ENERGY DEMAND MODEL TO SUPPORT THE DEFINITION OF SUSTAINABLE ENERGY SYSTEMS: RESIDENTIAL SECTOR

RUI XIMENES
Instituto Superior Técnico, IN+, Portugal
rui.ximenes@tecnico.ulisboa.pt

PAULO FERRÃO
Instituto Superior Técnico, IN+, Portugal
ferrao@tecnico.ulisboa.pt

ABSTRACT

A bottom-up energy demand model that reflects the use of various energy vectors to satisfy regional energy requirements is provided as a tool to promote sustainable energy planning at a regional level. The model is used to identify technology policy options that may improve energy efficiency and take full advantage of endogenous energy resources.

The model considers building geometric and thermodynamic characteristics, climatic data and technology penetration information and is calibrated with top-down information from national statistics. It is applied in a Portuguese municipality – Odemira, and a set of sixteen technology option scenarios are examined regarding energy consumption and CO_2 emissions.

The results obtained show that a demand driven model is critical to identify technology options that may contribute to simultaneously improve energy efficiency and to maximize the use of renewable and endogenous energy and therefore to increase local added value to the regional economy.

1. INTRODUCTION

The growing awareness for climate change facilitated the establishment of protocols and targets to reduce greenhouse gases emissions and, as a consequence, an increased interest in renewable energy systems implementation. National energy plans translate the ambition of the Nations, as they are primarily engaged in energy supply models. Energy efficiency although regarded as a priority, as it is associated with reducing energy consumption, is more difficult to implement, as the calculation of its potential impact requires a very detailed understanding of how and when energy is used at the consumer level. This is also critical in order to promote a better integration of endogenous energy resources as well renewable energies.

To promote a detailed understanding on how and when energy is used at the household consumer level constitutes the motivation for this paper, which develops a detailed energy demand based model for households. The work follows the principle that sustainable energy systems are always to be designed from demand to supply, allowing in first place to emphasize energy efficiency, and subsequently energy conversion technologies that satisfy the maximization of endogenous energy use and renewables, in order to promote the system sustainability and, as a consequence to maximize the added value for the region. The model developed in this paper provides a contribution to the articulation between energy demand and energy planning activities, and tests its potential for developing regional energy sustainable strategies is a case study that considers the largest Portuguese municipality.

1.1. Review of Energy Models

Various authors have addressed energy models classification. Amongst them, Beeck (1999) classified energy models in several different ways in order to identify which kinds of models are suitable to assist energy demand projections. He categorized the purpose of the model, assumptions, analytical and mathematical approach, underlying methodology, geographical and sectorial coverage, time horizon and data requirements. More recently, EEA (2008) also classified models but only in terms of thematic focus, geographical scale and analytical technique. Souza (2011) also proposes a classification based on the energy carriers considered, model focus, aggregation level, underlying methodology geographical scale, sectors considered, time horizon and time-scale of energy balance.

Amongst the different models classification suggested in the literature, the top-down vs bottom-up analytical approaches have been regularly discussed. Beeck (1999) summarizes both approaches, characterizing top-down as an economic approach and bottom-up as an engineering approach.

Swan & Ugursal (2009), focused on the modeling of energy demand in the residential sector, distinguish top-down and bottom-up as the two main modeling techniques. They conclude that top-down methods do not differentiate energy consumption by individual end-uses and estimate energy demand from aggregated data, usually easy to obtain, such has GDP, employment rates, energy prices, climate conditions, housing date and appliance ownership. The downside of these methods, besides reliance on historical data, is the incapability to identify and analyze new technological developments and therefore their impact in energy demand, which is extremely important for planning sustainable energy systems. On the other side, bottom-up approaches “focus on the energy sector exclusively, and use highly disaggregated data to describe energy end-uses and technological options in detail” (Beeck 1999).

Swan & Ugursal (2009) even distinguish two bottom-up categories: statistical and engineering. The former relies on dwelling energy consumption data from samples and on techniques to regress the relationships between end-uses and energy consumption. The later calculates energy consumption based on dwelling and end-uses properties, as well thermodynamic relations and technologies efficiency and power. The bottom-up engineering approach are the best to model new technologies however they do not incorporate economic factors, require intensive computation and do not include occupancy patterns, which affects energy use, as studied by Guerra Santin et al. (2009) and Santin (2011). On the other hand, the bottom-up statistical approach comprises macroeconomic and socioeconomic factors, as well behavior patterns.

In order to take advantages of both top-down and bottom-up models (statistical and engineering) approaches, several authors combined these methods to create hybrid models. Frei et al. (2003) merge a bottom-up activity analysis into a computable general equilibrium (CGE) top-down model to fulfill the limitations of the top-down model which lacks empirical evidence on elasticity determining technological evolution under energy policy constrains. McFarland et al. (2004) analyzed hybrid models and concluded that “it enhance the technological richness of a top-down economic model using bottom-up engineering information’’. Böhringer (1998) and Böhringer & Rutherford (2008) also combine both models and distinguish three levels of integration between models. ‘’Soft-linked’’ when the models are developed independently, a second level when the focus is in one of the models and the other is in a reduced representation, and a third level where the models are completely integrated within a single framework.

The energy demand models and its approaches are often associated to specific computational tools. Mendes et al. (2011) analyzed different tools for modelling Highly Integrated Community Energy Systems (ICES). EEA (2008) has created a modeling tools inventory, and Connolly et al. (2010) reviewed in details 37 tools that can be used to analyze the integration of renewable energy. Connolly et al. (2010) emphasize that there is not an ideal tool but rather one that is more suitable according to the decision-makers specific objectives.

