Design of a sustainable house including the requisites of the Spanish Regulation

Luis Abades Martínez, Erika Martínez Pérez, Laura Cristóbal Andrade, Pastora M. Bello Bugallo*

Department of Chemical Engineering and Seminar of Renewable Energy (Aula de Energías Renovables), University of Santiago de Compostela, Spain
** Corresponding author. Tel: +34 881816757, Fax: +34981528050, E-mail: pastora.bello.bugallo@usc.es*

Abstract: Green Building is a philosophy aiming to maintain a high quality of the built environment while optimizing the use of resources, both materials and energy. Related to green building, sustainable construction consists in the creation and operation of a healthy built environment giving rise to high-performance green buildings.
These building concepts have already been taken into account by the European Union (EU) that has promoted the use of alternative energies, thermal insulation and responsible consumption programs, among others. The Directive 2002/91/EC came into force to regulate energy efficiency in new buildings. Member States transposed this text to their legal systems, considering the particularities of to their territories, geography, economy and society. In Spain, the Spanish Technical Building Code (*CTE- Código Técnico de Edificación*) promotes sustainable building. Other regulations regarding energy buildings certification, energy efficiency or renewable energy promotion have already been adopted.
This work presents a house designed taking into account some aspects of the sustainable house design, and compares it with a reference house. These aspects include the thermal requirements of the house following a simplified option established in the basic documents HE1 (Limitation of the energetic demand) and HE4 (Minimal solar contribution for heating domestic water) of the Spanish Building Technical Code

Keywords: *Sustainable construction, Thermal insulation, CTE, Energetic demand*

1. Introduction

Almost 30% of world's energy is used in housing (40% in Europe [1]) and the 50% of this energy is used in building for the weather conditioning systems [2] (heating or cooling), and lighting. Energy consumption for housing and services was 371.4 Mtoe (millions tons of oil equivalent) in 2000 [3], which is higher than for other sectors such as transport and industry.

Due to the figures of the increased CO_2 emission levels associated with this energy production, the EU has decided to harden the standards for building and their heating and hot water systems in order to reduce the amount of energy consumed [4]. Simultaneously to these new standards a new philosophy, Green Building, has emerged, with the aim of maintaining high quality of the built environment while optimizing the use of resources, both materials and energy. On the topic of green building, sustainable construction is about the creation and operation of a healthy built environment based on ecological principles and resource efficiency [5], giving rise to "high-performance green buildings". The main characteristics of these constructions are [6]: significantly less energy, materials and water consumption; healthy living and working atmosphere; and great improvements on the quality of the built environment. The control of natural lighting and ventilation as well as better insulation also help, not only reducing energy consumption but also increasing safety and security, promoting welfare and helping assisted living [7].

Housing energy use has been a concern for the European institutions, which have promoted the application of alternative energies, thermal insulation and responsible energy usage campaigns by developing a specific legal framework. Accordingly, the European building sector has provided itself with the Directive 2002/91/EC [1], which aims to control the energy efficiency in buildings, and the Directive 2006/32/EC [8], whose purpose is to enhance the cost-effective improvement of energy end-use efficiency. Several Member States have transposed these European directives to their own legal systems, trying to adapt them to their geographic, economic and social characteristics. That is the case of Spain, where the European directives have been adapted to the national legal framework by Royal Decree 1027/2007 [9], on Thermal Installations in Buildings (*RITE –Reglamento de Instalaciones Térmicas en los Edificios*), that controls heating systems and hot sanitary water in buildings in order to reach a good comfort level and an optimal energy use, and Royal Decree 1675/2008 [10], the Spanish Technical Building Code (*CTE – Código Técnico de Edificación*), that came into force to promote sustainable building.

This work presents the energy-related considerations taken into account during the design of a sustainable house intended to be energy efficient, including the requisites of the Spanish Building Technical Code (*CTE*). The energy parameters of this house will be compared with a reference house designed under conventional criteria.

