Sustainable Housing Techno-Economic Feasibility Application

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Abstract. The high prices currently achieved in the acquisition of non-renewable energy for electricity production and the low levels of energy efficiency in the housing sector are the national situation, which leads the Portuguese government to encourage the acquisition, the installation and the use of technologies which exploit indigenous and renewable energy. This study presents an application that was developed in order to help the citizen in his decision to invest in renewable technologies in their homes. The application is able to elaborate an economic analysis based on the selected type of renewable technology, providing the user with the knowledge of benefits and the annual costs involved in the system that he selected. This tool aims at facilitating the interaction of any user with such technologies and it can be used as a helpful tool to support the decision of investment in such systems.

Keywords: Renewable energy, energy efficiency, photovoltaic, solar thermal, rainwater systems, technical and economic feasibility.

1 Introduction

Energy consumption in buildings or homes (residential sector) is closely linked to the climate of the region where these are "installed" and depends on it, representing a major share of total energy consumption in most countries [1].

The number of dwellings in the EU-25 is about 196 million of which 80% are concentrated in seven countries, Germany 18.6% Italy 13.8%, UK 13.2% France 12.7%, Spain 10.8%, Poland 6.5% and Netherlands 3.5%. The entire building stock in the EU accounts for more than 40% of final energy consumption, of which 63% relates to final energy consumption in the residential sector [2].

Nowadays, people spend about 80 to 90% of their time inside buildings. Incorrect methods of design and construction lead to low energetic efficiency buildings or dwellings [3]. This low, or weak efficiency results in a large number of social problems, including problems of health and well-being and it also causes an excess of energy consumption which is responsible for high emission of pollutant and harmful gases into the atmosphere, particularly carbon dioxide (CO_2), and entail high economic burden to their occupants [4]. It is therefore important the use of renewable technologies of energy in housing in order to reduce such costs and emissions and make it more efficient and sustainable.

With the increasing interest and knowledge regarding these technologies, we come to the need of tools capable of sizing and providing at the same time to the engineer, the designer, the user, and others economic perspectives that can help them in the decision to invest in these technologies. Such tools need to incorporate mathematical models of system components, know the possible situations that may occur in systems and rely on the weather information of various locations providing a pleasant and intuitive computing environment to the user [5].

There are currently several applications on the market able to perform simulations and provide the user with energy and economic analysis. However in the presence of the mentioned applications we've arrived at the conclusion that the majority relate to solar systems and are targeted at designers and engineers. They can be found at [5] and [6]. Concerning the systems of exploitation of rainwater, some applications have been found although they are mostly based on Excel spreadsheets. These applications can be found at [7], [8] and at the site of Sud Solutions company among others online. The computer tool developed differs substantially from these cases, as it is specifically intended for single family houses, geared to all users regardless of technical and specific knowledge they have about each technology.

This paper proposes a tool capable of performing a study of technical and economic feasibility of a sustainable housing in Portugal, being a sustainable housing the one which incorporates solar photovoltaic and solar thermal technologies – known as active technologies for decentralized energy generation - and technology of subsequent use of rainwater for non-potable uses or purposes, to provide the user interested in acquiring such systems for incorporation in his own house or any other, an initial idea of housing benefits and charges involved in these technologies and the possibility of comparing this type of housing with the standard one, i.e. without technologies using renewable energies. The application will consist of several sections, which encompass the choice of technology and data required for the proper functioning of it, the sizing of the systems and their economic analysis accounting for the economic gains and the energy savings associated with the choices made by the user as well as the periods or times of return (payback) of the investment in this type of housing.

This practice was developed based on various mathematical models proposed by different authors, who describe the individual performance of each technology, and it was developed in MatLab environment.

2 Contribution for Sustainability

The buildings or dwellings have shown as an area where environmental issues have not been taken in account at all. The reduction of energy consumption, of greenhouse gases, like CO_2, and of potable water consumption seems to be one of the key areas for achieving sustainability.

The aim is therefore to head for a higher level of energy sustainability, and to make this possible we must constantly take into account, that the way of achieving a more sustainable "community" is through a reduction of energy consumption in buildings, and consequent reducing of pollution levels associated with the use of primary energy and its global influence on the climate, and the reducing of potable water consumption in buildings, by adopting active strategies that lead to higher levels of efficiency thus making housing more sustainable. In this sense, the developed application which is set out below has the following objectives: (i) to provide any user, regardless of their knowledge in such technologies, with the possibility of sizing systems using renewable energies by means of an estimate of energy and of rain water usage over a year, (ii) to provide regardless the user's knowledge in such technologies, an initial idea of costs and benefits he could reach with the installation of such systems in his home and (iii) to offer a full economic analysis to the selected system by comparing it with a housing that does not have any of these technologies.

