DECISION SUPPORT SYSTEM FOR BUILDING RENOVATION

Ana Rita Campos[1], Rui Neves-Silva[2]

[1]*UNINOVA, FCT Campus, 2829-516 Caparica, Portugal*
[2]*DEE-FCT, Universidade Nova de Lisboa, FCT Campus, 2829-516 Caparica, Portugal*

Abstract: Buildings account for a significant share of energy use in Europe. Building owners are faced with new legislation to enable Europe to achieve targets of 20% increase in energy efficiency. In order to sell or rent buildings, owners need to have energy performance certificates. This is increasing the search for renovation solutions that can enhance energy efficiency. However, building owners find it complex to select the best technologies, among a growing market offer, to boost the energy performance of their building and fit their budget. The current paper presents a decision support system that supports investors in selecting the most suitable renovation scenario, considering budget, technical and use constraints. *Copyright CONTROLO2012*

Keywords: decision support systems, energy efficiency, sensitivity analysis, data processing.

1. INTRODUCTION

The European Commission has established its growth strategy for the coming decade, entitled Europe 2020, with the objective of making Europe a smart, sustainable and inclusive economy. One of the five ambitious objectives of this strategy is related to climate and energy, establishing targets to reduce greenhouse gas emissions by 20%, increasing share of renewable in final energy consumption by 20% and moving towards a 20% increase in energy efficiency (European Commission 2010). Improving energy efficiency is one of the simplest ways to cut greenhouse gas emissions and increase sustainability and security of supply. It supports economic development, creates jobs, and reduces energy costs for households and businesses (European Commission 2011). Buildings account for 40% of all energy use in Europe, more than transport or industry (ManagEnergy 2007). In order to reach the targets defined, the European Commission has developed important legislation, namely the Energy Performance of Buildings Directive.

Buildings with a dimension superior to 50 square meters need an energy performance certificate when built, sold or rented. This means that owners have been pressured to consider the energy efficiency of the building as one of the aspects to value, in order to maximize the marketing potential of the infrastructure. Owners are trying to renovate buildings to improve energy efficiency, and consequently achieve a more positive energy performance certificate. With the immense advance of technology to increase energy efficiency, particularly control technologies to be applied in lighting and heating domains, it is easy for a building owner to feel overwhelmed in selecting the best renovation scenario.

The current paper presents work being done to develop a decision support system to help investors in selecting the best renovation investment for a building. The proposed approach supports the investor in performing a financial analysis of a potential list of scenarios, and incorporating additional tangible and intangible criteria to the decision process. The list of renovation scenarios is developed based on the building details, its usage and an energy audit.

II. CONCEPT AND OBJECTIVES

When renovating a building, the investor should consider a multitude of factors when selecting the technologies that will maximize the energy efficiency. Retrofit-ting an existing building can implicate introducing simple control solutions, e.g. install presence sensors to optimize use of artificial lighting, or fundamentally improving the building, e.g. installing new windows and new wall insulation.

A mature and solid technology may be very suited for a specific building and totally inappropriate for another. Therefore, how to consider technical constraints while simultaneously managing financial aspects, such as a budget? It is a straightforward conclusion that the building itself, including all its characteristics, dictate the appropriateness of possible solutions to be implemented. This means that the possibility of knowing how the building is used, particularly energy-wise, can bring significant added-value to the renovation decision process (Vieira 2006). The project EnPROVE, *Energy consumption prediction with building usage measurements for software-based decision support*, is based on the key hypothesis that data gathered on how an infrastructure is used may serve to improve the accuracy on predicting future energy consumption impact of installing alternative sets of available technologies, including controllers (Campos and Neves-Silva 2011).

The system monitors the usage of a building, models the building's energy consumption, and uses these two elements to predict energy consumption under alter-native scenarios based on available market solutions and provide recommendations for a best solution, taking into consideration the decision-makers' criteria and restrictions (Campos, Marques and Neves-Silva 2010).

The collection of data from the building enables the creation of a baseline scenario that describes the full energy consumption of a building, according to its typical use, i.e. the measured usage. This provides specific information for the building, instead of considering datasheet consumption data of some manufacturer. The baseline scenario includes a complete building model, with a complete description of the infrastructure for lighting, heating, cooling and ventilation. It is then possible to create alternative scenarios by virtually "adding" new technologies to the building, and predicting the respective energy consumption (see Fig. 1).

