Consumption study and energy optimization of a typical Valencian house

A. Martínez, R. Royo & S. Tormo
Universidad Politécnica de Valencia

ABSTRACT: This paper reports on the energy consumption study of a typical Valencian house with the aim of achieving a maximum reduction in HVAC energy demand. With this purpose, an extensive simulation project was done by using TRNsys 17 software.
Previously, all necessary data were collected and studied. Then, an energy simulation of the original house was performed, hence obtaining experimental evidence to verify the predictive capability of the developed energy model. Subsequently, the energy optimization strategy was proposed and the measures to improve the energy demand were implemented on the model, in order to reach a zero HVAC demand.
Finally, the following conclusions were obtained: energy model adjustment is fundamental for reproducing the specific thermal behavior of the studied building and for the optimization of the energy demand and secondly, enhancing the building envelope is the most effective proposal for achieving the reduction in the HVAC requirements for the building.

1 INTRODUCTION

Growing energy dependence, as well as the profound economic crisis, have forced society to question many of the uses and energy procedures employed so far. It is becoming critical for them to be aware of the necessity for a rational and efficient use of energy.

Is essential to understand that energy saving and the efficient use of energy does not mean reducing comfort or well-being. With a change of habits and attitudes it is possible to maintain or even improve comfort conditions and significantly reduce energy consumption as well.

According to Boermans T. & Petersdorff C. (2007), up to approximately 40% of worldwide final consumed energy is concentrated in the construction sector. Buildings significantly contribute to the consumption of final energy. Therefore, the actions on the construction sector can be very effective in reducing energy consumption. Consequently, in recent years energy optimization and efficiency have acquired relevance in the building sector, due to its strong potential in saving energy. This is the first approach to an ambitious goal: striving to get energy consumption for buildings to be close to zero before December 2020, according to European regulation 2010/31/CE.

In this context it is of great importance to optimize the thicknesses of insulation to improve the thermal behavior of our buildings as much as possible (Lollini et al. 2006).

This paper presents an energy study for the rehabilitation of a country house made with traditional materials typically used in the Valencian orchard. The objective of this study was to obtain a maximum reduction in the HVAC energy demand with the priority being the application of passive measures, which finally results in zero energy consumption for active air conditioning.

The study has required a laborious and systematic work of simulation with TRNsys 17 software.

In addition, we consider that, on its own, the energy rehabilitation of a traditional house gives high additional value. Nowadays, it seems very convenient to get examples that can serve as models to be followed by other social elements.

2 METHODOLOGY

2.1 *Building description*

The selected building for this study is a two floor house, built in the first half of the XX century in the stage prior to the II Spanish Republic (1930). The house is located in a Valencian orchard, 820 meters from the Mediterranean coast, in the municipality of Alboraia (Valencia). The architectural typology is the modern *alquería*, a typical orchard farmhouse from the east and southeast coast of Spain and of Hispano-Muslim origin. Its main façade is orientated towards the east to take advantage of the breeze from the sea for ventilation and cooling of the farmhouse, especially during the summertime.

These types of buildings were houses of tillage in which the ground floor was used as a house, and the "cambra" or volume under the roof was for the storage of the harvest or for the breeding of silk worms. The geometry of the floors was typically rectangular, or as in our specific case, it could attach two rectangles forming a 90˚angle. The ground floor of the house is 60 m^2 in area and 2.8 m. high. The distribution is shown in Figure 2.

Access to the "cambra" is made initially through a staircase outside the house. This floor is 48 m^2 and has an average height of 1.4 m (Fig. 3).
To summarize, the constructive characteristics of the building are: old, solid brick masonry walls, without any thermal insulation. The floor and deck structure is made of wooden joists and beams. The pillars are solid brick. The south-facing shed roof is supported on the end gable of the roof east-west.

The roofs are finishing with curved tiles.

In Table 1, the average values of the transmittances of different constructive elements that form the envelope of the house have been collected, as taken from the Catalog of Spanish Construction Elements.

Figure 1. South building façade.

