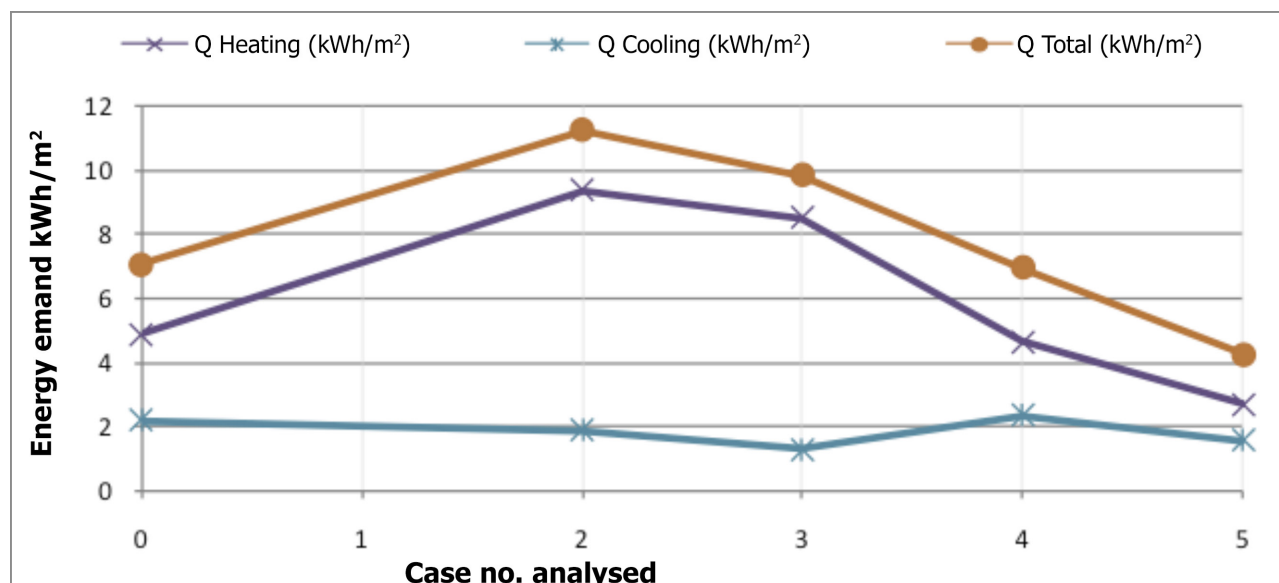
With this clarification, hereafter the results of energy demand and peak demand required are provided for the different sites.

3.1. MADRID

The results obtained for the original location of the project in Madrid are summarised in the following table:

MADRID	Q Heat (kWh/m ²)	Q Cool (kWh/m ²)	Q Total (kWh/m ²)	Q Heat +%	Q Cool +%	Q Total +%
CASO 0.	4.85	2.19	7.04	0.0%	0.0%	0.0%
CASO 1.	96.42	5.93	102.36	1887.2%	170.8%	1353.3%
CASO 2.	9.36	1.87	11.23	92.9%	-14.7%	59.4%
CASO 3.	8.53	1.29	9.81	75.7%	-41.3%	39.3%
CASO 4.	4.61	2.34	6.94	-5.0%	6.6%	-1.4%
CASO 5.	2.67	1.56	4.23	-44.9%	-28.8%	-39.9%

The data obtained shows the energy demand required to heat or cool the various rooms in each hypothetical case. Note that in Case 01, in which there is no thermal insulation, the energy demand for heating is much higher, whereas for cooling, the demand does not increase at the same rate. In this case, the demand for heating increases significantly and impedes proper analysis of the remaining results. Consequently, this case is removed from the following graphs so that the adjustments made in the other cases can be better appreciated, apart from the fact that under today's regulations an envelope wall could not be built without insulation. Nevertheless, this option should not be neglected in warm climates where there is no demand for cooling. The results obtained once Case 01 is removed are as follows:



This graph reveals most clearly the difference in results among the various study cases. Decreased demand for cooling and heating can be seen between Cases 02 and 03, when the insulation is fitted on the inside brick of the cavity wall compared to when it is fitted on the outside brick. Also significant is the fact that Case 5, where the interior wall is made of ceramic tile instead of plasterboard, reveals a lower demand for energy than Case 0.