This analysis shows that the literature does not provide a model capable of analyzing different energy demand scenarios with a strong incorporation of technological developments in its formulation and, at the same time, a geographical resolution adequate to municipalities. This limitations served as motivation to develop a bottom-up model that adopts an innovative approach by considering buildings geometric and thermodynamic characteristics, climatic data and technology penetration information, adequate to be integrated in energy planning models. This model is intended to be a tool to support energy technology policy options at a regional and national level.

1.2. Objectives

The objective of this paper is to develop a bottom-up engineering model to characterize energy demand, calibrated with top-down information, which can be integrated with energy planning models. The model developed includes a significant number of parameters (about 40), which are typically available in statistical data at a national level and that can be customized for regional analysis. This model provides a detailed analysis on energy consumption due to technological shifts, building properties changes and equipment’s penetration. It does also account for the different energy vectors, supporting the design of energy plans with emphasis in energy efficiency measures to maximize the use of endogenous resources and renewables.

1.3. Organization of the paper

In the next section we describe the mathematical formulation of the model, based on existing methods proposed by several authors. The model consists of six separate parts, each one corresponding to one domestic sector end-use. The model is a bottom-up engineering model, calibrated with top-down information. It has municipality level spatial disaggregation and an annual temporal resolution. In the end of this section, we present a case study of a Portuguese municipality - Odemira, and we explain the data used, how we calibrated the model and a short reflection on the limitations of the case study. Finally section 3 analyzes several possible energy efficiency measures applicable to our case study. This section includes a sensitivity analysis to two parameters: space heating degree-days reference temperature and cooling reference temperature, and an energy and emissions savings analysis for a set of sustainable energy strategies implementation scenarios. The conclusions summarize the key findings and contributions of the paper.

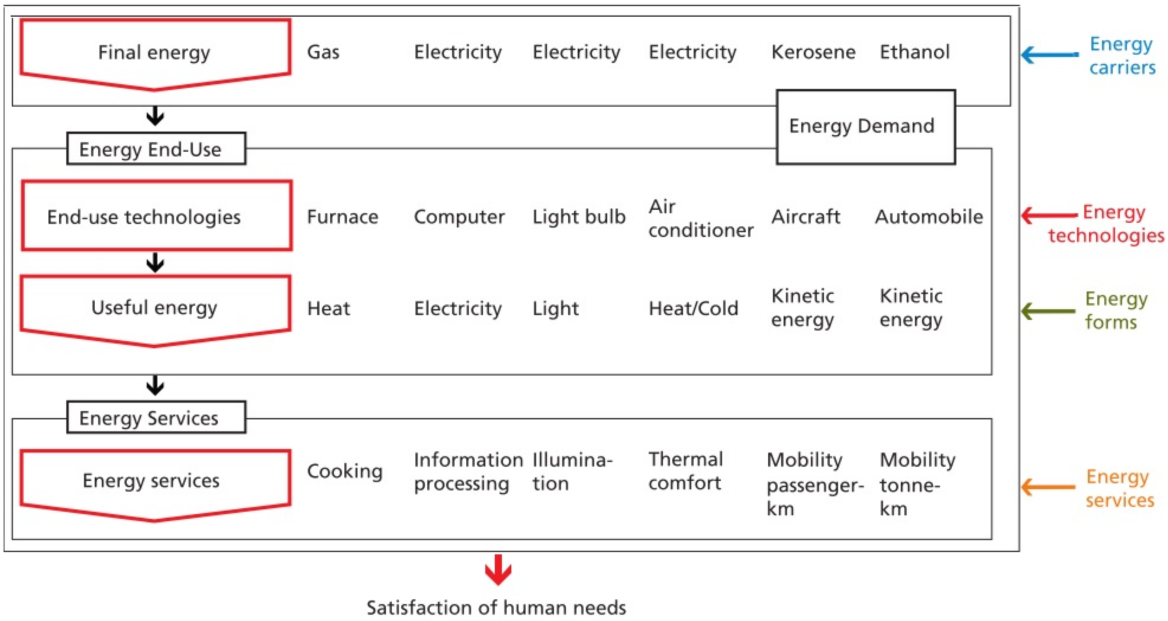
2. ENERGY DEMAND MODEL DEVELOPMENT

2.1. Demand driven energy systems

The domestic energy demand model is formulated in six separate divisions, each corresponding to a domestic end-use. The transformation of final energy to useful energy to than satisfy a specific energy service and therefore human needs, is made through different technologies, which constitute alternatives to different energy planning scenarios. This constitutes the main advantage in building a model that parameterizes technologies, and the different energy vectors that they may convert. *Figure 1*, adapted from the IAASA-Global Energy Assessment (Johansson et al. 2012), outlines this concepts.

The model is a bottom-up model that first calculates the useful energy needs for each end-use, followed by final energy needs calculations function of the different technologies and equipment shares.

Figure 1: Schematic diagram of the energy system with some illustrative examples.



Adapted from (Johansson et al. 2012, p.43)

2.2. End-uses formulation

A major contribution of the model developed consists on the articulation of a large number of methods to characterize the different energy services relevant at a household level, such as heating, cooling, lighting, cooking and the use of electric appliances. The next sections provide the details of the sub-models developed.

2.2.1. Space heating

The energy demand to satisfy the heating necessities of households has been addressed by several ways and many authors, such as Liao & Chang (2002); Yao & Steemers (2005); Shen (2006); Sardianou (2008); Caldera et al. (2008); Isaac & van Vuuren (2009); Guerra Santin et al. (2009); Meier & Rehdanz (2010); Santin (2011) and Daioglou et al. (2012). It can be concluded that the final energy demand depends essentially on four main elements: geographical location of the house, building characteristics, household behavior and heating technology. The geographical location is directly related with the ambient temperature throughout the year as well with solar irradiation. Building characteristics comprise building dimensions, orientation and constructive materials of the house, essential to calculate heat losses and gains from the outside. Behavior is also very important, it influences the desired room temperature, areas of the house which are heated or presence of people at home during the day is also determinant in the space heating energy necessities. Last but not least, the heating technology used to fulfill the space heating requirements is important since it defines the energy vector that is converted into useful energy- the heated air, and, due to its conversion efficiency, different technologies may require dissimilar amounts of final energy for the same useful heating energy demand.