This application aims at supporting the decision to invest in systems using renewable energies focusing on their interconnection with the final user. Figure 1 illustrates the framework of the conceptual model of the application.

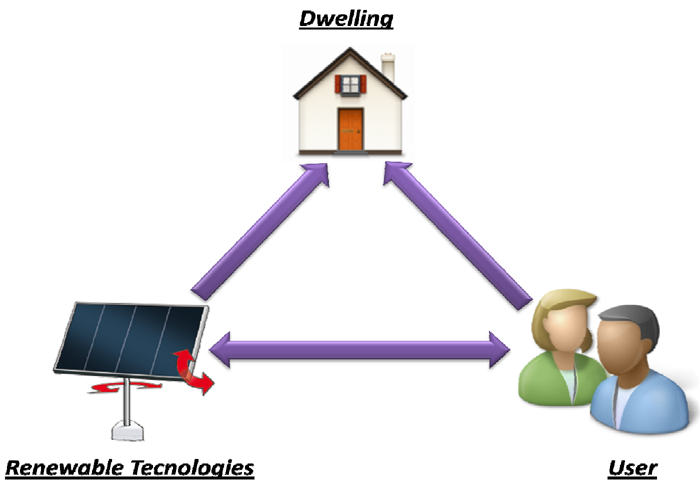

Fig. 1. Framework of the conceptual model of the application.

This approach represents the base of the structure and the way the application was conceived, always taking into account the user's needs and requirements. Through a graphical interface, the user can visualize and control the necessary variables that will bring him to an outcome that may or may not meet his expectations.

In general terms the "macro" structure of the application, illustrated in figure 2, is based on two layers. The first regards the layout of the application and the interaction with the user and the second regards selection / command and control. From the second layer the user can access to other secondary layers that correspond to each of the technologies that make up the application and subsequently to its sizing and its economic performance.

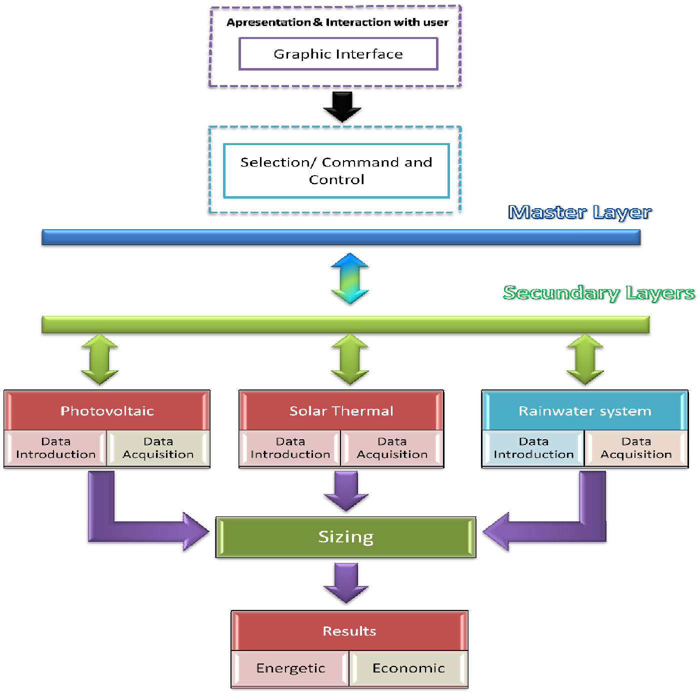

Fig. 2. Adopted structure in the application development.

3 Application Structure

The adopted structure in the development of this application aims at facilitating the interaction with the user. To accomplish this goal, it has been divided in several blocks of which the selection / command and control, the introduction the acquisition of data, illustrated in Figure 3, and the graphical interface are to be distinguished and explained below.

Selection/command and control
The selection / command and control is responsible for the orders given to the application via the graphical interface to call the layers for each technology as well as the layer for the energetic calculations. The selection / command and control can be viewed as the desktop of the application once all the others are invoked from here, with the exception of the layer related to the economic calculations that is released from the sub-layer of energy calculations and from the layers related to climatic data, released from the secondary layers of each technology.