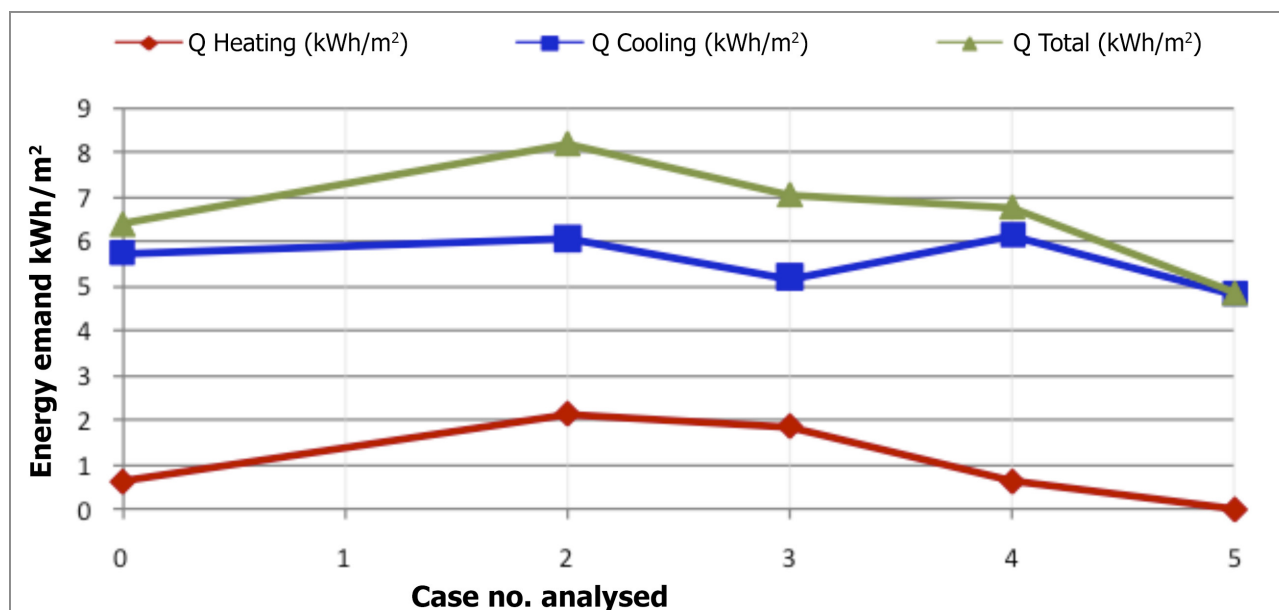
3.2. SEVILLE

The data obtained for the same house when located in Seville are summarised in the following table:

SEVILLE	Q Heat (kWh/m ²)	Q Cool (kWh/m ²)	Q Total (kWh/m ²)	Q Heat +%	Q Cool +%	Q Total +%
CASO 0.	0.65	5.75	6.40	-86.6%	162.5%	-9.1%
CASO 1.	41.85	17.51	59.36	762%	699.0%	742%
CASO 2.	2.15	6.05	8.20	-55.6%	176.1%	16.4%
CASO 3.	1.87	5.19	7.06	-61.3%	136.7%	0.3%
CASO 4.	0.65	6.13	6.78	-86.6%	179.9%	-3.7%
CASO 5.	0.03	4.83	4.86	-99.3%	120.3%	-31.0%

In Seville, given the warmer climate, energy demand for cooling is greater than for heating. In addition, total demand over the year is also lower when Passivhaus strategies are used in the home.

The following graph depicts the results once Case 01 without thermal insulation has been removed:



In this case, the same trend as in Madrid can be seen with a decrease in demand for heating and cooling when the thermal insulation is taken to be fitted on the inside of the cavity wall and in Case 5, when the interior walls are built with ceramic lined bricks, thereby increasing the thermal inertia of the envelope.

