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ScienceDirect
Energy and Buildings 39 (2007) 23–31
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

Energy efficient building design using sensitivity analysis—A case study

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Received 8 January 2006; received in revised form 4 April 2006; accepted 11 April 2006

Abstract

A case-study of a public building is presented as an example of the adequacy of timely analyses of building performance, based on a preliminary architectural design. The final design of the case-study building benefited of the thorough analysis performed at this early stage, the main motivation being the willingness of a town government of an intelligent design, leading to a sustainable town-hall building, in a town in the centre region of Portugal. A virtuous combination of a receptive building owner and a multidisciplinary design team, allowed a systematic methodology to be used, providing the opportunity for the consideration of several options for each class of constructive element and the possibility of choosing among the options for each case, based on quantitative results on the expected performance of the building. The options were created and analysed with the help of the VisualDOE™ building simulation tool, aiming at a comfortable and energy efficient building. Several parameters were used for enabling the sensitivity analyses, namely relating to wall structure and materials, window frames, HVAC system, etc.

Keywords: Building design; Energy efficient building; Building simulation; Public building

1. Introduction

The building sector is constantly expanding, with consequences on energy expenditure, be it in the residential sector or in the service sector. The energy consumption share of buildings in the European Union (EU) is about 40% of total final energy consumed [1], which shows the importance of efficient design and quality-oriented construction in the sustainability of the EU development. In Portugal, this share is about 23% [1] but the fact that this country signed the Kyoto Protocol and the problematic evolution of annual emissions since then, imposes the need for a strict policy of energy efficiency fostering. Despite the fact that this may not yet be a top government priority, it is nevertheless a hot topic, namely due to the recent oil price crisis.

The approach used in this work was informed by three key elements. First, a multidisciplinary team was gathered together for an adequate compromise solution between functionality, aesthetics, comfort and energy efficiency. Architects, engineers and researchers worked in a coordinated way for the project development [2]. Second, comfort and energy performance of the building have been evaluated at the preliminary design stage, in order to allow critical choices to be made before the final design work started. Third, the main tool used was sensitivity analysis of the influence of each element's characteristics on the overall building performance [3]. This approach was specially effective for a better justification of certain options regarding constructive elements or equipment.

The main steps and outcomes of the project were:

(a) simulate the building under study on an hourly basis along the period of a whole year, exploring different building design details, materials and equipment;

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0378-7788/$ – see front matter
doi:10.1016/j.enbuild.2006.04.017

(b) assess the thermal behaviour of a real case-study building, obtaining annual heating and cooling load curves;
(c) assess the building energy consumption characteristics and their dependence on the different alternatives considered in (a);
(d) the validation of the proposed methodology based on sensitivity analysis.

2. Case-study characteristics

The building owner is a municipal government of a town located at the centre region of Portugal. The open-minded attitude of its members as regards to sustainable development was a key-issue of the project development, leading naturally to a set of proposals by the multidisciplinary design team aiming at a rational building design.

The gross floor area of the building is 8535 m^2 and the usable floor area is 5690 m^2, the occupied ground surface being 2236 m^2. The location of the building imposes several constraints limiting the possibility of using sustainable design options:

(a) the ground area to be occupied by the building has a rectangular shape, the main dimension being oriented, unfortunately, along a north–south axis, raising difficulties to the use of direct gains through the south façade;
(b) the largest wall is facing west and a railway track runs parallel to it at approximately 40 m, requiring a special care with undesirable noise—the use of a curtain of trees may be a first insulating barrier;
(c) the wall facing south is small, requiring special attention in order to maximise direct gains in winter, not overlooking appropriate shading for the summer season;
(d) similarly, the north façade is also small, requiring mainly an appropriate thermal insulation level;
(e) the east façade may not have apertures due to the existence of an adjacent building and an unconditioned space;
(f) several other constraints exist, having to do with circulation of occupants and entrants, landscape, alignment with neighbouring buildings.

Some other concerns which do not directly have to do with building energy performance have, nevertheless, an influence in the building design. One of the most significant is maintainability of building elements, fixed equipment and surrounding areas. Easy access to parts of the building for maintenance and cleaning and sustainable solutions, for example for irrigation of plants, was considered.

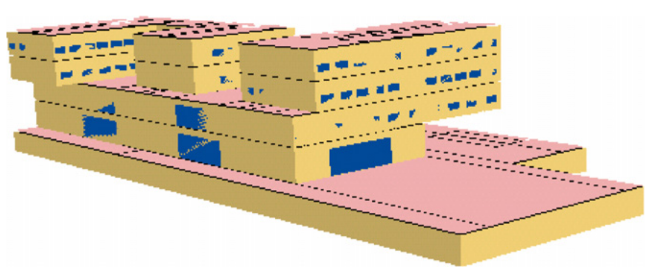

Fig. 1. 3D view of the model obtained with VisualDOE^{TM}—south/west views.

The building will have five storeys, one of them buried. The constraints referred above due to the orientation of the building and the relative dimensions of façades led to a non-conventional shape (see Fig. 1) which tries to get the most of the building relation with the environment in order to assure a good performance.

3. Computational model of the case-study building

The simulation software used was VisualDOE^{TM} releases 3.0 and 3.1, which allows importing architectural drawings.

The first task, of modelling the building within the simulator, benefits of the interactive intuitive interface, based on windows and dialog boxes.

As the approach used is based on sensitivity analyses, a base case was needed, to play the role of a reference against which the alternatives could be assessed [4]. At the preliminary stage of design, choices have to be made according to plausible and good engineering judgement criteria—constructive solutions, materials and equipment, such as walls, window frames, glazing or HVAC (heating, ventilation and air conditioning) systems. Frequently, default values presented by the simulator were kept at this stage, in the absence of relevant information to do differently [5]. Some of the initial choices were: the weather file, in the TMY format, corresponds to the nearest more important town, at a distance of 18 km, without any significant climatic differences; average occupancy density of 40 m^2/person; lighting power density of 15 W/m^2; equipment power density of 6 W/m^2; infiltration rate of 0.5 air changes/h (typically, 0.3 is adequate for strong weatherisation and 0.5 for average buildings [6]); a four pipe fan coil HVAC system (a single-zone system that is served by chilled water or hot water from a central plant [6,7]) was chosen, mainly because opposite types of needs may be expected simultaneously, especially during mid-season periods; heat was to be produced by a gas-fired boiler, also assuring domestic hot water supply, and an electric chiller should produce cold water, both devices specified as high efficiency equipment; the building is not occupied in weekends or holidays. Air change rate due to mechanical ventilation was set at 0.75 air changes/h (ACH) according to Portuguese legislation on indoor air quality (in the present case, it also matches the need for setting this ratio at a higher value than the natural infiltration rate, as demanded by the simulator [6]).

After modelling the building, the simulator provided the following general data: total conditioned area of 6220 m^2; window area of 468 m^2; ratio window area/wall area of 13.5%; skylight area of 63 m^2.

Building schedules have been partially based on VisualDOE^{TM} defaults, which were modified according to the knowledge of the future building occupancy. The changes concerned mainly occupancy, lighting and equipment schedules.

4. Methodology of building analysis

The simulations were organized according to the purpose of identifying the influence on the building performance of