Table 1. U-values of constructive elements from Spanish Constructive Elements Catalogue by CTE

	U-value (W/m^2K)
External wall	5.2
Floor in contact with ground	20.0
Roof	4.9
External cover	4.0
Single glass thickness=4mm	5.8
Aluminum carpentry	5.7
Wood carpentry	2.2

2.1 *Weather data*

The climate of the *Alboraia* orchard is similar to the city of Valencia: typically Mediterranean, mild and humid and with seasonal rainfall. The annual average temperature is about 18 ° C and with no extreme temperature swings. Normal relative humidity ranges between 60-75%. The summer is warm (temperatures average around 20 ˚C). In July and August temperatures are between 25˚C and 30 ˚C, with very few frequent values above 35 ˚C.

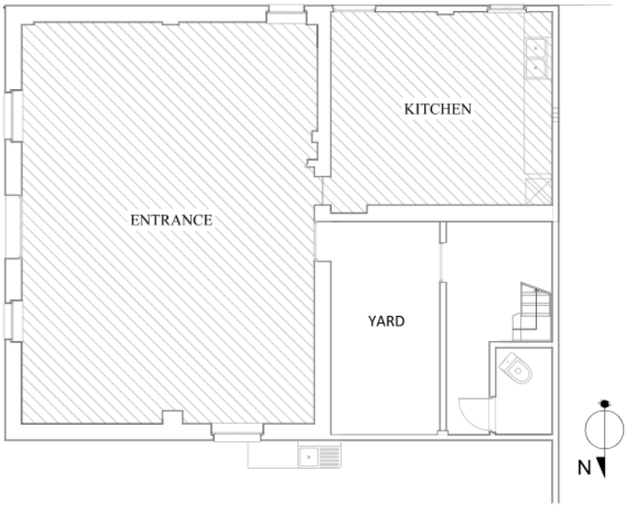

Figure 2. Ground floor building plan.

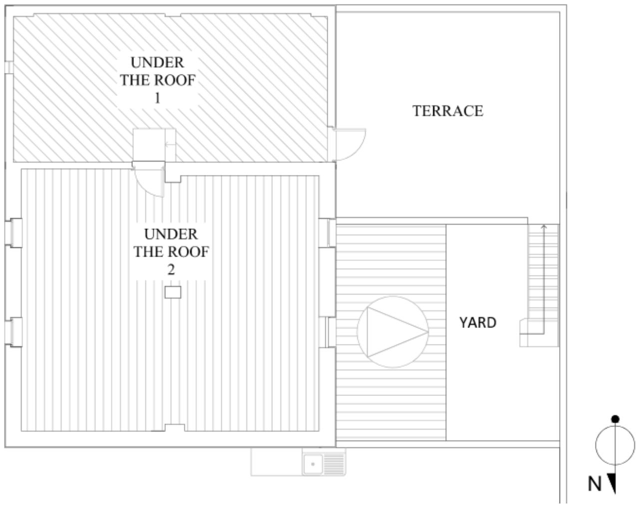

Figure 3. First floor building plan.

On some occasions heat waves have been produced due to the arrival of warm fronts from the North of Africa, or when dry winds blow from the West.

1. Winters are very mild, with the coldest months being December and January, with minimum temperatures of 5 ˚C. Very occasionally, there are cold waves due to the displacement of cold air masses coming from the north pole. The annual rainfall is higher than 450 l/m^2, with a very marked minimum in the summer, in the months of June to August. Historically, maximum precipitations have occurred throughout the fall, due to the effect of the weather phenomenon known as "la Gota Fria" (The Cold Drop) which brings severe weather with heavy rain or hail and possible flooding.

.

2.2 *Registration and processing of experimental data*

Prior to the energy analysis, an extensive collection and processing of experimental data was performed.

- During 8 months (September 2014-April 2015) monitoring of external climate data with the use of a weather station, *Watchdog 2007*, located in the house, was carried out. With these data, a climate file was produced and was used in the process of adjustment, calibration and validation of the energy model of the house.
- During the same months, a system of monitoring inside the house was installed (Martínez A. et al. 2016) and with which, data of temperature and relative humidity were collected.
- A Blower Door test was carried out according to ISO 9972:1996 and EN 13829. The effective surface of air infiltration was calculated from the data obtained with the test as it is described in Sherman M.H. (1987). This surface is used in the simulation program to calculate air infiltrations in a dynamic way, depending on the interior and exterior conditions at every time step (Martínez A. et al. 2016).

