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An integrated optimisation method for residential building design: A case study in Spain

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ABSTRACT

Designing a low-energy building requires the evaluation of a large number of parameter combinations. Currently, there are several software programs available that are able to calculate the energy performance and life-cycle cost. However, these programs provide little information regarding what actions will improve the energy performance and how much will they cost. An iterative software program that optimises the parameters would be a solution: however, the larger the database, the slower the data processing and optimisation. The SEDICAE project applies a new methodology based on a tabu search and a simplified method to calculate the demand. A tabu search is a good method to avoid local minima and to permit an evaluation of different solutions. The methodology is designed to estimate the annual energy demand, life-cycle cost and the energy rating. In this paper, 48 different scenarios were analysed with SEDICAE software.

1. Introduction

The global contribution from buildings to energy consumption, both residential and commercial, has steadily increased reaching figures between 20% and 40% in developed countries [1]. Global climate change also has a serious impact on the energy consumption of the building sector [2]. Accordingly, the European Union is ready to play an active role and allocate effort to achieve a 20% cut in Europe's annual primary energy consumption by 2020 [3]. The European Union has a defined a set of principles, a list of requirements, for the energy performance of buildings. These specifications are set by the Energy Performance of Buildings Directive (EPBD). Starting in December 2002, the EPBD set a common framework from which the member states in the EU developed or adapted their individual national regulations. More recently, this directive was been updated on the EPBD recast [4], and the new Directive was formally adopted on May 19, 2010.

In the framework of the EPBD recast, nearly zero-energy building (nZEB) design has become a high priority for architects and multidisciplinary teams of researchers related to architectural engineering and building physics [5]. In the next decade, all new buildings will have high energy ratings, and zero-energy buildings will be buildings with a net energy consumption equal to zero over a typical year. This implies that the energy heating demand and electric consumption will be decreased and the reduced energy needs will be covered by renewable energy sources.

The objective of those buildings is not only to minimise energy consumption but also to design a building that balances energy requirements with active techniques and renewable technologies. These buildings can be measured in terms of primary energy consumption or carbon emissions to classify and label them according to Spain's energy labelling scheme [6].

This paper presents the SEDICAE methodology, an innovative system that allows the user to select suitable materials for buildings to improve their energy efficiency without penalising the Life-Cycle Cost (LCC). The materials are chosen as a function of their thermal properties, such as their U-values, the solar factor, the g value or their airtightness. Reaching an equilibrium between cost and building energy performance is a complex task due to the enormous variety of materials available for building construction. The system uses a Tabu Search (TS) to solve the problem of selecting materials to reach the maximum energy efficiency at the minimum cost. SEDICAE is a computer-based tool used in a series of empirical problems, obtaining considerable savings in energy and cost.

The weather conditions and building configuration are required to perform dynamic simulations. Energy performance software

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tools such as EnergyPlus, TRNSYS, ESPr or DOE2 use highly sophisticated computer models to accurately assess the effectiveness of building energy technologies. A comparison of these programs can be observed in [7]. The observance of the Spanish Building Code [8] is determined through the use of a specific energy performance software tool (LIDER). The building energy rating is assessed by the use of a second software tool (CALENER). Both tools follow a transient and hourly base assessment that has been validated via the Bestest [9]. Both tools were implemented following Directive 2002/91/EC [10], but none of them present quantitative data regarding LCC.

The drawbacks of using computer simulations include a considerable amount of input data and time required to obtain the solution of each case. In the design process, the user must check multiple combinations of the different elements of the building to find the combination of building materials with the lowest energy rating and lower cost estimate of the building's life cycle. The process also has to combine the environmental (CO_2 emissions), energetic (heating and cooling demand) and financial (investment and operating costs) factors involved in the life cycle cost, to reach the best possible solution.