2. Methodology

This work compares energetic parameters of two houses intended to be in the same location and with the same space distribution, but that have been designed under different building criteria. The first one is the “reference house” (RH), designed using conventional building criteria. The second house, the “sustainable” one, is the so called “insulated house” (IH), which applies the *CTE*, specifically the simplified option established in the basic document HE1 about *Limitation of the energetic demand*, as well as the guidelines set by the basic document HE4 about *Minimal solar contribution for heating domestic water*. This calculation option is based on the indirect control of the building energetic demand, limited by the characteristic parameters of the internal and external walls (thermal envelope). Accordingly, the methodology includes the following steps:

- Definition of the climatic area.
- Classification of the spaces of the building.
- Thermal isolation.
- Analysis of the thermal requirements of the house.
- Air infiltrations.
- Underfloor heating system.
- Boiler selection.
- Solar collectors for hot water production.
- Materials selection.

Finally the energetic parameters proposed in the *CTE* are compared for both houses, showing the benefits of the “sustainable” design.

3. Characterization of the houses

3.1. Definition of the climatic area

The proposed houses will be located in Lugo (Galicia), in the northwest of Spain. Lugo is classified by the *CTE* climate severity criteria as a D1 region, which means that the Winter Climate Severity (WSC) is high (D in a scale from A to E), and the Summer Climate Severity (SCS) is low (1 in a scale from 1 to 4).

3.2. Classification of the spaces of the building

Both the RH and the IH are intended to be located in a North-South oriented rectangular parcel with a 20% slope, which is not affected by any shadowing element in its environment. The houses will have four levels: the underground level, where the garage is located; the ground floor, with the kitchen, living-room, one bedroom and the access to the house; the first level, which is the dormitories area; and finally the top floor, which is really a terrace where the collectors and control devices will be located.

3.3. Thermal isolation

In the RH the external walls will be conformed by external plasterwork (25 mm), a double brick layer and an internal layer of plasterwork (25mm). The 290 mm width structure will be protected by both internal and external painting.

In the IH external walls are conformed by external plasterwork of 25 mm, a layer of light thermo-clay of 190 mm followed by another concrete layer. Insulation is provided by two layers: 20 mm of expanded polystyrene and an air chamber of 20 mm. Finally it is an internal brick layer covered by plasterwork. The 370 mm width structured is protected both internally and externally by painting. The formation of thermal bridges has also been considered, owing to the energy losses they involve.

3.4. Thermal requirements

The study of the thermal requirements will be based in the indirect control of heat demand as required in the *CTE*. This estimation method uses the characteristic parameters of the thermal envelop or U-values. Thermal transmittance U ($W/m^2{\cdot}K$) is defined by Eq. (1), where R_T is the total thermal resistance for the constructive component.

In the case of associations of materials in homogeneous thermal layers, total resistance could be calculated by Eq. (2), where R_1, R_2 are the thermal resistances of the n layer conforming the wall, and R_{si}, R_{se} are the superficial thermal resistances corresponding to the internal and external air, considering the wall situation in the building and the direction of the heat flow.

The last consideration is the calculation of the thermal resistance in a thermal homogeneous layer provided by Eq. (3), where e is the thickness of the layer (m) and k the thermal conductivity of the material ($W/m{\cdot}K$).

Global transmission coefficient for the building also has been calculated, Eq. (4), in order to collect the previous parameters in a more representative figure, where sub-index w, s, r and h refer to walls, soil, roofing and holes respectively, and A is the area of each layer.

$$U = \frac{1}{R_T} \quad (1)$$

$$R_T = R_{si} + R_1 + R_2 + \dots + R_n + R_{se} \quad (2)$$

$$R = \frac{e}{k} \quad (3)$$

$$U_G = \frac{(U_W \cdot A_W) + (U_S \cdot A_S) + (U_R \cdot A_R) + (U_H \cdot A_H)}{A_W + A_S + A_R + A_H} \quad (4)$$

3.5. Air infiltrations

Air renewal by infiltrations is an important parameter affecting both the hygienic conditions and the overall heating demand, as the incoming air must be conditioned. Air renewal takes place by infiltration through carpentries and by ventilation. Infiltration can be quantified by permeability, defined by Eq. (5), where C_v is the window coefficient (specific for the woodwork, dimensionless), ΔP is the pressure difference between indoors and outdoors (mm H_2O) and S_h is the total surface of the hollow (m^2). Ventilation is mainly controlled by the inhabitants except for the kitchen and the bathrooms, both having independent mechanical ventilation systems.

$$\rho = C_v \cdot \Delta p \cdot S_h \qquad (5)$$

3.6. Heating System Design

Aiming to determine the heating requirements of the building, specific studies of every single space of the house have been carried out, considering heat losses by transmission and air renewal in each one of the spaces. Heating system, by underfloor heating, was designed considering that indoor temperature is set at 20 ºC and that the system must face up minimal temperatures of -5 °C during winter time.