Lastly, in the final process of optimization for the minimization of the energy demand, the simulation uses the data file of historical climate, standardized for the period from 1961 to 1990, made by *Meteonorm*.

2.3 *Energy Model of the house*

The energy model of the house was made using TRNsys 17, a software program for energy simulation.

The building was modeled using the TRNsys multizone standard model known as *Type 56*. In the energy model, all the features of the house that affect the thermal behavior were defined.

To simulate the airflow circulating in the house, the module TRNflow was used (Transsolar 2009).

The external weather data are incorporated in the model in two different forms:

The first one introduces the built climate dataset. A specific editable text (Type 99) file was used.

The second procedure was to introduce the archive of climatic data from *Meteonorm*, that takes into consideration a normal period in Valencia. This is done through a TRNsys processor of standard climatic data, known as *Weather data*.

Previous to the next step, in order to obtain a feasible energy model of the building, a fit, calibration and validation procedure was performed (Martínez A. et al. 2016). The indoor measure datasets were compared with the results from the simulation (Fig.4) in order to check the predictive capability of the developed thermal model.

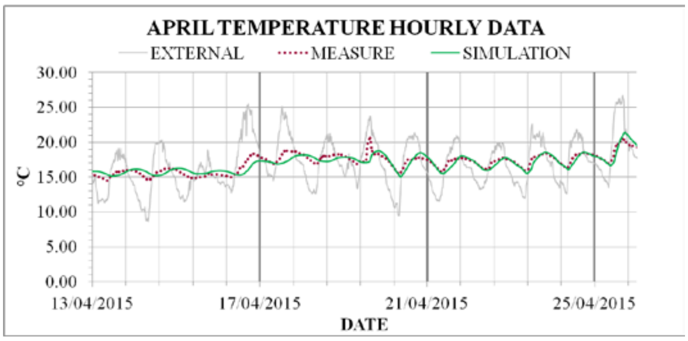

Figure 4. Two weeks of hourly April Temperature data with external measure (EXTERNAL), indoor measure (MEASURE) and hourly indoor temperature data were obtained by means of simulation (SIMULATION) from the entrance zone.

2.4 *Optimization strategy*

To achieve the objective of close to zero HVAC energy demand, a series of measures were sequentially implemented, testing different possibilities and combinations with the objective being to choose the most beneficial ones.

The studied passive measurements were:

- Thermal insulation in roofs and walls.
- Selection of optimized windows surface for south, east and west orientations.
- Glazing characteristics for the windows.
- Shadowing periods for the windows.
- Natural cross ventilation.

The active measurements studied were:

- Use of heat recovery.
- Air ventilation system.

The fundamental improvements have been applied, with the following justification:

- To place thermal insulation in the building envelope is one of the most effective measures to decrease the energy demand for existing buildings. There are a great number of studies in which its efficiency has been evaluated, for example, Al-Homoud D.M.S. (2005), Boermans T. & Petersdorff C. (2007).
- Referring again to the study by Boermans T. & Petersdorff C. (2007) (Ecofys VII), the conclusion is that for mild weather, the insulation at ground level is not adequate from a thermal point of view.
- It is usual that windows are the weakest thermal point in the envelope of the buildings, so, it will be fundamental to study this, with the objective to use windows and carpentry that reduce the energy losses whenever possible (Roos A. et al. 1994).

– The uncontrolled external air inlets and infiltrations are always harmful for periods with heating requirements, so it is necessary to avoid them as much as possible, taking as a limit the criterion from the Passivhaus standard, of 0.6 renovations per hour for a Blower Door test with a pressure difference of 50 Pa.

  When high air tightness for the building is attempted, controlled mechanical ventilation will be necessary to preserve the interior air quality. The ventilation flow is defined according to the limit values described in the Spanish regulation, CTE (Código Técnico de la Edificación) DB-HS3.
– The heat recovery system for this building type with very low energy consumption seems very convenient. Some energy standards such as Passivhaus make its use obligatory.

The first objective was to reduce the heating demand as much as possible, choosing the option that also does not imply an excessive increase in the refrigeration demand.

The second objective was to obtain the highest reduction in the refrigeration demand, without having any important effect on the heating demand.