Introduction / data acquisition
The data entry can be done in two possible ways, either by user or by reading and importing data from a database (data acquisition). There are common data which have to be imported such as solar radiation and environmental temperature for the

photovoltaic and solar thermal systems and meteorological data for the rain water system and specific data for each system. All data were collected and inserted in a database consisting of an Excel file. This database was compiled as follows: The temperature and radiation data were acquired online at the website of the European Commission through the free application Photovoltaic Geographical Information System (PVGIS) and meteorological data acquired through the Portuguese website of the Institute of water through the national information system of water resources (SNIRH). It also collected data regarding the technical components of each system (technical characteristics of pv modules, inverters, solar collectors, hot water storage tanks and storage tanks for rainwater) and their prices. These data were provided by companies currently operating in the Portuguese market.The graphical interface allows the user to select a particular component, depending on the selected system and the application performs a search of the database and imports the characteristic data for the selected component. The import of the climate data is performed in the same way taking into account the available information of the different cities and their municipalities in Portugal delivered to the user.

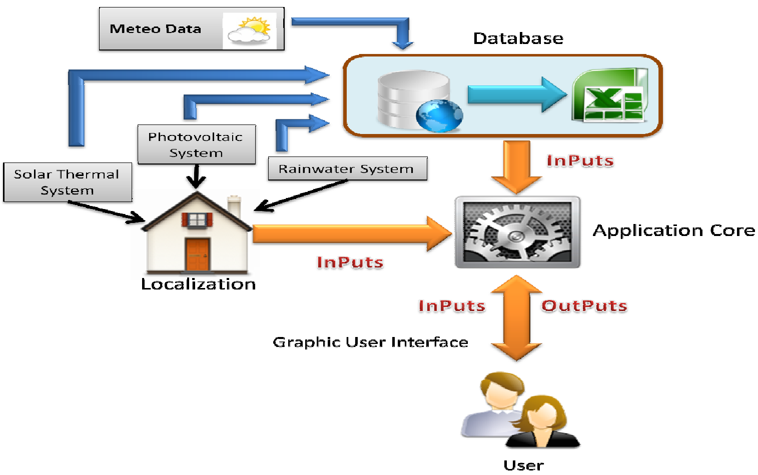

Fig. 3. Schematics of the Introduction / Command and Control

The core of the application is where you process all requests, orders and necessary responses, i.e., it acts as a kind of coordinator of services. It coordinates the delivery of services in order to provide an adequate response to a particular user's need, which may involve the selection of particular equipment, the associated calculations and the visualization of the results.

Graphic interface

The GUI shown in Figure 4 is responsible for the user interaction, helping him in the choice of several possible options for each technology and in the visualization of the data depending on his choice and the out coming results. It is equally responsible for the acquisition of necessary data which are demanded to the user. It was developed with the aim of providing the user with a clear and friendly environment.

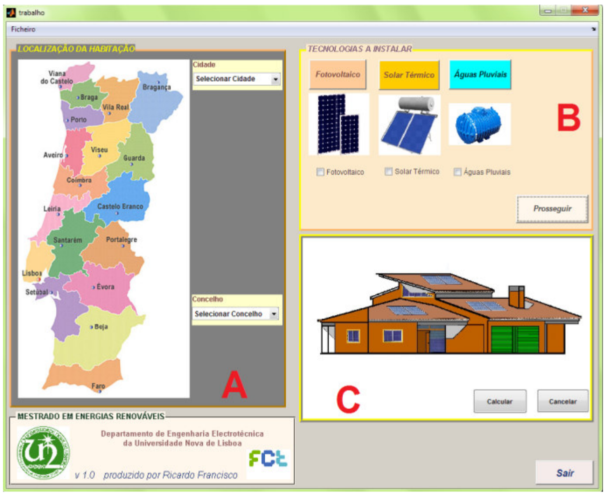

Fig. 4. Graphical interface, the main application window

In Fig. 4, the main interface is divided um several areas, each one related to a specific task. A summary of each block, identified with capital letters, is presented below:

A - represents the acquisition module of the housing location, essential for the proper acquisition of climatic data for solar technologies and of rainfall data associated with the technology of rainwater harvesting.

B - represents the module of the available renewable technologies for selection.