Heating system design is based on the results obtained for the heat losses. Design parameters considered were water flow and water temperature, which can be calculated by Eq. (6) since Q is the known total heat losses, where T_{ma} is the average water temperature (ºC), T_{obj} is the objective temperature set in 20 ºC and U is the global thermal transmission coefficient, considering heat flow will occur by conduction and convection.

Water flow for heating system is calculated by Eq. (7), where C is the mass flow rate (kg/h), Cp is specific heat of the water (kJ/kg·K) and ΔT is the difference between inlet and outlet water in the system, considered to be 10 ºC.

$$Q = U \cdot \left(T_{ma} - T_{obj}\right) \qquad (6) \qquad\qquad Q = C \cdot C_p \cdot \Delta T \qquad (7)$$

3.7. Boiler Selection

The installation of efficient boilers is promoted by the *RITE* to reduce pollutant emissions and improve energy savings. In this case study a condensation boiler has been selected because it can be adapted to the thermal needs of an underfloor heating, providing hot water at 60 ºC. Moreover a 30% energy saving and a 70% NO_x y CO_2 emissions reduction is expected.

3.8. Sanitary Hot Water Installation

The sustainable design also includes a solar thermal installation able to provide a great percentage of the total hot water demand for the house, exceeding the 30 percent required by the *CTE* for this kind of houses.

Initial data needed for the design and calculation of this installation, will be the use conditions of the Sanitary Hot Water (SHW) and weather specifications of local region. Energetic demand is determined by the monthly hot water consumption rate and the temperature set for the SHW, while climatic specifications are obtained by the global radiation in the collecting field, average day temperature and network water temperature.

Calculation method was the f-chart method. This method allows the assessment of the solar device coverage as well as its average performance in an amount of time.

3.9. Fuel consumption

It is nearly impossible to estimate fuel consumption in heating systems, since it heavily depends in variable conditions such as weather, user needs or control systems. However, it is possible to perform yearly estimations by using a method that can be found in UNE 100002 [11] regulations. It can be done by using Eq. (8), where G stands for HDD (ºC), P for consumed power (kcal/h), U is the use coefficient (dimensionless), I is the intermittence coefficient (dimensionless), η is the boiler performance, LCP is the Lower Calorific Power of the natural gas (kcal/m^{3}N), (T_i-T_e) relates to the difference of temperatures between the inside and outside of the house. For this case, T_i is set as 20 ºC and T_e as 2 ºC.

$$C = \frac{G \cdot 24 \cdot P \cdot I \cdot U}{\eta \cdot LCP \cdot (T_i - T_e)} \qquad (8)$$

4. Results

This section presents the results obtained after applying the aforementioned equations to the proposed case studies. The limit values set by the *CTE* for the proper design of the IH are: 20 ºC indoors temperature, 55% indoors relative humidity, 273 $m^3/h\cdot m^2$ woodwork permeability for a D1 zone, and 30% of annual minimal solar contribution for fossil energy source at 60 ºC.

According to Eq. (1-3) and following the layer schema described in the previous section, calculations of the U-values have been done. The results obtained are presented in Tables 1 and 2, where sub-index W, S, R and H refer to walls, soil, roofing and holes respectively. Next sub-index are: IH: Insulated House, LV: Limit value set by the *CTE*, RH: Reference House.

Table 1. U-values comparison for the insulated house and the reference house with the limit values established by CTE.

Orientation	U_{WIH} (W/m^2 K)	U_{WLV} (W/m^2 K)	U_{WRH} (W/m^2 K)	U_{HIH} (W/m^2 K)	U_{HLV} (W/m^2 K)	U_{HRH} (W/m^2 K)
N	0.46	0.66	1.57	2.23	2.50	3.8
E	0.49	0.66	1.69	2.10	2.90	3.68
O	0.48	0.66	1.57	2.18	2.90	3.25
S	0.52	0.66	1.63	2.18	3.50	3.68

Table 2. U-values comparison between the insulated house and the reference one with the limit values established by CTE.