Finally, some additional adjustments were carried out to achieve the prior objective of effective zero energy demand.

For the first objective, it was decided to simultaneously study the chosen options for the insulation thickness at walls, roofs and south windows glazing surfaces, with the objective being to find a compromise between the heat losses from conduction and the heat gains from direct solar radiation, achieving the most beneficial combination.

After the implementation in the model of the optimal combination of the described measurements, the next step was to study the carpentry and glazing characteristics.

Once the building envelope was optimized according to the heating requirements and minimum heat losses through the envelope were achieved, the definition of the heat recovery began.

The first described objective is achieved when an effective heat recovery performance has been obtained at heating periods. Therefore, the second phase begins, with the next aim being to get the highest reduction in the refrigeration requirements.

Firstly, recovery operation was adjusted to make it work properly in the periods in which the demand is for cooling, and then shadow devices were implemented. Their use schedules were studied, choosing from the possible options the awning, as the authors believe that it is the most suitable system for total protection against direct solar radiation, while it still allows diffuse light so as not to darken the interior of the house completely, contributing in this way to the natural lightning of the building. For deciding what shadow device was the most appropriate, a study using the Ecotect Analysis (2011) software from Autodesk, was conducted. Once the elements of shadow and their periods of operation are properly defined, the following measure is to reduce the demand for cooling by increasing the ventilation flow.

Finally, the natural cross ventilation is studied, opening and closing doors and windows located in the east, west and south facades. When windows and doors are opened, the forced ventilation and the heat recovery are disconnected, limiting the use of extra forced ventilation solely to periods where outdoor temperatures are very high.

In this way, the second objective is obtained. Then, to finally reach a HVAC demand close to zero, small adjustments are made to insulation thickness, south windows surface, control of extra mechanical ventilation, and cross ventilation from opening of doors and windows.

3 RESULTS

3.1 *Description of the optimized building model*

In the initial state of the building, the annual HVAC energy demand according to the simulation results was 206.5 kWh/ year m^2 for heating and 36.4 kWh/year m^2 for refrigeration.

The high demand in the original state of the house was due to the bad condition of walls, roof and windows that led to a high level of air infiltration, making the heating requirements very high. Another additional contribution comes from the fact that the house is in darkness for much of the day, and does not obtain heat by direct sunlight through the windows. It is true that cooling requirements are considerably lower than the heating ones, since the conditions of darkness and the high infiltration are favorable to reducing refrigeration requirements.

Prior to the energy rehabilitation, the structural consolidation of the building was required.

A continuous renewal of air by means of a simulated mechanical system of 0.8 renovations per hour is provided when no doors or windows are open in the different rooms, to comply with the provisions in the Spanish legislation on the quality of indoor air, CTE DB-HS3.

In Table 2, the measures implemented in the model to achieve the final optimum level are summarized.

Finally, the demand obtained with the highly optimized model is 0.7 kWh / year m^2 for heating and 2.2 kWh / year m^2 for cooling. So, with the optimized model, a reduction of almost 100% in the energy demand has been achieved.

Table 2. Summary of energy improvement measures implemented in the energy model.

Nearly Zero Energy Demand house model specifications:
Insulation Insulation material LW, thermal conductivity 0.04 W/m K. Walls insulation thickness 16 cm. Roof insulation 20 cm.
Glazing type LowE 4/84; U-value 2.48 W/m^{2}k
Window glass area Ground floor: South: 3.6 m^2,North: 0.75 m^2,East: 2.4 m^2 First floor: East: 0.7 m^2,West:0.7 m^2
Shadow devices Awning used, windows are totally in shadow. Summer: Implemented every day. Spring and fall: Implemented if exterior temperature is higher than 22 ºC.
Heating recovery system Efficiency: 0.75. Connected if doors and windows are closed. Cooling demand (Indoor temperatures higher than 26 ºC): Indoor temperature is lower than exterior temperature. Heating demand (Indoor temperatures lower than 21 ºC): Indoor temperature is higher than exterior temperature.
Natural cross ventilation Windows and doors are opened when exterior temperatures are between 21 ºC and 25 ºC.
Extra mechanic ventilation Active in summer, spring and autumn periods, when doors and windows are closed.

