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# Using the building energy rating software for mathematically modelling operation costs in a simulated home

María J. Ruá[1], Natividad Guadalajara[2]

*[1]Department of Mechanical Engineering and Construction, Universitat Jaume I,*
*Avenida de Vicent Sos y Baynat sn, C.P. 12071, Castellón de la Plana, Spain*

*[2]Department of Economy and Social Sciences, Universitat Politècnica de València,*
*Camino de Vera sn, Edificio 7J, 3ª Planta. C.P. 46022, Valencia, Spain*

Corresponding author: María J. Ruá, email: rua@uji.es

# Using the energy rating software for mathematical modelling of the costs of construction and energy in a simulated home

The building industry is becoming very important in sustainable development. The recently developed policies in European Union directives on energy and their transposition to Spanish regulations make the Energy Performance Certification process for buildings mandatory. Two software tools have been developed in Spain to carry out this process: Lider and Calener. These software tools have been used in this paper to simulate energy performance in new semidetached houses after taking into account the thermal envelope of the building and facilities. This has been done in different climatic zones in Spain and for all the possible energy ratings.

Based on the energy rating and construction cost variables, it has been possible to obtain mathematical models that explain the behaviour of global costs of buildings based on energy ratings and climatic zones. Depreciation costs, maintenance costs, energy consumption and $CO_2$ emissions during the service life of a house have also been modelled.

Keywords: Cost model, regression, construction law, energy performance in buildings, private cost, social cost

## 1 Introduction

The greenhouse gases (GHG) emitted during energy production has become a major problem and many countries are working on different policies to reduce them [18]. It is known that buildings are responsible for the consumption of between 20% and 40% of the energy produced in developed countries [21]. However at the same time, building is one of the sectors in which GHG emissions can be reduced most cheaply, so it is considered an excellent opportunity to reduce such emissions [17].

In this context, some measures are being taken in the European Union (EU). Directives 2002/91/EC and 2010/31/EU (Energy Performance of Buildings Directive, EPBD) on the energy efficiency of buildings aim to ensure better energy efficiency in buildings. This implies that lower energy consumption is needed and, therefore, less GHG emissions. These directives establish basic principles and requirements, and Member States are responsible for their transposition into national regulations.

In Spain, the implementation of the EPBD was partly achieved with the introduction of the Technical Building Code (Código Técnico de la Edificación, or CTE in Spanish), as promulgated by Royal Decree (RD) 314/2006, of 19 October and also through the Thermal Installation in Buildings Regulation (RITE), RD1027/2007, of 20 July. Royal Decree 47/2007, of 19 January, provides details of the basic procedures to certify energy performance in new buildings. Initially, certification was not compulsory for private dwelling, but only for public buildings. Afterwards, legislation was completed by RD 235/2013, which includes existing buildings. Moreover with this legislation, the energy performance label has become mandatory for dwellings that are either for sale or for rent as of June 2013.

These regulations are the basis of the development of various simulation software tools that verify compliance with the minimum requirements of these regulations (CTE and RITE), which can estimate the energy performance of buildings by calculating the expected value of the primary energy consumed and its translation into kilograms of $CO_2$. Simulation makes the implementation of measures that intend to improve energy efficiency in buildings during the design phase possible, which can be most useful for architects and designers.

In this paper, a case study has been used to estimate the cost linked to a building's energy performance. A terraced family house has been selected as a representative sample. By using the simulation software Lider and Calener, we simulated the energy performance of the house for different climatic zones in Spain, and we obtained different energy performances by changing constructive solutions and facilities. By doing this, we obtained different configurations: climatic zone-energy performance. In each configuration, the following costs, which can be classified as private costs, were considered: investment cost when the dwelling is built, maintenance cost, and the energy consumption cost that must be paid by the user during the building's service life. Furthermore, the simulation software enable the $CO_2$ emissions to be obtained, which could be starting point to quantify the social cost in relation to the use of the building. With these data, mathematical models were constructed using linear regression. These models helped determine the construction cost, the operation cost and the $CO_2$ emissions in the simulated house.