EnPROVE aims at supporting investors in renovating building infrastructures, directing the investment to enable the best effective return through the installation of energy efficient technologies. In order to achieve this objective, the EnPROVE system is subdivided in three solution aspects (see Fig. 2):

- Wireless Sensor Network (WSN) is a group of sensors installed in the building to collect data, which is concentrated in a gateway. The data collected is specific for each situation and needs to be defined in advance.
- Building Performance and Usage Auditing (BAU) processes the data collected in the building, filtering information and identifying patterns.
- Energy Prediction and Decision Support System (EPDSS) supports an investor and technical consultant in navigating through a complete assessment project, starting from the definition of a building and objectives to be fulfilled, until the definition of alternative scenarios and making the final decision about the renovation.

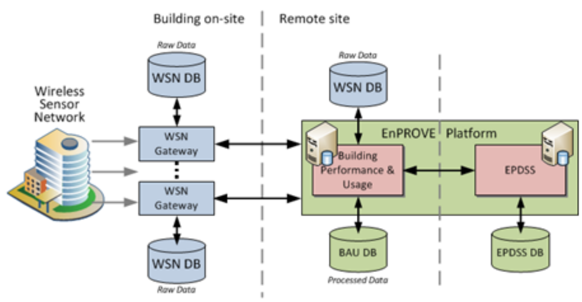

Fig. 2. The EnPROVE Platform.

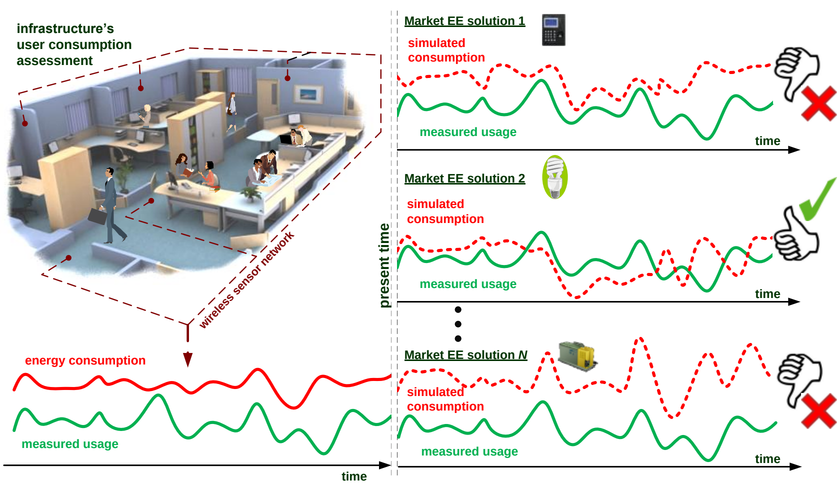

Fig. 1. Predicting energy consumption based of market solutions.

The EPDSS has three main components:

- Scenario Creation uses the processed audit data to create the baseline scenario of the building, considering also the complete infrastructure description. In addition, this module suggests a list of potential technologies to be applied to the building. A technical consultant analyses the suggestions creating a set of alternative renovation scenarios that can be implemented in the building.
- Prediction Engine simulates the energy consumption of each renovation scenario identified by applying detailed technical information of each energy efficient technology to the baseline scenario. The module includes detailed algorithms to calculate energy consumption derived from lighting, heating, cooling and ventilation.

Decision Support receives the defined alternative renovation scenarios, including simulated energy consumption, and supports the building owner, or investor in selecting the most appropriate one.

III. DECISION SUPPORT APPROACH

The Decision Support module has the main objective of helping the investor in selecting the most appropriate investment scenario for a specific building. This module filters and ranks the scenarios produced by the scenario creation module. The selection of a renovation scenario requires the combination of technical and financial information. Therefore, two main roles have to be included in the decision process: technical consultant who has technical information about the building and energy-efficient technologies, and the investor who has the final word on how the money should be spent.

In order to provide a comprehensive support, this module has to enable the users to consider both tangible and intangible criteria in the decision process. The process has to provide financial analysis, considering tangible constraints, but also enable the concern of intangible criteria, such as comfort level, for example. Additionally, there are external parameters to be considered, such as the existence of specific legislation for determined technologies or geographic locations, or the possibility of financial incentives for a specific solution.

The Decision Support Module is used sequentially by the Technical Consultant and the Investor, as represented in Fig. 3.