These values are very low, compared with the specified limits in the Spanish legislation for the climate zone in which the building is placed, 15 kWh/year m^2 for heating demand, with the same value for cooling demand, These coincide with the limits imposed by the Passivhaus standard.

3.1 *Influence Analysis of every optimization measure applied*

In this section, an analysis of the impact of every implemented measure is carried out.
In this way, the sequenced stages of the simulation are contemplated, as is outlined in the table in Figure 5, in order to be able to evaluate how every measure affects the improvement in demand with respect to the previous step. And then finally, how the implementation of all of them affects the reference point of the basic model of house demand, observed without any energy saving measures.

As shown in Figure 6 with the improvements of insulation, glass and shadows, the achieved heating demand is virtually the limit in the Passivhaus standard, and the cooling demand is well below this standard.

Perceptually, (Fig.7) the implementation of insulation and heat recovery are the measures with the largest effect on the heating demand.

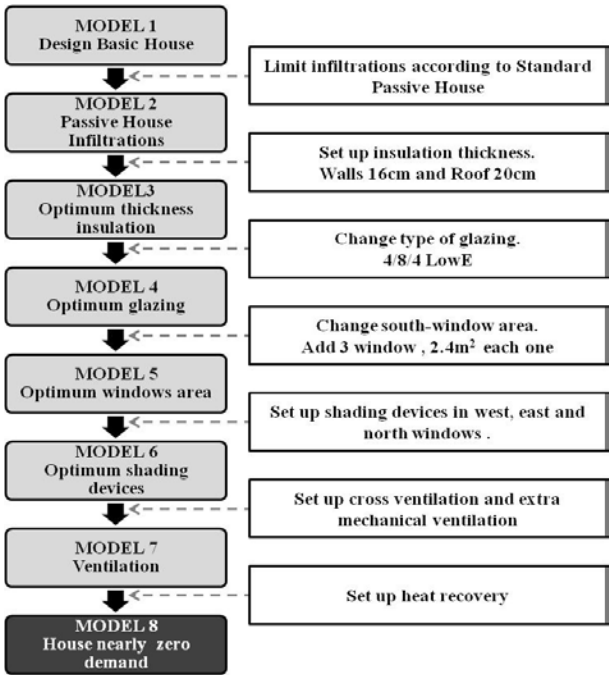

Figure 5. Scheme of the Influence Analysis of every applied optimization improvement.

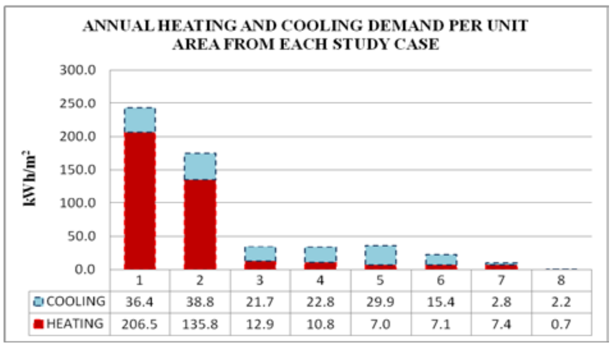

Figure 6. Annual heating and cooling demand per unit area from each energy improvement measure.

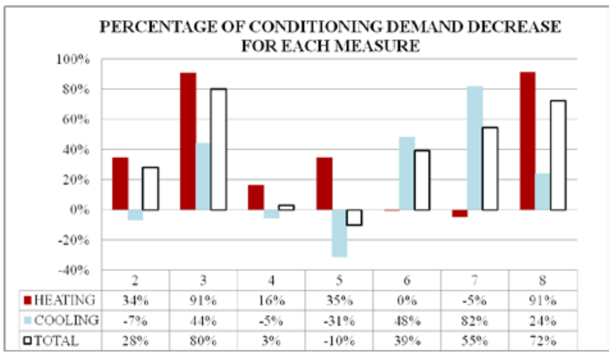

Figure 7. Percentages of heating, cooling and total demand decrease for each improvement compared with the Basic House Design.

Regarding the cooling, the most effective measures are the proper shading of windows and the natural ventilation of the dwelling.