The formulation used to quantify the space heating final energy demand is represented in equation (1), and is a combination of the highly detailed model from the Portuguese energy regulation of residential buildings (REH) (Emprego 2013), which is well synthetized in ITeCons (2013), and a simpler formulation already adopted by several authors like Durmayaz et al. (2000) and Stavropoulos (2013).

$$Q_{SH}=(Q_{t\ sh}+Q_{v\ sh}-Q_{g\ sh}).f_{u\ sh}/\eta_{Tsh} \tag{1}$$

In equation (1), $Q_{t\ sh}$[kWh] are the heat losses by transmission, $Q_{v\ sh}$[kWh] are the heat losses by ventilation and infiltration, $Q_{g\ sh}$[kWh] are the heat gains, η_{Tsh}[-] is the space heating technology efficiency and $f_{u\ sh}$[-] is a calibration factor which accounts for less measurable parameters such as the households behavioral ones. The heat losses are obtained through equations (2),(3) and(4).

$$Q_{t\ sh}=0{,}024.HDD.H_t \tag{2}$$

$$H_t=U_{wall}.A_{wall}+U_{window}.A_{window}+U_{floor}.A_{floor}+U_{ceilling}.A_{ceilling} \tag{3}$$

$$Q_{v\ sh}=0{,}024.HDD.\frac{C_p.\rho}{3600}.ACH.V \tag{4}$$

HDD is the heating degree days, H_t[W/ºC] the global heat transfer coefficient, U's[W/(m^2.ºC)] and A's[m^2] the overall heat transfer coefficients and areas respectively. C_p[KJ/(Kg.K)] and ρ[Kg/m^3] are the specific heat and density of air respectively. ACH[h^{-1}] is the air changes per hour and V[m^3] the building volume.

The heat gains are given by equation (5) where Q_{int} and Q_{sol}[kWh] represent the internal and solar irradiation heat gains respectively, calculated by equations (6) and(7), and η_{gu}[-] is the gains utilization factor and it is a function of ratio between gains and losses, and a parameter 'a' which accounts for the building thermal mass. This last parameter is calculated according to ITeCons (2013).

$$Q_{g\ sh}=\eta_{gu}.(Q_{int}+Q_{sol\ sh}) \tag{5}$$

$$Q_{int}=0{,}72.q_{int}.M_{sh}.AFA \tag{6}$$

$$Q_{sol\ sh}=G_{south}.\sum_{w}[X_w.F_w.A_w].M_{sh} \tag{7}$$

q_{int}[W/m^2] is the internal gains, M_{sh} [months] the number of months of the heating season, AFA[m^2] the average floor area of the building, G_{south}[kWh/(m^2.month)] the average monthly solar radiation through the heating season on a vertical south orientated surface, A_w[m^2] is the window 'w' area, X_w[-] is the window 'w' orientation coefficient and

F_w[-] is a coefficient that reflects obstruction elements and properties of window ‘w’. The latter two coefficients won’t be addressed in detail since it would require an exhaustive description which is available in ITeCons (2013).

2.2.2. Space cooling

Similarly to space heating, space cooling energy depends on the geographical location of the house, building characteristics, household behavior and cooling technology. Equation (8) stands for the space cooling energy demand of a building.

$$Q_{SC}=(1-\eta_{gu})Q_{g\,sc}.f_{u\,sc}/\eta_{Tsc} \tag{8}$$

$f_{u\,sc}$ and η_{Tsc} [-] are respectively a calibration factor and the space cooling technology efficiency. η_{gu}[-] is the gains utilization factor as already described in section 2.2.1. . $Q_{g\,sc}$[kWh] represents the heat gains and are thus represented by the sum of solar and internal gains. However, the solar gains for the cooling season are now expressed by equation (9). This equation takes into account the solar gains during the cooling season from both windows and exterior walls.

$$Q_{sol\,sc}=\sum_{w}\left[G_{solar,w}.F_w.A_w\right]+\sum_{i}\left[G_{solar,i}.F_i.\,\alpha_i.U_i.A_i.R_i\right] \tag{9}$$

$G_{solar,w}$ and $G_{solar,i}$[kWh/m^2] are the average cooling season solar radiation for window ‘w’ and wall ‘i’ orientations. Notice that G_{solar} is the equivalent of the product $G_{south}.X_w.M_{sh}$ in equation (7) of space heating. F_w and F_i[-] are factors that accounts for obstruction elements and properties of window ‘w’ and wall ‘i’. α_i[-] Is the surface solar radiation absorption coefficient of element ‘i’, .U_i [W/(m^2.ºC)] and A_i [m^2] are the overall heat transfer coefficient and area of surface element ‘i’. R_i[(m^2.ºC)/W] is the outer surface thermal resistance of element ‘i’.

Finally, in order to obtain η_{gu}, the heat exchange by transmission, ventilation and infiltration must be taken into account through equations (10) and (11).

$$Q_{t\,sc}=0{,}72.M_{sc}.(\theta_{ref}-\theta_{ext}).H_t \tag{10}$$

$$Q_{v\,sc}=0{,}72.M_{sc}.(\theta_{ref}-\theta_{ext}).\frac{C_p.\rho}{3600}.ACH.V \tag{11}$$

θ_{ref} and θ_{ext}[ºC] are internal cooling temperature and external average temperature.