C - represents the module for launch of energy calculations that can be seen as the sizing module of the system previously selected by the users for integration in his home.

By means of the main window, the user selects the city and the municipality where he is and then can decide later which technologies he wants to install. You can either select one, two or all three technologies. The choice of technology leads to a new window, where the necessary data for proper sizing of each system for subsequent economic analysis will be inserted and acquired. At the end of the introduction and acquisition of necessary data, there is a simple scheme of the connection of the individual components and of the overall system for better understanding by the user of the selected system. After the introduction and acquisition of all necessary data for each system, the user is introduced through the main application window to the next step, illustrated in Figure 5, which includes the step of sizing systems and the path to the final step, the economic evaluation of the entire system selected. This window is available to the user to configure the systems, which form a basis for economic analysis and the estimation of energy produced annually, and / or potable water saved annually. It is a window of "calculation", i.e. it does not require any insertion of data; the user has only access to the button for each technology, which calculates all necessary parameters and inserts them in the respective fields for later viewing. Next you can then follow the final step, illustrated in Figure 6, where after entering some data, such as: discount rates, desired lifetime of the project, if the project will be funded or not and if it is for how long, etc., you get the total investment needed for each technology and the total investment in all the selected systems, the annual benefits discounted to the period of life chosen for the project of each technology and of the global system selected, the return period on invested capital for the global system and the economic viability of the overall indicator selected by Net Present Value (NPV).

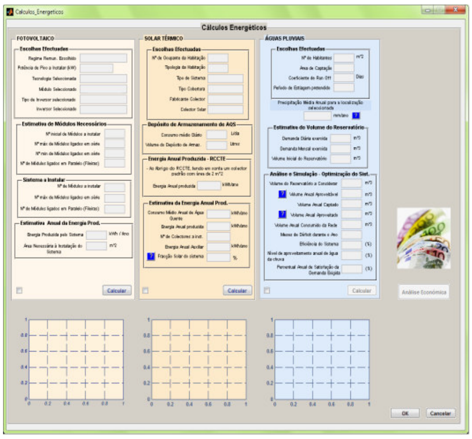

Fig. 5. System sizing

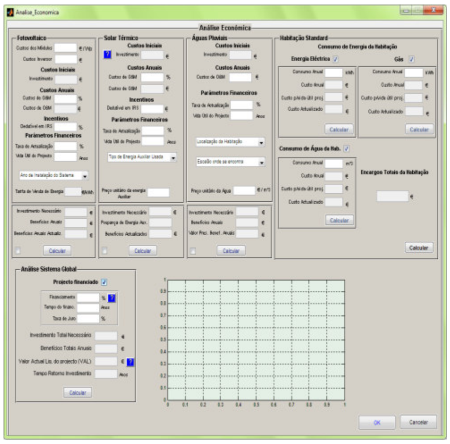

Fig. 6. Economic Analysis

4 Experimental Results

In this section, we present the results obtained for a residence located in the city of Aveiro and in the municipality of Vale de Cambra, which are illustrated in Figure 7 and 8. The economic analysis carried out corresponds to a system composed of the three available technologies in the application. A period of 15 years of useful lifetime for this project has been adopted, with a financing of 80% of the needed capital for 10 years, a discount rate of 7% and an interest rate of 6%. The choices for each technology are listed in Table 1.

The sizing of photovoltaic solar system resulted in the need for installation of 18 photovoltaic modules whose configuration results in nine modules connected in series along two rows. With this system you get an annual production of around 5500 kWh / year and you need an area of 23 m^2 for the system installation.

The solar thermal system sizing resulted in the need for a system composed of a solar collector and a storage tank of hot water with a capacity of 240 liters. With this system, the user can produce an energy saving of 1700 kWh / year corresponding to 53% of his energy consumption in water heating throughout the year and it requires an area of 2.50 m^2 for the system installation.

Table 1. Tecnology parameters

Photovoltaic		Solar Thermal		Rainwater	
Remuneration scheme	Subsidized tariff	Housing typology	T3	Monthly demand (m^3)	16
Pp to install (kW)	3.45	Number of occupants	4		
Solar module	Isofoton 180	Solar colector	AS-EFK 2.2		
Module type	c-Si				
Inverter	Sunny Boy 3800				
Inverter type	With transformer				

Taking into account the rainfall levels of the place, the sizing of the rainwater harvesting system resulted in a storage tank for rainwater with a capacity of approximately 20 m^3. With the installation of this system the user has an available, usable volume of about 125 m^3 of rainwater, of which he uses 112 m^3 for the satisfaction of his dwelling consumption, i.e., he will consume annually about 81 m^3 of potable water from the network, leading to a system efficiency of around 58% having the system installed a level of utilization of 90% of rainwater which means that about 90% of rain that falls on catchment area of this place is saved by the system.