This paper is arranged as follows: Section 2 briefly explains the energy performance procedure in Spain; Section 3 describes the case study and the constructive changes made to obtain the different energy performances and $CO_2$ emissions by means of the simulation software systems; Section 4 deals with the estimates made to calculate private costs and shows the emissions obtained through simulation; Section 5 presents the developed models for both private costs and $CO_2$ emissions; finally, Section 6 offers the conclusions reached from the obtained results.

## 2 Software tools for energy certification in Spain

The procedures for rating the energy performance of residential buildings in Spain are detailed in the document [1]. New buildings are assigned an energy rate on a scale of five values indicated by letters A to G, with A being the best rating. According to (Royal Decree) RD 47/2007, new buildings are assigned a label that indicates their energy rate which corresponds to this scale. These ratings are based on annual emission values in kg of $CO_2$ and on the annual primary energy consumption in kWh depending on: type of building; thermal envelope; climatic zone; the municipality in which the building is located; heating and cooling facilities; minimum solar contribution to the domestic hot water (DHW) required in the municipality. New buildings that meet the CTE must have an E grade or above, while lower F and G grades can be used in existing buildings.

Two official government software tools were used for calculations: on the one hand, Lider v.01, for compliance with minimum energy demand limits; on the other hand, Calener-VYP, v1.0 (version for residential buildings) to obtain the energy performance (energy efficiency label as specified in RD 47/2007) and the $CO_2$ emissions of the simulated dwelling [9-11]. The output of Calener is CO2 emissions and the energy consumption of a simulated building. Depending on the kg of CO2/m2/year, a rate is given. Every rate is defined by a numerical range, which also depends on the climatic zone. By developing mathematical models, we can quantify these parameters and see the variation when comparing different rates.

These software programmes were developed by the Thermotechnics Group of the School of Industrial Engineers at the University of Seville for the Institute for Energy Diversification and Saving (IDAE) of the Spanish Ministry of Industry, Tourism and Trade. Software Lider v1.0 and Calener-VYP v.01 are the Spanish versions of DOE-2.2. This is the most commonly used simulation engine for this purpose that offers a detailed description of the building. These programmes simulate the average building conditions, although it has to be considered that real performance depends on the actual occupants' use. In some countries, comparisons between the theoretical and actual results have been made regarding energy efficiency [8, 20]. In Spain, [13] proved that the consumption predictions calculated and based on simulation with Calener were similar to the real consumption levels for two buildings in the Polytechnic University of Valencia (East Spain).

Firstly, the thermal envelope of the building has to be described in detail when using Lider. This is composed of all the enclosures that limit living spaces with the external environment (air, ground or another building) and all the internal partitions that limit habitable spaces with no habitable spaces which, in turn, come into contact with the external environment.

In the energy ratings process, climate is a key factor as external conditions will be highly influential to calculate a building's energy requirements. This means that determining the climatic zone where the building is located is necessary. Some countries with a homogeneous climate do not require this classification. However in countries with climate variations, climate zones have to be determined. This is the case of Italy (climatic zones A, B, C, D, E and F) and France (H1a, H1b, H1c, H2a, H2b, H2c, H2d, H) or Spain. According to the CTE, there are 12 climatic zones in Spain. The system used to name the climatic zone is composed of a letter and a number indicating the severity of winters and summers, respectively. For example, a letter A indicates mild winters, while a letter E denotes the coldest winters. A number 1 indicates cool summers, while a number 4 suggests the hottest summers. Consequently, the progression from climatic zone A to E indicates a greater need for heating, whereas the progression from climatic zone 1 to 4 suggests a more acute need for cooling. A representative city has been selected for each climatic zone. The empty cells in Table 1 represent non-existent combinations. This is the specific nomenclature for Spain, so the heating and the cooling degree days and the average temperatures for January and August are also included to illustrate the climatic conditions for the selected cities:

## 3. Methodology and information sources

The analysed building is a terraced family house with a garage and utility installations in the basement, and a ground and first floor for residential use. The ground floor surface area covers 68.10 $m^2$ and is 58.88 $m^2$ on the first floor. It is located on the end of a terraced row, points 25°N, and is considered to be the worst of the 13 houses forming the development from an energy efficiency point of view. This is because the longer façade is exposed and also presents a less favourable orientation.