2.2.3. Water heating

The water heating energy demand includes all the energy used to heat water for domestic use except water heating of specific appliances like washing machines and dish washers which have their own water heating system. The energy required for domestic water heating purposes in a household is given by equation (12) as Q_{WH}[kWh].

$$Q_{WH}=V_{w}.f_{e\ wh}\frac{C_{p\ w}.\rho_{w}}{3600}.\Delta T.d.n./\eta_{Twh} \tag{12}$$

V_w[l/(person.day)] is the daily water volume per person, $f_{e\ wh}$[-] is a factor that accounts for hydraulic efficient systems, $C_{p\ w}$[KJ/(Kg.K)] and ρ_w[Kg/(l)] are the specific heat and density of water respectively, ΔT[K] the water temperature increase by the heating system, d[days] the annual number of days of used water, ‘n’ the number of people in the household and $\eta_{Twh}$the water heating technology efficiency.

2.2.4. Lighting

The artificial lighting necessities for a household depend mostly on the amount of natural light available and on the activities being undertaken by the occupants(Stokes et al. 2004; Richardson et al. 2009). As referred by Souza (2011), the lighting requirements would ideally be measured in lumens. This also presents the advantage of being able to analyze the impact of using different light bulbs with different efficiencies, measured in watt per lumen, on the electric energy consumption. The main challenge in estimating the lighting demand is to accurately define and simulate the occupants’ activities since they have different durations and lumens necessities. Therefore, a similar model to Daioglou et al. (2012); Souza (2011); Shen (2006) and Dopazo et al. (2012) was formulated.

$$Q_{L}=0{,}001.AFA.\sum_{Tl}\left[S_{Tl}./\eta_{Tl}\right].L.T \tag{13}$$

In equation (13), Q_L[kWh] is the annual energy demand for lighting for a single household, AFA[m^2/hh] is the average floor area per household, S_{Tl}[-] and η_{Tl}[Lm/W] are the share of lighting technology ‘Tl’ and its efficiency correspondingly, L[Lm/m^2] is the lighting requirement and T[hours/year] is the equivalent amount of lighting hours required per year. The latter two combined can be interpreted as the average lighting needs in lumen times hours per square meter. As mentioned by Daioglou et al. (2012), ‘’for electrified households, data suggests that lighting demand (at frozen efficiency) forms a linear relationship with floor space’’, which therefore legitimates de use of the product L.T, calculated from historical consumption data, to estimate future energy consumptions for lighting in function of floor area and light bulbs technologies’ shares and its efficiencies.

2.2.5. *Cooking*

Adopting the same definition as Instituto Nacional de Estatística (2011), cooking comprises all the energy demand from the usual equipment used for meal time preparation as well large and minor appliances with exclusive or common usage in the kitchen, often called ‘white appliances’. The total energy demand for cooking, Q_C[kWh], is consequently the sum of all the appliances consumptions, as given by equation (14).

$$Q_C = \sum Q_{C,a} \qquad (14)$$

The energy demand for each type of appliance in a certain group of households depends on the equipment power rating, usage and penetration in households. The power rating and usage can be combined in the form of the appliance specific energy consumption if this parameter is otherwise available. A more detailed formulation for an equipment consumption may as well be used in case it is as well available. Therefore, like Dopazo et al. (2012) and Souza (2011) have used, the cooking demand for a certain appliance ‘a’ is modelled as equation (15).

$$Q_{C,a} = hh.P_a.Sc_a \qquad (15)$$

Where, for an appliance ‘a’, $Q_{C,a}$[kWh] is the annual energy demand, hh[households] the total number of households, P_a[units/household] the appliance penetration and Sc_a[kWh/year] the specific energy consumption.

2.2.6. *Electronic appliances*

The general formulation to calculate electronic appliances energy consumption is identical to the one we adopt for cooking appliances and it is expressed by equations (18) and (19).

$$Q_{EA} = \sum Q_{EA,a} \qquad (16)$$

$$Q_{EA,a} = hh.P_a.Sc_a \qquad (17)$$

Q_{EA}[kWh] is the total energy demand for electronic appliances, $Q_{EA,a}$[kWh] is the demand for a certain appliance ‘a’, hh[households],P_a[units/household] and Sc_a[kWh/year] are the total number of households, appliance penetration and specific energy consumption respectively.

2.3. Case Study: Odemira

Odemira is a Portuguese municipality located in the south west coast of Portugal and was used as initial case study to test, calibrate and validate our model.

With approximately 1720 km^2 of area, it is the largest Portuguese municipality and has one of the lowest population densities in the country with a rough total of 26 thousand inhabitants distributed by 13 parishes. With an average exterior summer temperature above 22ºC and heating degree-days below 1300 HDD (18ºC base Temperature), it is characterized by hot summers and cool winters, receiving an REH climatic zone classification of Summer-3 and Winter-1 (from 1 to 3).

2.3.1. Available Data

Ideally the data used in our model would be organized in typologies, having as many indicators has variables present in the mathematical formulation. To illustrate this concept, one typology could have the number of isolated buildings built during the 90s, with 2 floors, with floor area interval between 40 and 50m^2, average window orientation to west, and heat pump as heating technology. This example would be a building typology with 5 correlated parameters, and an even more specified typology could be used if available. We managed to collect data with the number of buildings per age group and with the number of buildings per number of floors, and the correspondence between buildings age and building floor numbers was assumed in our model.