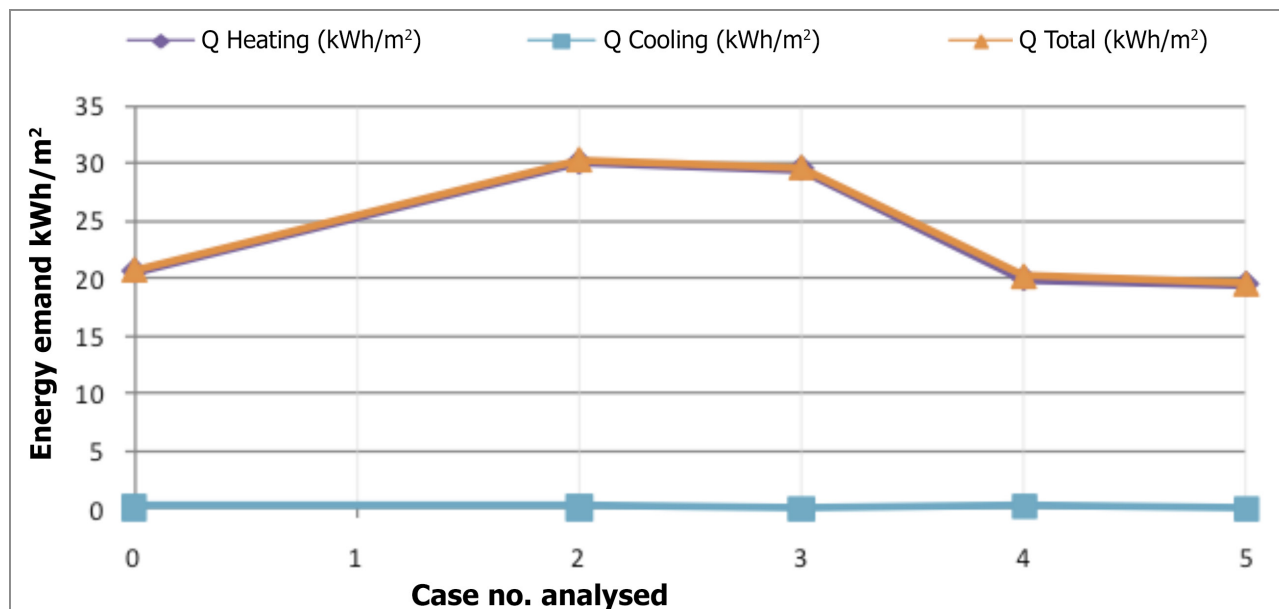
3.3. BERLIN

The results obtained for this case are shown in the following table:

BERLIN	Q Heat (kWh/m²)	Q Cool (kWh/m²)	Q Total (kWh/m²)	Q Heat +%	Q Cool +%	Q Total +%
CASO 0.	20.57	0.15	20.73	323.99%	-92.95%	194.3%
CASO 1.	177.71	0.27	177.98	3562.43%	-87.70%	2426%
CASO 2.	30.10	0.15	30.25	520.31%	-93.17%	329.4%
CASO 3.	29.53	0.04	29.57	508.61%	-98.02%	319.9%
CASO 4.	19.92	0.24	20.16	310.53%	-89.14%	186.2%
CASO 5.	19.44	0.07	19.50	300.60%	-96.94%	176.94%

In this climate zone, energy demand for cooling is almost zero throughout the year, so that total demand practically matches the demand for heating. In cold climates, the only way of reducing total energy demand is by isolating envelopes properly, so the

thermal inertia of the façade and partition walls has little effect on overall demand. This enables us to state that ceramic material will have little impact on end comfort for the dweller or on total energy consumption throughout the year:



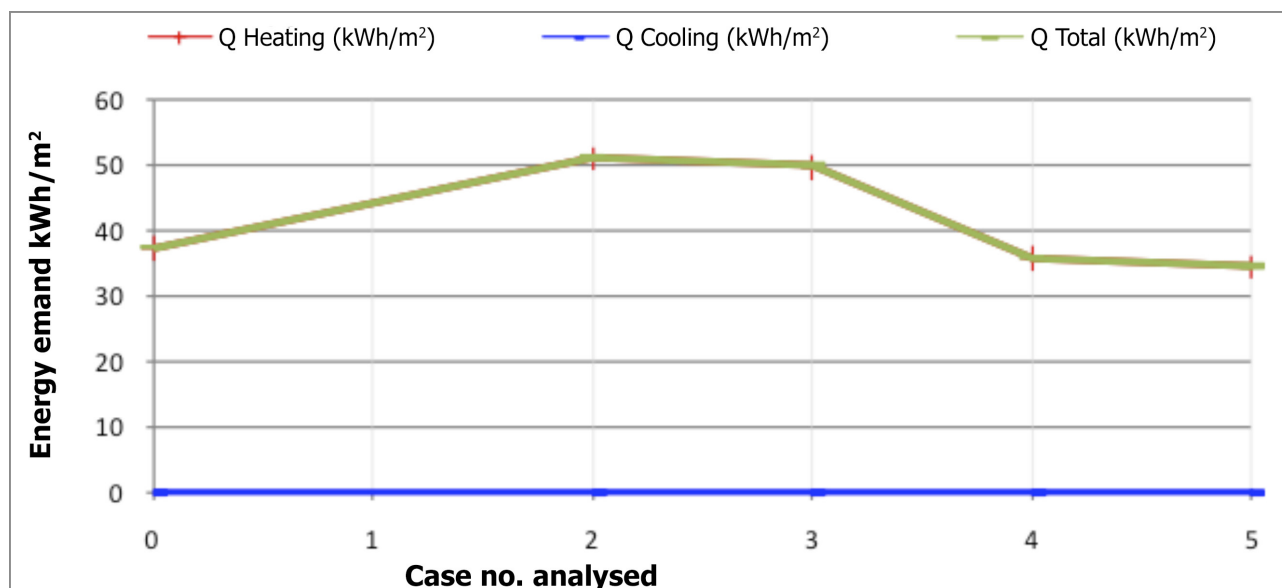
The graph shows the little influence of thermal inertia on total energy demand.