Initially, the constructive solutions of the building are the minimum requirements to fulfil the energy demands that the CTE specifies for new buildings, with an E rating. Afterwards, some solutions are applied to reduce emissions, which have to do with the thermal envelope of the house. For example, increasing the thickness of the insulation layers in the envelope, changing the window materials (aluminium, wood), the thickness of window panes, and so on, which are used to improve energy performance. Facilities, including heating, air-conditioning and DHW, also contribute to this improvement.

In this case, electricity is always used for cooling facilities, whereas heating and DHW facilities are simulated with different kinds of boilers and energy sources, such as electricity, natural gas or biomass, by taking into account the minimum input of solar energy for DHW according to the CTE. This is consistent with the Final SECH-SPAHOUSEC Project Report [7]: the types of energy used mainly in Spain are natural gas (24.9%), electricity (35.1%) and renewable energies (17.7%, mainly biomass in its different forms, accounting for 94.2% of renewable energies).

The combination of materials, constructive solutions and facilities allows various configurations to be obtained for each energy performance and climatic zone. There are 60 possible combinations resulting from the five energy performance grades (A-E) and the 12 climatic zones. However, only 50 combinations are obtained because performance E was not reached at times after implementing the commercial format of constructive solutions, and because it was not possible to achieve performance B on occasion with the materials and facilities used in this study.

Having obtained the configurations, costs are calculated. Private costs are the sum of three costs, these being:

### *3.1 Depreciation cost*

The investment cost is calculated by drawing up an estimation or budget with the chosen constructive solutions for the 50 climatic zone-energy performance configurations. We used Excel sheets to estimate the budget for per combination. Every budget is composed of 21 budget items covering different works: groundwork, drainage, foundations, structure, walls and partitions, roof, carpentry, iron work, glass works, flooring and ceiling work, plumbing, electrics, solar energy, heating and air conditioning, ventilation, painting, quality control, protection against fire, health and safety, kitchen and waste treatment. The sum of the costs of all the budget items comprises the total building cost.

The depreciation cost is calculated from the investment cost, for which it is necessary to estimate the service life of the different elements making up the building. This allows the cost per year to be estimated. The service life for the whole building is considered to be 100 years, as confirmed in various sources [6, 14-15, 24] and in valuation regulations (Order ECO 805/2003 of 27 March on Valuation of Property and Financial Regulations, Article 19.). This matches the observed ages of buildings from the Spanish building stock according to Spanish National Statistics Institute (INE) data. The service life for facilities and materials is shorter than that of the building considered as a whole. Fifteen years is the time adopted for facilities, while 25 years is used for constructive elements such as tiles, kitchen utilities, and so forth. A linear depreciation is to be considered with a null residual value.

Prices are obtained from the Cype S.A. database for construction prices. It allows them to be adapted to the Spanish province and to the total built-up area being considered.

### *3.2 Maintenance cost*

This is calculated in accordance with different sources: some authors [4-5, 16, 19, 22] and prestigious institutions in the building sector, such as the Catalonian Technological Institute. Another source is the *Libro del Edificio* (Building Log Book), which is a document drafted when a building is constructed and it contains, several building management aspects during its operational phase.

From all the collected data, 45 maintenance routines, each with a different periodicity, have been considered. Every maintenance budget is divided into 19 budget items, which cover different works, these being: drainage, walls and floor in contact with soil, façades, carpentry, garage door, blinds, glass work, lattice walls, audiovisual equipment, DHW and heating, air conditioning system, solar energy, electrics, plumbing, natural gas, ventilation system, roofing, flooring and paintwork, and protection against fire.

### *3.3 Energy consumption cost*

The three types of energy considered for heating and hot water are electricity, natural gas, and biomass. Only electricity is used for cooling. The electricity and gas rates were obtained from the Spanish Official State Gazette (BOE 31.12.09) and VAT was excluded. If official rates were absent, biomass prices including delivery were obtained as the market price averages from various suppliers.