U_{SIH} (W/m^2 K)	U_{SLV} (W/m^2 K)	U_{SRH} (W/m^2 K)	U_{RIH} (W/m^2 K)	U_{RLV} (W/m^2 K)	U_{RRH} (W/m^2 K)
0.33	0.49	1.70	0.33	0.38	0.62

Fig. 1 represents the comparison of the U-values for the considered elements (walls, soil, roofing and holes) for the IH, LV and RH. The U-values selected for walls and holes correspond to the north orientation.

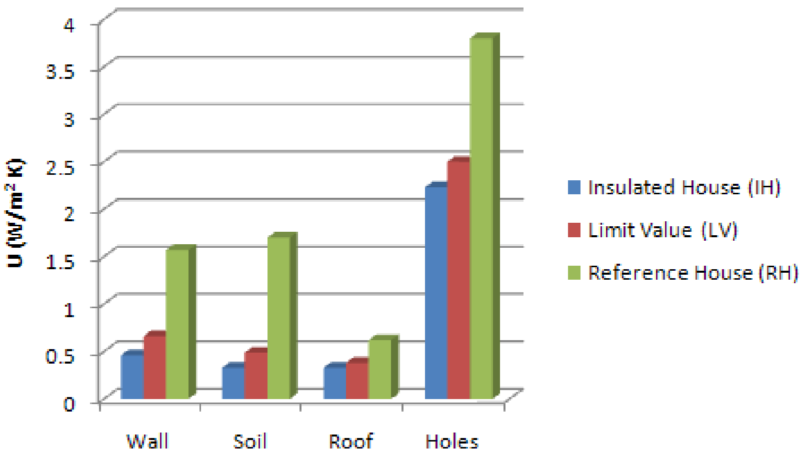

Fig. 1. Comparison of U-values for the walls, soil, roof and holes in the IH and the RH regarding the limit values set by the CTE.

The air renewal parameters have resulted in the data displayed in Table 3, whereas Table 4 shows the results obtained after calculating the thermal requirements for both houses. Heating system design results are included in Table 5.

Table 3. Calculations to establish the total ventilation of the buildings.

Air renewal	Reference house	Insulated house
Permeability (m^3/h)	1263,14	248,14
Mechanical Ventilation (m^3/h)	114,55	114,55
Natural ventilation (m^3/h)	97,52	97,52
TOTAL (m^3/h)	1475,21	460,21

Table 4. Thermal Requirements in the building.

	Reference House	Insulated House
Total Area (m^2)	204.91	204.91
Heat losses by transmission (W)	16,528.30	6,378.13
Heat losses by air renewal (W)	11,956.38	5,640.01
Total Heat losses (W)	28,484.68	12,018.14

Table 5. Resulting heating system parameters.

	Water temperature (ºC)	Flow rate (l/s)
Insulated House	30	0,267
Reference House	47	0,658

To calculate the SHW installation it is necessary to consider some additional factors. Hot water consumption is estimated to be 30 liters/inhabitant each day at 60 ºC. Concerning weather conditions, Lugo is located 465 meters high and in 43 º latitude. The house is placed in a flat ground with little vegetation, and atmosphere is considered clean since the house location is within a rural zone.

A Buderus Logasol SKN 3.0 is chosen as the collector. This device has an open surface of 2.25 m^2 and its efficiency slope parameters are η_0=0.775, k_1=3.599 W/m^2·K and k_2=0.008 W/m^2·K^2. Table 6 contains the results obtained for an installation comprising 3 collectors and an accumulator of 400 liters.

Table 6. Results for SHW installation calculations.

Parameter	Value
Total thermal load (MJ)	13,658.0
Net energy collected (MJ)	10,413.1
Yearly Solar Coverage (%)	76.2
Yearly Average Performance (%)	33.7

Finally, fuel consumption and CO_2 emissions were calculated to complete the analysis and comparison between both houses (Table 7).

Table 7. Fuel consumption estimation for each house and related economic costs and CO_2 emissions.