In Figure 7, there are measures whose effect is an increase in the demand, and those ones therefore appear with a negative percentage. For example, this is what happens when the infiltrations are decreased to the limit established by the Passivhaus standard, thus causing an increase in the demand on cooling. However, because of the great impact it has on reducing the heating necessities, the final effect on total energy demand is very favorable. Nevertheless, the most critical measurement for the increase in the cooling demand is the introduction of new windows. The increase of the total demand shows clearly that it is not possible to define new glazing without proper shading.

Globally, as seen in Figure 7, the most effective measure for energy saving is the implementation of insulation in the building envelope. Second in order of its effect on the demand would be the implementation of heat recovery, but always with appropriate operating controls and previously optimizing the thermal envelope of the building.

4 CONCLUSIONS

From the study which was carried out, the following conclusions have been obtained:

– The most effective measure is the use of an appropriate and optimized thickness of thermal insulation; the initial total energy demand is reduced by 80%.
– Promoting a high level of air tightness is a priority in the energy rehabilitation of housing, because air infiltrations significantly increase the heating requirements.
– An accurate study of the position of the window in relation to the orientation of the house is fundamental for the following reasons:
    - When dealing with windows with a south orientation, it is necessary to find an optimal ratio between window area and opaque walls in order to get a passive warming from direct solar radiation that is higher than the thermal loss through the envelope.
    - The proper use of cross ventilation has an important effect on the energy consumption
– An effective shading of these windows will be very important so as not to worsen the demand for cooling.
– It is better to avoid windows oriented to the East and West as much as possible and only have what is necessary to ensure proper cross ventilation. In addition they must also be suitably shaded.
– In mild climates such as the Valencian region of the Mediterranean, when referring to the characteristics of the windows, the quality of the glass is more important than the joinery.
– Heat recovery is an effective measure in terms of energy saving if the thermal envelope of the housing has been optimized properly, and its operation controls are appropriate.

5 AWARENESS

After the analysis, new lines of study have been opened up for the future. Some of these ideas are:

– Studying the effectiveness of thermal recovery in mild climates related to acquisition and installation costs.
– Solving problems with the standards for energy efficiency created for cold climates that have to be extrapolated for milder and warmer climates. This is something which is not so easy to do!

6 REFERENCES

Agencia Estatal de Meteorología.(2011). Guía resumida del clima en España 1981-2010.

Al-Homoud D.M.S. 2005. Performance characteristics and practical applications of common building thermal insulation materials, Building and Environment 40: 353–366.

Boermans T., Petersdorff C. (Nov. 2007). *U-values for better energy performance of buildings (Ecofys VII)*. Report for EURIMA, European Insulation Manufacturers Association.

CENER, Centro Nacional de Energías Renovables (2012). CTE Plus. El potencial de ahorro de energía y reducción de emisiones de CO_2 en viviendas mediante incremento del aislamiento (España 2005-2012). Report for ROCKWOOL.

Código Técnico de Edificación.(2013). Documento Básico Ahorro de Energía. HE 1 Limitación de la demanda energética. E.N. NBN, 13829. Therm. Perform. Build. Air Permeability Build. Press. Method.(ISO 9972 1996, Modif. 1996.

Instituto Eduardo Torroja de ciencias de la construcción con la colaboración de CEPCO y AICIA (Ministerio de Vivienda).(2010,Marzo). *Catálogo de elementos constructivos del CTE*.

Lollini, Barozzi, Fasano, Meroni, M. Zinzi 2006. Optimisation of opaque components of the building envelope. Energy, economic and environmental issues, Building and Environment 41: 1001–1013.

Martínez-Ibernón A., Aparicio-Fernández C., Royo-Pastor R., Vivancos J.L. 2016. Temperature and humidity transient simulation and validation in a measured house without a HVAC system, Energy and Buildings 131: 54–62.

Roos A., Karlsson B. 1994. Optical and thermal characterization of multiple glazed windows with low U-values, Solar Energy, 52: 315–325

Sherman M.H. 1987. Estimation of infiltration from leakage and climate indicators. Energy and Buildings 10: 81–86.

TRANSSOLAR Energietechnik GmbH. (2009). A module of an air flow network for coupled simulation with TYPE 56 (multi-zone building of TRNSYS). User TRNflow Manual. Stuttgart, Alemania.