3.4. HELSINKI

This represents the most extreme case of all the proposed cases, in which there is a permanent demand for heating:

HELSINKI	Q Clefac (kWh/m²)	Q Refrig (kWh/m²)	Q Total (kWh/m²)	Q Clefac +%	Q Refrig +%	Q Total +%
CASO 0.	37.30	0.01	37.31	668.74%	99.51%	429.76%
CASO 1.	262.45	0.00	262.45	5308.83%	-100.00%	3626.32%
CASO 2.	51.02	0.00	51.02	951.53%	-99.93%	624.46%
CASO 3.	29.53	0.00	49.72	924.68%	-100.00%	605.93%
CASO 4.	19.92	0.01	35.77	637.15%	-99.76%	407.92%
CASO 5.	19.44	0.00	34.42	609.43%	-100.00%	388.75%

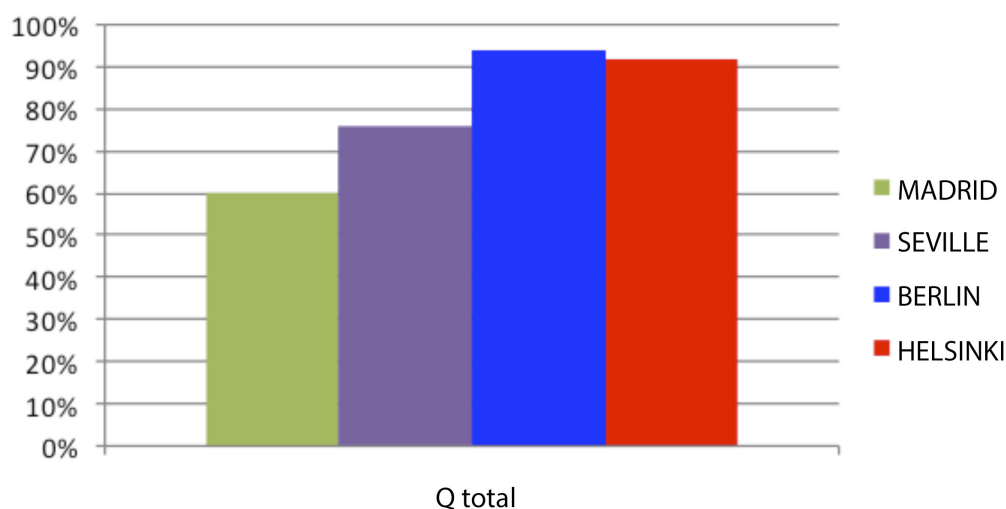
The results expressed as percentages relate to the house in Madrid, and since there is a much greater demand in Helsinki, very high percentages emerge:



As in the case of Berlin, the effect of thermal inertia on overall energy demand is less than in the study cases located in warm climates.

From this analysis of four different geographical situations, a graph can be plotted that reflects the reduction in energy demand with regard to the cases that reveal the greatest differences, i.e. the project model (Case 0) and the case in which the interior partition walls are made of ceramic bricks lined with mortar and ceramic tile on both sides (Case 5). The results for each climate zone are as follows:

Overall energy demand



The graph shows the reduction in energy demand with regard to the initial case proposed in the project. It reveals how the overall energy demand is reduced in the case

of Madrid and Seville, with demand decreasing by as much as 40% in Madrid. This is due to a reduced demand for heat because incoming heat during daylight hours builds up in the interior walls. The same effect occurs with night cooling during the summer. In warm and continental climates, this effect is enhanced.

4. CONCLUSIONS

From the partial, individual, results obtained so far, the intention is to find and select the best possible option to obtain maximum reduction in energy demand. This has to be done gradually, adding each of the elements one by one so that their effect can be quantified individually.

All the values presented herein refer to energy demand in kW hour/m² per year. Infiltration values, by-pass performance and activation temperatures for the thermal conditioning systems were not modified when the simulations were made.

The modelling shows the importance of strategies to accumulate cold and heat in warm and temperate climates, as they enable heat to be stored during winter days and natural cooling to occur on summer nights. Another noteworthy result from our modelling is the significant reduction in energy demand when ceramic materials are used.

The steps taken in this study are closer to the actual use made by dwellers, which implies that it is advisable to use tools that allow for this type of actions rather than simplified tools with pre-set values that are difficult to ascertain and control.

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