The scenarios that result from the module of scenario creation need to be filtered and annotated with some technical information before the investor can analyze them. Therefore, the technical consultant is asked to intervene in preparing this information. The technical consultant verifies the legislation applied to the country where the building is located, checking if any scenario needs to be discarded. Additionally, the technical consultant also verifies if there are any incentive schemes that apply to the control solutions used in any of the scenarios proposed. If yes, the technical consultant provides any necessary data, e.g. percentage of beneficiation interest rate, or available subvention. Finally, the technical consultant also completes the scenarios with information regarding yearly associated costs and implementation estimated period.

The investor receives the filter and annotated scenarios from the technical consultant and uses the decision support module to make a first financial analysis, in which discounted cash flows are elaborated to calculate some financial indicators. The investor can use any of the indicators to order and filter the scenarios, trying to reduce the number of propositions. The objective is to finalize this first financial analysis with 10 or 15 scenarios to be further scrutinized. Afterwards, the investor defines the full decision criteria to be considered and compares the scenarios regarding the non-tangible criteria. The scenarios are automatically compared by the decision support module regarding tangible criteria. Each scenario receives a rank and a full list is displayed to the investor, who is then responsible for selecting one for implementation.

The functionality implemented in this decision support module is detailed in the following sections.

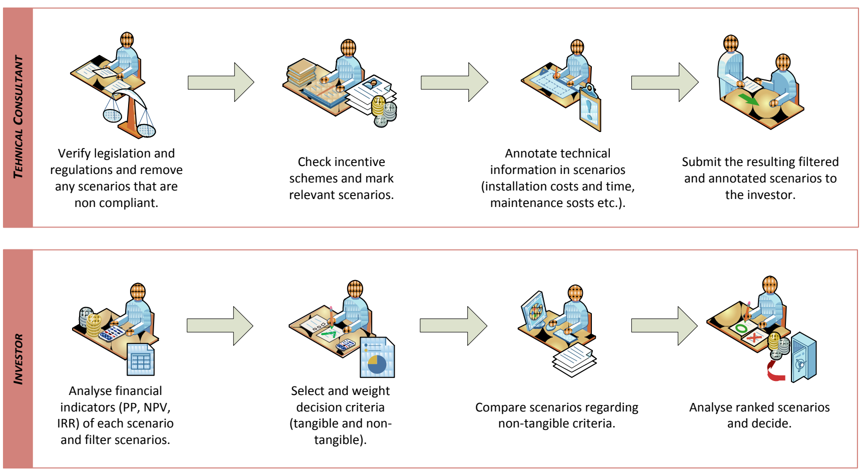

Fig. 3. Decision support module workflow.

3.1 Legislation and incentives

The technical consultant has to start by defining legislation and incentive schemes that can be applied to the geographical location. This can be done independent of any specific assessment project, prior to the beginning of the decision process.

For any entry in the catalogue of available control solution, it is possible to de-fine legislation constraints (e.g. minimum use of renewable energy sources) or financial incentives (which can be tax benefits, grants or subventions, and low interest loans) valid for a specific geographical location (i.e. country or region).

During the decision process and based on the address of the building being analyzed and the scenarios proposed, the module searches for any applicable legislation, regulation and applicable financial incentives. The module also checks, if possible, the specifications of the laws with the scenario definitions. The user analyses the information and, if necessary, removes the scenario from consideration. According to the possible incentive found (tax benefit, grant/subvention or low-interest loan), the user may have to provide additional information. For instance, a specific tax benefit reduces tax by some percentage for a period of time, or a subvention is granted to install a specific technology with a maximum amount defined. The technical consultant has to provide these details, enabling the module to include them in the following financial analysis.

Finally, the technical consultant sees the complete details of one scenario, including building zones targeted, strategies applied, control solutions selected, con-figurations specified etc. Based on this information, the user defines, for each scenario: costs of installation equipment, costs of installation labour, yearly maintenance costs, decommission costs, life expectation (years) and installation period (months).

3.2 Financial analysis

After the definition of a list of alternative renovation scenarios that can be applied to the specific building, which are annotated with all relevant technical information, the investor steps into the decision process. A renovation scenario is a set of renovation solutions applied to each zone of the building. This combinatorial possibility can lead to a considerable amount of scenarios to be considered in the decision process. It would not be efficient, or even feasible, to ask the investor to select one scenario among a list of one hundred. Therefore, the first step is to make a financial analysis, which can be used to filter the most promising scenarios to be further considered.

The first financial analysis is based on the elaboration of discounted cash flow for each scenario and calculation of financial indicators: payback period (PP), net present value (NPV) and internal rate of return (IRR). The module also calculates one global financial indicator that represents a weighted average of the previous three financial indicators. The user defines the weight given to each indicator (PP, NPV, and IRR).