Our model is calibrated for the national data and whenever available we customize it with regional data. For example, in terms of buildings characteristics and demographic aspects we managed to obtain a satisfying level of spatial resolution, but we have used data for appliances penetrations and technologies from national statistics surveys. In order to understand the relevance of the key assumptions adopted, a sensitivity analysis was performed, as detailed in section **3.**

Table 1: Data, source and desegregation level

Data Source	Data	Desegregation level
B.P.I.E. (2010)	U values per building age group ACH	National
I.N.E. & B.G.R.I. (2011)	Number of isolated buildings Number of semi-detached buildings Number of townhouses buildings Buildings per number of floors Buildings per age group Dwellings per floor area group Number of residents Number of households Households per size Households without younger than 65 years old members Households without unemployed members	Subsections

Instituto Nacional de Estatística (2011)	Energy vectors consumption per end-use	NUTS I
	End-uses technologies share	
	Appliances penetration	
	Average Heated area per household	
	Average Cooled Area per household	
Quercus (2008); Quercus (2011)	Percentage of windows per orientation category	Climatic region
	Appliances penetration	
ITeCons (2013)	Climatic data	NUTS III
	Space heating, cooling and Hot Water technologies efficiencies	
Limited (2015)	Heating degree days	NUTS III
Sousa et al. (2013)	Glazing area percentage per building age group	National
ISR-UC (2008)	Appliances average consumption	Europe
Almeida & Fonseca (2006)	Appliances average consumption	National

Table 1 summarizes the type of data collected from each source and its level of spatial desegregation. Most building characteristics and population data is from the 2011 Portuguese Census (I.N.E. & B.G.R.I. 2011) and it is available in 4 spatial desegregation levels: municipality, parishes, sections and subsections. Information about the family was as well collected from the Portuguese Census. Climatic data was obtained from D.R. n.º 234, 3.º Suplemento (2013) and Limited (2015) and it was available by NUTS III. Technologies share, appliances penetration and energy vectors consumption distribution were assumed identical to the Portuguese mainland ones.

The emission factors used in section **3.** are from Comissão Europeia (2012) with the exception of electricity which we used the 2014 average emission factor from EDP (2009).

2.3.2. Model validation

The model was validated with data of energy consumption for each energy vector, at municipal level, as provided by DGEG. The results obtained are very satisfactory as the model could represent the regional energy demand for electricity within an overestimation of about 20%. This is explained by the fact that energy demand was modeled based on the permanent residence statistics which overestimates the real population that permanently lives in the region.

The key parameters used were an heating degree days base temperature of 15,5ºC which is in line with other studies for Lisbon (Stavropoulos 2013), or Turkey (Sarak & Satman 2003). The cooling reference temperature adopted was 26,7ºC, in comparison with the 25ºC referenced in ITeCons (2013), as there is less adoption of cooling techniques in this municipality.

Water heating was calculated with the daily volume of heated water per person. For the case study, we used a value of 36,5liters. For lighting, we used equation (13) to first calculate the artificial lighting hours required, T[hours/year], assuming $L=80Lm/m^2$ for lighting requirement (Shen 2006), adopting lighting technologies efficiencies from Souza (2011) and using DGEG data for mainland electric energy consumption just as well for lighting technologies penetration(available per technology per power intervals). Since in DGEG there was not a penetration per power interval for LEDs technology, we assumed a LED power equal to 1W based on Quercus (2011) as well a technology efficiency identical to the CFL bulbs, 60lm/W (Souza 2011). Subsequently we obtained T=3,7hours which is a reasonable value when compared with 4 hours assumed by Shen (2006) and Dopazo et al. (2012).

As explained in section 2.2.5. , our Cooking model includes energy used to cook and appliances usually found in the kitchen, the commonly called ‘white appliances’. The electric energy consumed by this appliances was calculated based on their penetration (DGEG) and specific consumption (REMODEC.). The energy used for preparing food was subsequently calculated in order to match the energy consumption by energy vector in DGEG.

For electronic appliances, a similar approach was taken. We use the appliances with available penetration data (DGEG) and specific consumption (REMODEC), and we assume as ‘other appliances’ the deficit in electronic appliances electric energy consumption, once more, to match the electronic appliances energy consumption (DGEG).

3. ANALYSIS OF ENERGY EFFICIENCY MEASURES

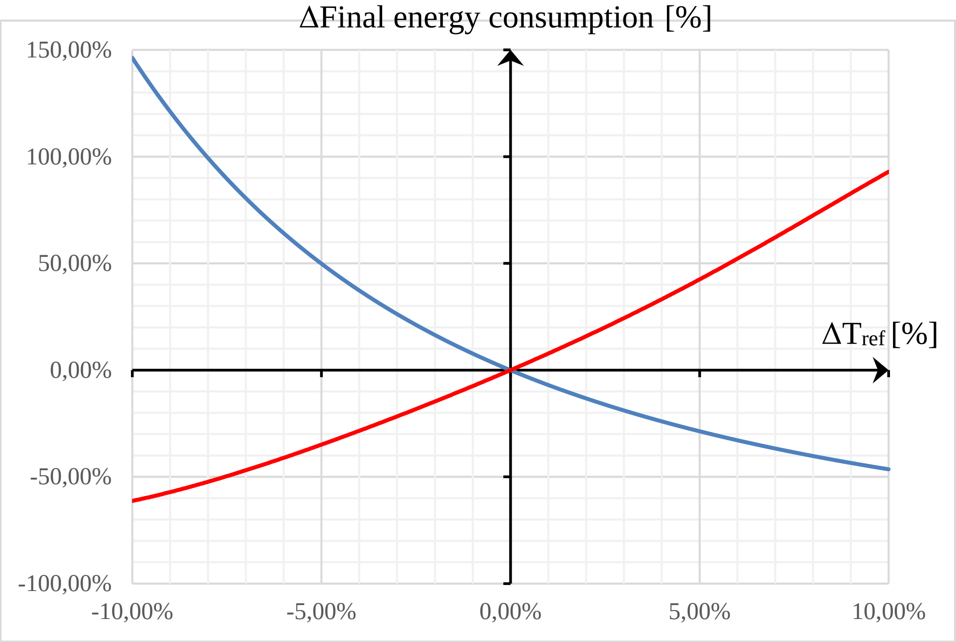
3.1. Sensibility analysis

The sensibility analysis of the model parameters is essential to understand their influence on energy consumption and subsequently their environmental and economic impact. In a certain way, this analysis may be used as a guide line for assessing which parameters should be taken into consideration while making energy efficiency plans.