	Fuel consumption (m^3/year)	Economic costs (€/year)	CO_2 emissions (ton/year)
Insulated house	1,759	1372.20	4.00
Reference house	4,169	3252.17	9.60

5. Discussion

The comparison of both houses, RH and IH, leads to some obvious conclusions. First of all, when selecting building materials the priority has been their insulating capacity, but keeping also in mind their environmental impact and life-cycle. In fact, thermo-clay is a recyclable ceramic material with really good chemical, mechanical, thermal and acoustic properties. Expanded polystyrene is an excellent insulating material, also recyclable, and the woodwork employed is made of PVC with thermal break, with a Climalit glass of 9 mm thickness. Besides, aiming to reduce thermal gains through the windows in summer, eaves have been installed to reduce solar radiation penetration in the south faced windows and the balcony. This measure is expected to cause a 50% reduction in radiation depth for these rooms.

Concerning U-values for the thermal envelope (Tables 1 and 2), it is observed that the insulating measures used in the design of the IH make it possible to comply with the *CTE* requirements. More detailed analysis of these data reveals that U-values for the IH are about 24% lower than the limit values whereas the results for the RH are much higher in each part of the thermal envelope. For the global transmission coefficient, results are U_{GIH}=0.51 W/m^2·K and U_{GRH}=1.61 W/m^2·K. Coefficient value for the RH is about 3 times the insulated coefficient value.

The results obtained for air renewal show that, in the IH, the total air renovation is roughly the same as the volume of the house, as demanded in the *CTE* (Table 3). Concerning the RH, air renovation is 3 times the volume of the house, which is excessive and will lead to extra fuel consumption.

According to results shown in Table 4 for thermal requirements, it is possible to assess that total heat losses for the IH are only the third part of the RH. This fact leads to the reduction of the fuel oil consumption, and therefore the reduction of CO_2 emissions to the atmosphere.

Regarding the heating system design, results show that for the same heating system, water temperature and flow rate are lower in a well insulated house (Table 5). Consequently both the energy needed for water heating and electrical energy to drive the pump will be lower.
The fulfilling of the conditions of the *CTE* is proved, since the SHW installation provides a solar contribution of 76% of the total energetic needs in the house with a yearly average performance above 30%, as requested in the *CTE* (Table 6).

Finally, the application of constructive solutions in the IH project means saving around 5.5 ton CO_2/year emissions (Table 7).

Therefore it can be concluded that taking into account energy efficiency criteria during building design can result in important savings in energy consumptions, as heat losses are highly reduced (even three times shorter in the IH than in the RH) and hot water requirements are much lower than in a typical house. The application of the *CTE* not only limits the energy demand in buildings on the basis of U-values for thermal envelope, but it also avoids surface condensations inside the enclosure or the woodwork, limits energy loses by air infiltrations and minimizes solar contribution for sanitary hot water.

References

[1] European Union, Directive 2002/91/EC on the energy performance of buildings, Official Journal of the European Communities L1, 2002, pp. 65- 71.

[2] D. M. Roodman, N. Lenssen, A building revolution: how ecology and health concerns are transforming construction, Worldwatch Institute, 124, 1995.

[3] Eurostat, Annual Report, 2000, available at http://ec.europa.eu/index_en.htm.

[4] European Union, Combating climate change - The EU leads the way, European Communities, 2007, available at http://ec.europa.eu/publications.

[5] C. J. Kibert, Principles of sustainable construction, Proceedings of 1st International Conference on Sustainable Construction, 1994, pp. 1-9.

[6] C. J. Kibert, The next generation of sustainable construction, Building Research & Information 35 (6), 2007, pp. 595-601.

[7] European Union, Summaries of the European Legislation. http://europa.eu/legislation_summaries/index_en.htm

[8] European Union, Directive 2006/32/EC on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, Official Journal of the European Communities L114, 2006, pp. 64-85.

[9] Spanish Government, Royal Decree 1027/2007 approving the Regulation of Thermal Installations in Buildings, Official Gazette 207, 2007, pp. 35931- 35984.

[10] Spanish Government, Royal Decree 1675/2008 amending the Royal Decree 1371/2007, which approves the document DB-HR Protection against noise of the Technical Building Code and amending the Royal Decree 314/2006 approving the Technical Building Code, Official Gazette 252, 2008, pp. 41655- 41656.

[11] Spanish Association for Standardization and Certification (*Asociación Española de Normalización y Certificación – AENOR*), http:// www.aenor.es