The module displays a list of all scenarios with the four financial indicators. The user can order the table using any of the indicators. The objective is to use one of the indicators to set a threshold under which scenarios should not be considered. The objective is to reduce the amount of scenarios that continue to be further analyzed (ending with around 10 or 15). Shortening the list of scenarios considered in the decision process will enable the investor to analyze each scenario and consider not only the financial indicators, but also compare the scenarios regarding some intangible indicators.

The investor has access to a list of all scenarios being considered and the respective financial indicators calculated, i.e. NPV, IRR and PP. However, it is possible to analyze the details of each scenario, by inspecting the discounted cash flow elaborated by the module, as presented in Fig. 4.

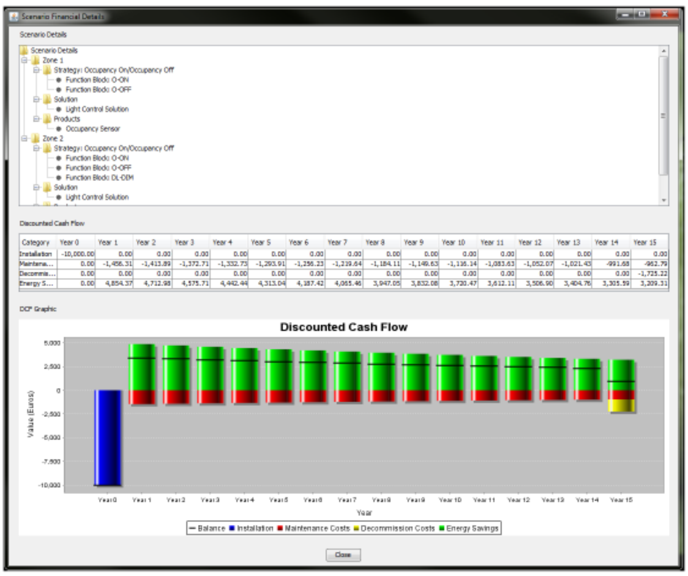

Fig. 4. Financial analysis screenshot.

3.3 Scenario ranking

The shorter list of renovation scenarios will then be analyzed by the investor, considering tangible and intangible criteria. This part of the decision process is based on the Analytic Hierarchy Process, which is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogeneous elements with respect to a common criterion or attribute (T. Saaty 1994). This process uses a series of one-on-one comparisons to rate a series of alternatives to arrive at the best decision.

The module presents a general set of criteria that can be used in any renovation decision. The user has to define the importance of each criterion, which can be done in two possible ways: define the absolute importance of each criterion; or compare pair of criteria judging their relative importance.

The investor can define the weight of each criterion, analyzing the full criteria in a tree and their relative weight in a spider chart, as presented in Fig. 5.

The user has to define how each scenario fulfils each non-tangible criterion selected (e.g. comfort level). To facilitate this task the user compares pairs of scenarios regarding each criterion, answering questions such as “Which of these two scenarios provides superior comfort to building users and by how much?”.

The AHP method includes two modes for ordering alternatives: relative, which ranks a few alternatives by comparing them in pairs and absolute which rates an unlimited number of alternatives one at a time (Saaty and Vargas 2001).

The method proposed in this paper considers tangible and intangible criteria to support the investor in making the decision. In addition, there is a strong possibility of having a considerable amount of scenarios to choose from, even after the reduction made in the previous step. Therefore, the proposed decision approach combines the absolute and relative modes of AHP. The ordering of alternatives is made in two sequential steps.

Rate alternatives using tangible criteria. The alternatives are first analyzed considering only the tangible criteria. Each scenario being considered contains details that permit its individual rating. Using the results from the financial analysis and additional information, the module computes how each scenario fulfils the goals established in the beginning of the assessment project (e.g. installation period, targeted energy savings). This corresponds to the absolute measurements mode of AHP, which is suitable for a larger set of alternatives and does not require pair-wise comparisons made by the human actor.

It is important to note that although these tangible criteria are mostly currency related, they may use different scales. It has been studied that using absolute measurements with several criteria can lead to inconsistencies, using both the distributive or ideal modes of AHP (Wedley 2011).

After making the initial calculations for all scenarios, the module compares the scales used in each criterion and normalizes the scales. This ensures a proper comparison of results. Additionally, the proposed approach uses the ideal mode of AHP, in which alternatives are rated against a best or ideal alternative.