For instance, a sensibility analyzes can be used to assess the priority that could be given to improve a certain type of equipment in households that may be related to the buildings physical properties like glazing area percentage, floor heat transfer coefficient or even outside walls color. Or can be made to more subjective parameters that depend on households’ behavior, like the reference temperature from which occupants turn on the heating. The later type of analysis is essential in order to understand the possible impacts of, for example, an awareness campaign to the population regarding this matter.

As an example, we analyze the relevance of heating degree-days base temperature and cooling reference temperature sensibility analysis. In *Figure 2* the change in final energy consumption in Odemira is plotted as a function of a variation of +/-10% of heating degree days base temperature (in red) and cooling reference temperature (in blue). Notice that the energy consumption scale is ten times the one for parameters change.

Figure 2: Energy consumption sensibility to HDD and Cooling reference temperatures.



This shows that a 10% increase in heating temperature, therefore from 15.5ºC to 17.1ºC results in a 90% increase in energy consumption, while an identical drop in reference temperature decreases the energy consumption by 60%.

For the space cooling reference temperature, a 10% increase, from 26.7 to 29.4 represents a 46% saving in final energy consumption, whereas the identical decrease represents a 146% in energy consumption.

From this analysis the strong influence of a slight increase or decrease of the reference temperature for heating and cooling is clearly highlighted.

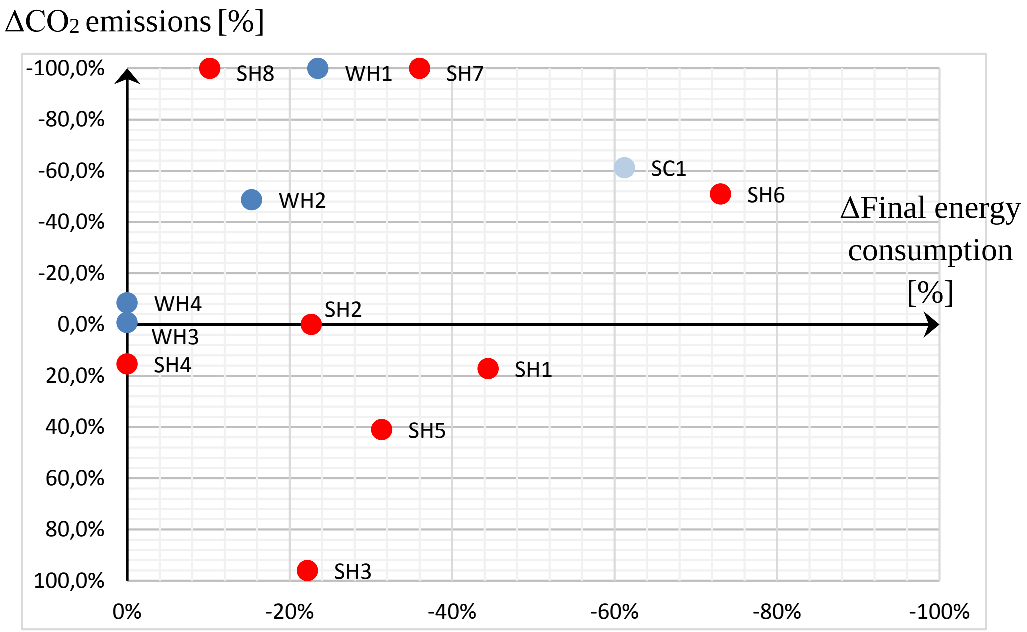
3.2. Sustainable Energy Strategies Scenarios

In this section we analyze different possible scenarios that can be taken regarding equipment and technologies choices to satisfy users' end-uses energy services. In this paper we focus on the energy and CO_2 emissions dependence on the previously mentioned choices, discarding any economic breakdown of the measures applied. Nevertheless the latter is as well an imperative factor to have in consideration in full energy efficiency plans.

3.2.1. Heating and cooling technologies

The impact in CO_2 emissions and final energy consumption are represented in *Figure 3*, which comprises all used energy vectors, according to the thirteen possible scenarios that correspond to eight technologies changes in space heating (SH), four in water heating (WH) and one in space cooling (SC).

Figure 3: Final Energy and CO_2 emissions impact from different SH, WH and SC technologies scenarios in Odemira.



The analysis of *Figure 3*, shows that the scenarios summarized in *Table 2*, show that we may obtain distinct performances in terms of energy consumption and GHG emissions, by adopting technological solutions with a high range of contributions for energy efficiency (from 0% to 80%) to which correspond reductions or even increased GHG emissions. The scenarios which increase the share of biomass fueled heating technologies are the least CO_2 emitters. Scenarios that adopt the increase of heat pump technology penetration are the ones with the major final energy consumption reduction. Other scenarios may became relevant under other perspectives: for instance, if a certain energy vectors like natural gas has a much lower price, technologies that use this vector may be a far more interesting alternative then more environmental friendly options. Similarly, if a certain energy vector has a stronger endogenous presence, this may be seen as a preferable option by the municipality decision makers.