Several methodologies have been developed that can be used to estimate energy consumption or demand. Some of these methodologies are based on estimates [11] and [12]. SEDICAE uses a simplified model to estimate the annual energy demand of a building. The model includes the energy demand for heating and cooling following the model developed by Alvarez et al. [13]. SEDICAE can be classified as a system for material selection, life-cycle cost and energy rating optimisation. This paper presents a case study solved step by step, and the solution of four case studies in 12 different climatic situations.

2. Nearly zero-energy building

Life cycle energy analysis is an approach that accounts for all energy inputs of a building in its life cycle and includes the energy use of the following phases: manufacture, use and demolition [14]. The methodology used to calculate cost-optimal levels have been established by the European Council for an Energy Efficient Economy, a comparative methodology framework is required to calculate cost-optimal levels of minimum energy performance requirements for buildings and building elements [15]. The comparative methodology framework requires Member States to calculate the costs of the energy efficiency measures during the expected economic life cycle applied to the reference buildings. This study takes into account investment and operating costs and is focused on the operation phase encompassing all related activities over its life span. This includes the use of electricity and fuels for heating, cooling and domestic hot water.

SEDICAE develops a strategy to reduce energy needs in buildings. If renewable energy sources are used, these buildings are considered 'net-zero energy' buildings, but different definitions have been used. As defined by the EU, a "net-zero energy" is "a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site" [16]. SEDICAE could help the user to reach a nZEB by proposing the best combination of building construction materials and HVAC systems, assuring very low energy consumption following a life-cycle energy analysis.

3. Methodology

SEDICAE methodology focuses on improving the efficiency of the design process. As shown below, the methodology includes two

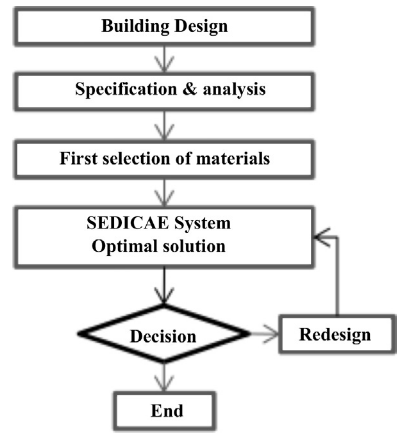

Fig. 1. Expert system for the search process of a building with low demand or high energy rating.

simulations using a detailed software tool (LIDER–CALENER), one at the beginning and one at the end. The first simulation with the detailed software tool is used to calibrate the coefficients of the simplified model, as presented below in Eqs. (1) and (2). By acting this way the results of the simplified model for the initial case are exactly the same as those corresponding to the detailed model. The second simulation with the detailed software tool is used to obtain the most suitable results by means of the optimum proposed scenario.

SEDICAE applies this methodology which allows the user to evaluate and study the design issues before the construction begins and also assists in the study and identification of solutions and alternatives. It also enables the user to perform a sensitivity analysis to quickly test the economic advantages and disadvantages of changes incorporated into the project by evaluating those elements in the database.

The activities that are part of the proposed process (Fig. 1) are as the following:

1 Building design: The architect or designer (user), builds a reference model (initial) based on a fixed set of independent variables related to the location of the building that is generally accepted in the Spanish Technical Building Code (TBC).
2 Specification and analysis: The user selects the type of building, the climate zone, and other specifications and analysis parameters.
3 First selection of materials: The user selects an initial group of elements and materials.
4 Expert system: The architect or designer then runs the SEDICAE system, which contains a simplified model of analysis. This simplified model calculates the heating and cooling demands and the estimated LCC for the reference building, and the Energy Efficiency Index (EEI). Then, the user selects the elements of the structure that can vary in the analysis, which will then correspond to the variables of the model. Using the data stored in a database of material properties and prices, the expert system obtains the optimal solution in terms of EEI (first) and LCC (second) represented by its elements/materials, and a report of the estimated demand, estimated costs and energy rating. The system works as follows:
   (a) Sensitivity analysis and study: the system checks the possible values taken by the variables as well as the effect of variations or slight changes in the model. The optimisation procedure is based on a TS, exploring the solution space and trying to escape from local optima.