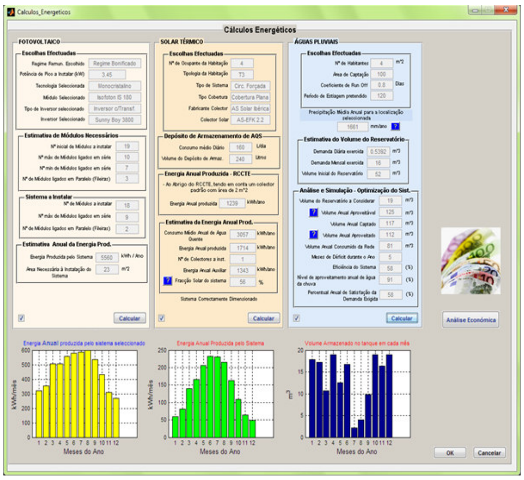

Fig. 7. Sizing of selected systems

As for the Economic Analysis, in the case of overall results, the total investment required is € 25,462. The update benefits during the lifetime of the project, amount to € 27,734, which means that the net present value (NPV) of the project is positive and amounts to € 2271. The decision to invest in this project can be considered favourable. Regarding the time of return on capital invested in this system, taking in account the financing and time allowed for financing, it will be paid within 11 years. Considering the adopted period of life 15 years, it means that the last four years of operation of the system will result in profit for you or for your home. This can be seen in Figure 8 through the graphic of the return period. Note that, in terms of cumulative value, the system will present, in the last year of life of this project, a benefit of approximately € 11,000.

Another interesting point to consider is the comparison between housing, with the integration of these technologies for exploiting renewable energy, and housing without them, considered as standard. In the analysis of housing considered as standard, an annual electricity consumption of 2600 kWh per year, a gas consumption of 650 kWh per year and water consumption of approximately 60 m^3 per year are assumed. The same life period which was considered for housing with these technologies should be considered, in order to obtain a point of comparison. For the 15 years considered, the housing will present about € 18,170 of expenses in present value for this period. The housing with the incorporation of these technologies, as outlined above, presents a benefit for the same period of time amounting to € 27,734.

Then, establishing the comparison between the two houses it is clear that the option for sustainable housing, and taking into account the defined period of 15 years, the user can save in the end about € 9500, while continuing with its housing built without such technologies you will only have associated charges. It is also important to mention that by introducing this type of technology in his home the user makes it more efficient and sustainable.

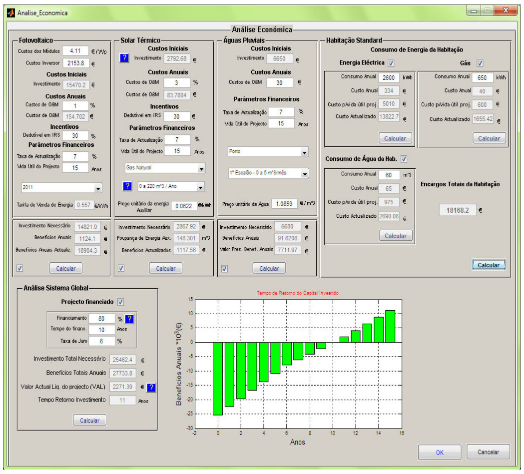

Fig. 8. Economic analysis of selected system

5 Conclusions

Introduction of renewable technologies of energy in housing makes homes more efficient and more sustainable and provides both economic and environmental benefits to its inhabitants also contributing to the security in energy supplying among others. Thus, this work has built an easy tool to use aiming at helping you in your decision to invest or not in these technologies.

A solid useful and accurate application resulted from this work providing results that can be displayed graphically (for a better perception) and be obtained from relatively simple data entry. It provides the user with a clear friendly graphical interface allowing him a most comprehensive knowledge of each renewable technology as well as the various aspects of its operation, either individually or at the system as a whole.

A consistent and profitable software tool in the supporting of investment decision in these technologies for incorporation into a dwelling is thus available for any user, regardless the knowledge he has about them.

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