Table 2: SH, WH and SC technologies scenarios in Odemira

	Scenario description
SH1	Conversion from fireplaces and heating stoves to heat pumps
SH2	Adaptation of heating recovery systems to open fireplaces
SH3	Conversion from fireplaces and heating stoves to natural gas boilers
SH4	Conversion of all boilers to natural gas fueled ones
SH5	Using electric radiators instead of fireplaces or heating stoves.
SH6	Substituting all technologies by heat pumps
SH7	Substituting all technologies by solar heating system
SH8	Substituting all technologies by heating stoves and fireplaces with heat recovery systems

WH1	Substituting all technologies by heat pumps
SC1	Substituting all technologies by solar water heating system
SC2	Substituting all technologies by electric water heaters, except solar water heating systems
SC3	Conversion of all boilers and water heaters to natural gas fueled ones, except solar water heating systems
SC4	Conversion of all boilers and water heaters to natural gas fueled ones, except solar water heating systems and biomass fueled ones

3.2.2. Lightbulbs

Regarding the lighting service, we consider a hypothetical scenario where all incandescent and halogen bulbs are replaced LED bulbs. In *Figure 4*, which represents the present electric energy consumption and lighting service share by technology for lighting, it is distinct the influence that light bulbs efficiency has on energy consumption. Incandescent bulbs consume the largest part of the electric share, 63.2%, although being only responsible for 21.8% of the lighting needs.

Figure 4: Energy consumption (left) and lighting service share (right) by technology.

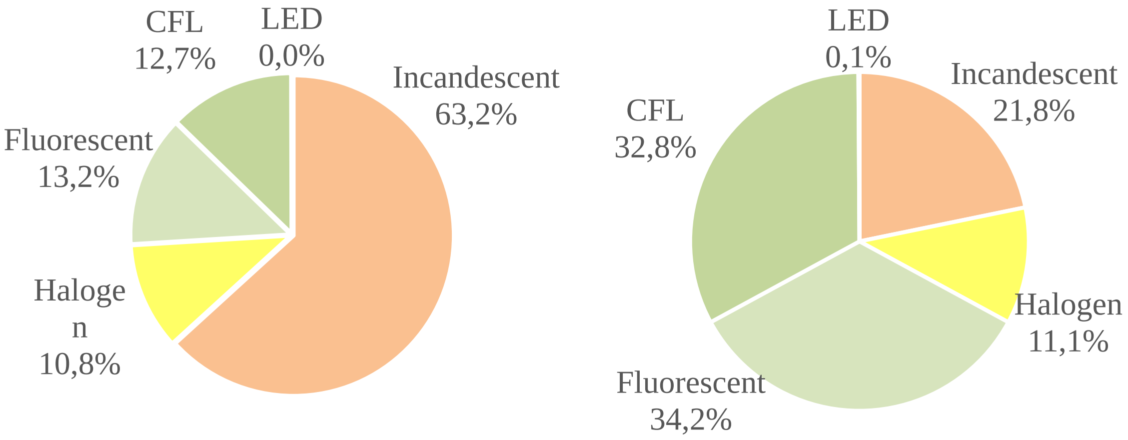
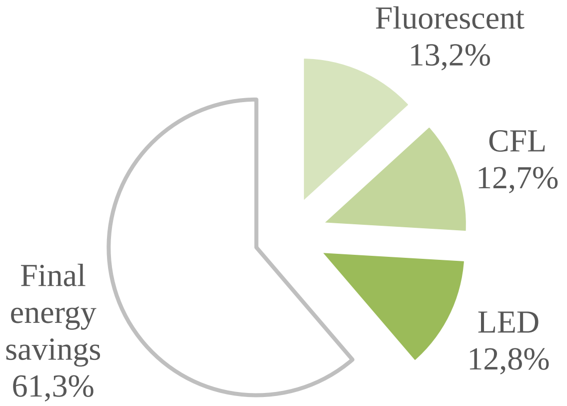


Figure 5 represents the share of energy consumption from the proposed scenario. The substitution of the incandescent and halogen bulbs by LEDs represents a 61.3% final energy savings, revealing LEDs enormous energy saving potential.

Figure 5: Scenario for lighting in Odemira.



3.2.3. Cooking

A scenario in which all refrigerators, freezers, washing machines drying machines and dishwashers, with EU efficiency label lower than ‘B’ are replaced by equivalent appliances of efficiency ‘A+++’ was analyzed. The replacement of less efficient appliances affects 44.5% of the total white appliances lot, 14800 for Odemira, resulting in 11.8% final energy savings for the cooking end-use, and 12% less CO_2 emissions, and is thus a relevant measure.

4. CONCLUSION

In this paper we developed a bottom-up engineering model to characterize domestic energy demand, calibrated with top-down information, mostly available in statistical data and national surveys. The model adopts an innovative approach by considering building geometric and thermodynamic characteristics, climatic data and technology penetration information, adequate to be integrated in energy planning models at a regional level. The significant amount of parameters and the end-uses model formulation, allowed for a detailed analysis of the residential energy services and its influence on alternative energy vectors use as a function of technological shifts, building rehabilitation and equipment’s modernization.

The results obtained show that a demand driven model is critical to identify technology options that may contribute to simultaneously improve energy efficiency and to maximize the use of renewable and endogenous energy and therefore to increase local added value to the regional economy.

5. REFERENCES

Almeida, A. De & Fonseca, P., 2006. Residential monitoring to decrease energy use and carbon emissions in Europe. *International Energy …*, pp.1–14. Available at: http://www.isr.uc.pt/~remodece/news/Paper_DeAlmeida.pdf.

B.P.I.E., 2010. COUNTRY FACTSHEETS. Available at: http://www.buildingsdata.eu/.

Beeck, N. Van, 1999. Classification of Energy Models: FEW 777. *FEW 777*.

Böhringer, C., 1998. The synthesis of bottom-up and top-down in energy policy modeling. *Energy Economics*, 20(3), pp.233–248.

Böhringer, C. & Rutherford, T.F., 2008. Combining bottom-up and top-down. *Energy Economics*, 30(2), pp.574–596.

Caldera, M., Corgnati, S.P. & Filippi, M., 2008. Energy demand for space heating through a statistical approach: application to residential buildings. *Energy and Buildings*, 40(10), pp.1972–1983.