The investor analysis the alternatives rated against the tangible criteria. This result is again used to enable the investor to further reduce the scenarios being considered.

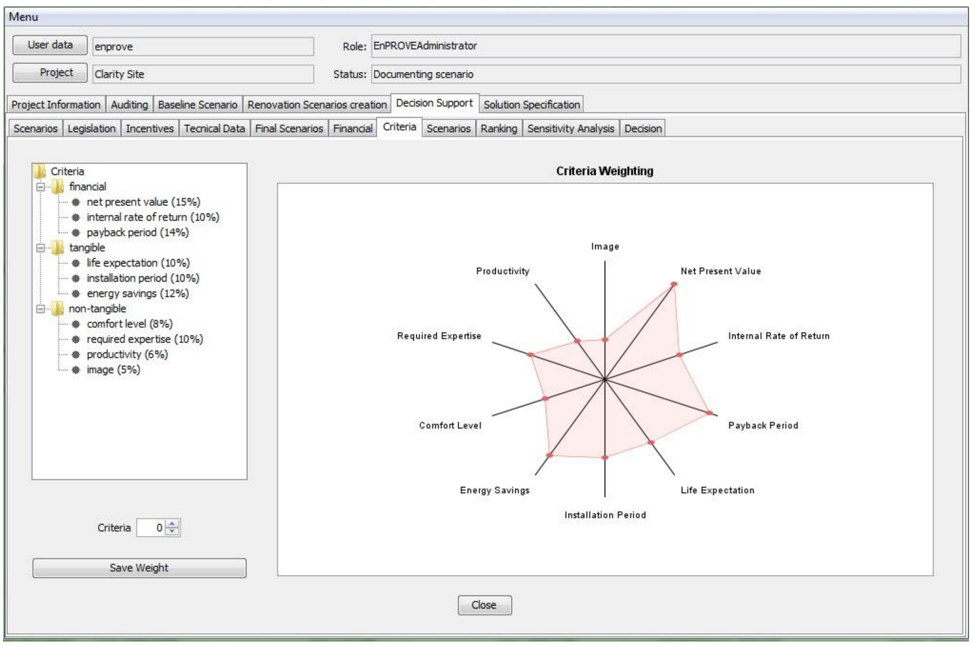

Fig. 5. Criteria weighting screenshot.

Rank alternatives using intangible criteria. The second part of the process consists on involving the investor's opinion to rank the alternatives against intangible criteria (e.g. comfort level or company's image). This step is therefore based on the relative measurements of AHP. In order to keep the efficiency and reliability of the method, the investor should realize this step of the decision process with a maximum of 7 to 9 scenarios.

The investor is asked to compare the scenarios in pairs for each intangible criterion being considered. The comparisons are made using the scale proposed by Saaty, of numbers 1-9 and reciprocals. This scale uses 1 to define items of equal importance and differences until 9, representing absolute importance.

The module computes the rank of each alternative using the weight of the criteria and the alternatives judgment, using the ideal mode of AHP.

Sensitivity analysis. The user can perform a sensitivity analysis to study the impact of changing some decision parameter (e.g. energy price or interest rate) or changing the criteria weights (e.g. making comfort level more important than payback period).
The user analyses the final scenario ranking and selects one scenario to be implemented in the building. The investor has the opportunity to provide any additional annotations to the decision made.

IV. CONCLUSIONS

This paper presents a decision support approach to help building owners in selecting the most appropriate investment option to renovate a building to improve its energy efficiency. The approach described is implemented as a software module, integrated in a system, the EnPROVE platform.

The EnPROVE platform is currently being tested in a pilot facility, where a wireless sensor network was deployed to audit the building. The audit data results are being processed and stored in a database, which is accessed by the decision support system. The first results indicate that the system can actually combine the technical perspective from the building consultant and the financial view from the owner/investor to support the decision process.

The platform will be further in the current test-bed and an additional one, to collect diverse input from actors involved in building renovation. The tests and improvements during the upcoming year, reaching a level of maturity that will enable its demonstration as a technology showcase.

The EnPROVE platform has a unique combination of measured data, obtained from the wireless sensor network, and simulation/prediction methods. Several users with quite diverse backgrounds, e.g. a building owner and an engineer, can use the platform with limited training. There are already tools available that can predict or simulate energy consumption of a building. These tools require the definition of very specific information about the building that can only be provided by skilled users with technical expertise on building and energy domains. EnPROVE provides a simpler approach based on the real usage of each building.

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