### *3.4 $CO_2$ emissions*

$CO_2$ emissions are obtained by simulating every configuration with Calener VYP.

## 4 Results

### 4.1 *Private cost and $CO_2$ emissions*

Table 2 shows the private costs obtained, in €/m$^2$/year, for the simulated configurations. Generally for private costs, the higher the energy performance level is, the more the private cost. However, there are some cases where this does not happen; i.e., in zones C1, C2, D1, D2 and E1, where rate C is slightly more costly than rate B in terms of private costs, and also in climatic zone 4 if comparing rates C and A. The explanation for this has to do with the amount calculated per cost type (depreciation, maintenance and energy consumption costs); by way of example, if we consider the different costs for climatic zone C1: depreciation and maintenance costs increase slightly (from 12.50 to 12.81 €/m$^2$/year, and from 12.26 to 12.28 €/m$^2$/year, respectively). However, the energy consumption cost decreases from 3.08 to 2.32 €/m$^2$/year. The sum is slightly higher in C than in B because the decrease in energy terms is more marked than the rest of the considered costs.

Usually the better the energy performance, the higher the investment and maintenance costs, and the lower the energy costs [3]. From Table 1 it can be inferred that, in the simulated configurations, better energy performance results in higher private costs in each zone. Therefore, it is concluded that according to the current level of construction costs, maintenance and energy prices, the optimal energy rating from a private perspective is always the lowest (that is a D or an E). Thus, a reduction in $CO_2$ emissions may be a means to motivate home users to improve energy ratings.

Table 3 shows the $CO_2$ emissions obtained by using Calener VYP for every configuration~~:~~ by the grey cells, while the white cells show the limit values that are considered to achieve a rate.

From the values obtained for the 50 configurations, some mathematical models for private costs and $CO_2$ emissions have been developed in accordance with the energy performance and climatic zone explanatory variables.

## 4.2 *Mathematical models*

The mathematical models to express private costs components and $CO_2$ emissions were developed by a multiple regression analysis using ordinary least squares in which the dependent variable (V) is expressed as follows:

$$V = a + \sum_1^n b_i X_i + \varepsilon = a + b_1 X_1 + b_2 X_2 + \ldots\ldots + bn\, Xn + \varepsilon \qquad (1)$$

where:
a : constant term
bi : coefficients of the explanatory variables
Xi : explanatory variables
ε : random disturbance term

The dependent and explanatory variables used in the analysis are:

Dependent variables:

- $C_{DEP}$: Annual depreciation cost per square meter (€/$m^2$/year)
- $C_{MAN}$: Annual maintenance cost per square meter (€/$m^2$/year)
- $C_{EN}$: Annual energy consumption cost per square meter (€/$m^2$/year)
- $KCO_2$: Annual $CO_2$ emissions per square meter (kg $CO_2$/$m^2$/year)

Explanatory variables:

- Energy performance defined by five dummy variables (A, B, C, D and E), one per energy rating
- Climatic zone, quantified by the average annual temperature (T). Other variables were considered for climatic zone, such as level of humidity, altitude and latitude, but the result not significant. Therefore, these variables were ruled out.

Table 4 shows the costs and $CO_2$ emissions models. According to the models, the average temperature significantly explains depreciation, maintenance, energy consumption and $CO_2$ emissions. Energy performance D is not significant, meaning that there are no differences between E and D. This is logical to assume if we consider that an E energy rate is reached only in five climatic zones (B4, C1, C2, D1 and D2) and, moreover, when the kilograms of $CO_2$ obtained for these E rates almost reach the upper limit for energy rating D.

Model 1 represents the depreciation cost. It indicates that the depreciation cost will increase by 1.34, 2.40 and 3.26 €/m$^2$/year for energy performances C, B and A, respectively. According to Section 3.1, there are many budget items to calculate the initial investment cost. These results are logical to assume when considering that the better energy performance is, the higher the initial investment. By way of example, climatic zone A3 and energy ratings A and C are considered. The budget in the A-rated house is more costly when comparing budget items. For example, rate C includes aluminium frames in windows and a gas boiler to cover hot domestic water (DHW) and heating demands. Moreover, rate A contains wooden frames in windows, a biomass boiler and pellets storage to meet DHW and heating requirements.