Comissão Europeia, 2012. Regulamento (UE) Nº 601/2012 da Comissão de 21 de junho de 2012 relativo à monitorização de comunicação de informações relativas às emissões de gases com efeito de estufa nos termos da Diretiva 2003/87/CE do Parlamento Europeu e do Conselho. , Regulament(30), pp.30–104. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:181:0030:0104:EN:PDF\nhttp://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:181:0030:0104:PT:PDF.

Connolly, D. et al., 2010. A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, 87(4), pp.1059–1082. Available at: http://dx.doi.org/10.1016/j.apenergy.2009.09.026.

D.R. n.º 234, 3.º Suplemento, S.I., 2013. Despacho (extrato) n.º 15793-F/2013. , (26), pp.26–31.

Daioglou, V., van Ruijven, B.J. & van Vuuren, D.P., 2012. Model projections for household energy use in developing countries. *Energy*, 37(1), pp.601–615. Available at: http://dx.doi.org/10.1016/j.energy.2011.10.044.

Dopazo, C., Fueyo, N. & Gómez, A., 2012. *Staff Consultant ' s Report 100172-S41689 Preparation of Sector Road Maps for Central and West Asia Uzbekistan : Energy technical report A BBREVIATIONS AND ACRONYMS*,

Durmayaz, A., Kadoğlu, M. & En, Z., 2000. An application of the degree-hours method to estimate the residential heating energy requirement and fuel consumption in Istanbul. *Energy*, 25(12), pp.1245–1256.

EDP, 2009. Origens da Eletricidade. Available at: http://www.edpsu.pt/pt/origemdaenergia/Pages/OrigensdaEnergia.aspx.

EEA, 2008. *Modelling environmental change in Europe: towards a model inventory*, Available at: http://reports.eea.europa.eu/technical_report_2008_11/en.

Emprego, M.D.E.E. Do, 2013. Decreto-Lei n.º 118/2013. *Diário da República*, 159, pp.4988–5005.

Frei, C.W., Haldi, P.A. & Sarlos, G., 2003. Dynamic formulation of a top-down and bottom-up merging energy policy model. *Energy Policy*, 31(10), pp.1017–1031.

Guerra Santin, O., Itard, L. & Visscher, H., 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings*, 41(11), pp.1223–1232.

I.N.E. & B.G.R.I., 2011. Dados alfanuméricos e geográficos de 2011. Available at: http://mapas.ine.pt/download/index2011.phtml.

Instituto Nacional de Estatística, 2011. *Consumo de Energia no Sector Doméstico 2010*, Available at: http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_destaques&DESTAQUESdest_boui=107694566&DESTAQUESmodo=2.

Isaac, M. & van Vuuren, D.P., 2009. Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy*, 37(2), pp.507–521.

ISR-UC, 2008. Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe. Available at: http://remodece.isr.uc.pt/.

ITeCons, 2013. Regulamento de desempenho energético dos edifícios de habitação (REH), Sítese da regulamentação aplicável.

Johansson, T.B. et al., 2012. Summaries. In *Global Energy Assessment: Toward a Sustainable Future*. pp. 3–93. Available at: http://ebooks.cambridge.org/ref/id/CBO9780511793677.

Liao, H.C. & Chang, T.F., 2002. Space-heating and water-heating energy demands of the aged in the US. *Energy Economics*, 24(3), pp.267–284.

Limited, B.S., 2015. Degree Days.net - Custom Degree Day Data. Available at: http://www.degreedays.net/.

McFarland, J.R., Reilly, J.M. & Herzog, H.J., 2004. Representing energy technologies in top-down economic models using bottom-up information. *Energy Economics*, 26(4), pp.685–707.

Meier, H. & Rehdanz, K., 2010. Determinants of residential space heating expenditures in Great Britain. *Energy Economics*, 32(5), pp.949–959.

Mendes, G., Ioakimidis, C. & Ferrão, P., 2011. On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renewable and Sustainable Energy Reviews*, 15(9), pp.4836–4854.

Quercus, 2011. Ecofamílias ii 2009 - 2011. , p.117.

Quercus, 2008. Projecto EcoFamílias. , p.116.

Richardson, I. et al., 2009. Domestic lighting: A high-resolution energy demand model. *Energy and Buildings*, 41(7), pp.781–789.

Santin, O.G., 2011. Behavioural patterns and user profiles related to energy consumption for heating. *Energy and Buildings*, 43(10), pp.2662–2672. Available at: http://dx.doi.org/10.1016/j.enbuild.2011.06.024.

Sarak, H. & Satman, a., 2003. The degree-day method to estimate the residential heating natural gas consumption in Turkey: A case study. *Energy*, 28(9), pp.929–939.

Sardianou, E., 2008. Estimating space heating determinants: An analysis of Greek households. *Energy and Buildings*, 40(6), pp.1084–1093.

Shen, L., 2006. 2030: Energy Demand Scenarios and Biomass CHP Options for Rural Households in Beijing. *Dept. of Science, Technology and Society*, MSc Thesis(February), p.113.

Sousa, J. et al., 2013. Research on the Portuguese Building Stock and Its Impacts on Energy Consumption – An Average U-Value Approach. *Archives of Civil Engineering*, 59(4). Available at: http://www.degruyter.com/view/j/ace.2013.59.issue-4/ace-2013-0029/ace-2013-0029.xml.

Souza, G.B.H. de, 2011. *A multi-objective decision support methodology for developing national energy efficiency plans*. FEUP.

Stavropoulos, A.S., 2013. *Spatial analysis of heating and cooling energy needs in Lisbon*. TULisbon.

Stokes, M., Rylatt, M. & Lomas, K., 2004. A simple model of domestic lighting demand. *Energy and Buildings*, 36(2), pp.103–116.

Swan, L.G. & Ugursal, V.I., 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, 13(8), pp.1819–1835.

Yao, R. & Steemers, K., 2005. A method of formulating energy load profile for domestic buildings in the UK. *Energy and Buildings*, 37(6), pp.663–671.