Model 2 shows maintenance costs and reveals that there are no differences for the various energy ratings. This seems logical because maintenance work differs only slightly between the ratings as many operations are the same; i.e., painting, fire prevention, audiovisual, or ventilation facilities, etc. The initial cost of 16.93 €/m$^2$/year lowers by 0.381 €/m$^2$/year for each degree of increased temperature in the climatic zone. According to the $R^2$ of Model 2, temperature explains up to 49% of maintenance cost variability. This could be consistent with the constructive solutions implemented since usually colder climatic zones require constructive solutions that need more expensive maintenance tasks. For example, a cold climatic zone may require wooden frames with thicker glass panes than a mild one.

Model 3 represents the cost of energy. It indicates that temperature and energy ratings C, B and A explain 79% of the value obtained. In this case, and as expected, the cost of energy consumption decreases in warmer areas. For this reason, the temperature variable has a negative coefficient.

Finally, Model 4 shows $CO_2$ emissions in kg. All the variables together explain 86.6% of the variability of emissions and have negative coefficients. This means that warmer areas have lower emissions and that these emissions decrease as the energy rating improves. The way the coefficients diminish among ratings C, B, and A follows a logical and expected pattern as kg of emitted $CO_2$ is the indicator that the VYP Calener v.01 programme uses to qualify buildings. The maximum emission is 61.55 kg per year for ratings D and E, which decreases at a rate of 1.862 kg for each degree of increased temperature; and is 11.96, 20.19 and 28.80 kg for ratings C, B and A, respectively. As energy performance has been defined by dummy variables (A, B, C, D and E), one per energy rating, this means that id compared to rates D or E, C-rated houses reduce $CO_2$ emissions by 11.96 kg of $CO_2$/m$^2$/year, and this reduction increases to 28.80 kg of $CO_2$/m$^2$/year for rate A.

Standardised residuals were analysed to test the linearity and homoscedasticity of the models.

## 5 Conclusions

The building industry is presented as an opportunity to achieve reduced $CO_2$ emissions per building with greater energy efficiency. Establishing climatic zones and the issuance of energy ratings can help reach this goal. Nowadays it is possible to assign a rating to a building by using some simulation software tools. Besides we can relate it to the private costs over a building's lifetime: investment costs, annual energy costs and annual maintenance costs. From the simulation obtained, we collected data for a dwelling after considering all the Spanish climatic zones and all five possible energy ratings for new buildings (A-E). Based on these data, we developed mathematical models to express the aforementioned private costs. Besides, the $CO_2$ emissions obtained through the software tools have also been modelled. In each zone, improving energy ratings implies higher initial investments, but maintenance costs remain the same. In contrast, energy costs and $CO_2$ emissions decrease as energy ratings improve.

According to this study, more energetically efficient dwellings imply higher costs for users. According to the model developed for $CO_2$ emissions, there is a clear decline in emissions as energy performance improves. From the economic or private viewpoint, a rational purchaser will buy more economic dwellings, and possibly less energy-efficient ones. However, energy savings and lower environmental pollution costs for society favour the promotion of energy-efficient dwellings.

The building's energy performance level can be considered a new variable to influence the market value or the purchase cost of building properties. In Spain, where such legislation is quite recent, there are no market values available that consider the energy performance of dwellings. Nonetheless in other countries whose legislation is more consolidated, there is still no clear evidence for this possible influence for either sales or rents. In fact, some studies done in Germany [2], Belgium and Denmark [8] and the Netherlands [20] highlight that energy efficiency does not clearly influence purchasers' decisions.

In order to promote energy efficiency of buildings, governments should encourage citizens using different market-based measures such as subsidies, tax on energy consumption or tax exemptions [23]. Even a combination of measures could be proposed. In fact, after RD 47/07 came into force, some aids became available for social housing with A, B and C energy ratings in national and regional housing programmes. Having said that, the sums offered were rather small and they have since been cut due to the economic recession.

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