Integrated Life Cycle Design for Buildings: Invest in Simulation to Increase Comfort and Environmental Sustainability at a Reasonable Cost

With the evolution of both technological and cultural aspects on sustainability, the building industry is facing the need to reconcile energy savings and environmental and economic sustainability during both construction and operation phases.

The more comprehensive theme of "life cycle sustainability" involves all members in the production; from designers to final users, and it increases attention to different aspects, ranging from the capability to meet final users' needs (safety, comfort and aesthetics), to reduce energy dependence and environmental impact (natural resources and materials consumption and emissions). However, it often happens that the "life cycle thinking" approach turns out to be nothing more than an "expanded" look at the global process, while it hardly ever involves an effective effort to break down and analyze each single contribution.

The latter requires a strong change in the building industry. As for manufactured products, there is a need to use software tools and methods that can grasp and integrate all the opportunities offered by materials and technologies. A decision support tool for considering, analyzing and optimizing energetic, environmental and economic performances would be helpful - especially during early design phases when it is really important to:

- Identify issues
- Identify design alternatives
- Highlight differences
- Give a consistent point of view
- Consider multiple criteria

BENIMPACT PROJECT: PROGRAM AND OBJECTIVES

Definition of the technical-technological and functional requirements of the work-flow

In 2008, EnginSoft started to think of a workflow to support the building design process by taking into account, not only energetic performances but also environmental aspects and costs, as well as considering the entire life cycle/period of use (construction, management, and disposal/recovery).

As a first step, methods and simulation software available on the market and their diffusion were compared to identify the most suitable approach for each evaluation. Functional specifications

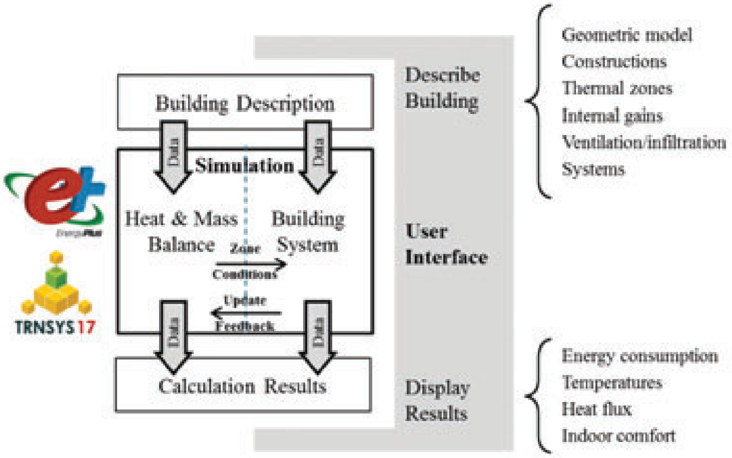

Fig. 1- Input/output and data workflow in energy simulation software

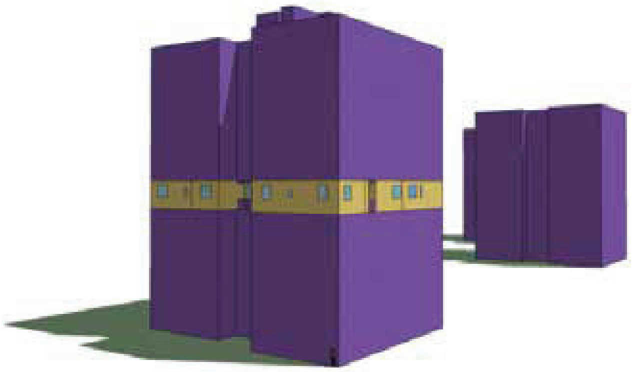

Fig. 2 - 9-story building simplification

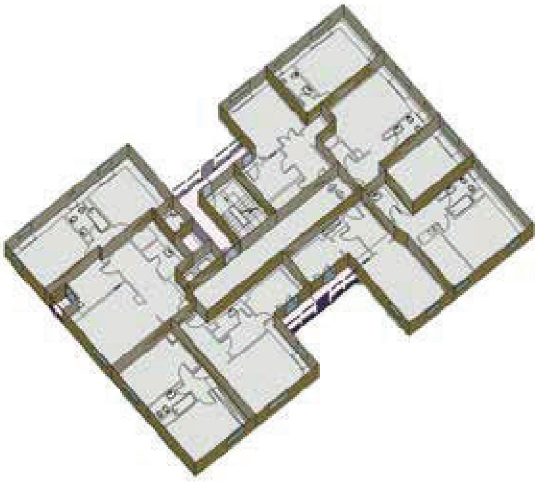

Fig. 3 – Central floor breakdown into thermal zones

and integration/interoperability requirements (data exchange mode) were also considered during the comparison.

The result of the project was a mathematical workflow for the evaluation and optimization of different configurations from the energetic, environmental and economic point of view during the entire life cycle.

This methodology was developed by considering the whole building as the "object of the analysis" - taking into account impacts related to raw material extraction, construction of building and its components and use of the building. In particular, the latter includes both energy consumption and maintenance/replacements of main elements, but not disposal/recycle, which largely depends on the specific characteristics of each case.

The analyzed system consists of an accurate virtual model of the building (evaluation model) with a series of input and output data, which are measurable, quantifiable and clearly assignable to specific materials/components/issues (life cycle inventory).

Parameters required for the calculation of the energy level, environmental and economic impact were calculated by summing up the following factors:

- Envelope: floors, opaque vertical closures, windows, roof.
- Installations: generation systems (conventional and renewable) and the distribution grid.
- Energy demand (quantity and type of energy source) required for heating, cooling and domestic hot water production.

Development of simulation and optimization methodologies and strategies

The optimization process of a complex system, such as a building, involves a integrated design approach that takes into account various disciplines and parts of the system, and their interaction, to identify configurations that better respond to one or more (often conflicting) objectives.

While it is quite simple to find solutions which optimize a single objective - such as cost or energy consumption, it is much harder to efficiently identify good compromises whose behavior is inbetween the extremes. This goal can be achieved by applying multi-objective optimization strategies, to reduce time and effort when evaluating the multiple configurations and responses of a building system.

Multi-objective optimization provides strong support, especially during early stages when design choices have the greatest influence on the building performance, so changes can still be easily (and less expensively) adjusted.

It is important to emphasize that the aim of the tool is to support the decision making process, while the actual task of choosing between proposed solutions still remains in the hands of the designer.

There are two pre-requirements that need to be satisfied in order to automatically optimize a problem. The first is to reformulate it so that it can be adressed and solved with mathematical tools, AND all the disciplines that contribute to the response of the system need to be adequately modelled. The second comprehends the definition of objectives, constraints and responses to be monitored, and the parameterization of the model.

During the BENIMPACT project, an automatic procedure was implemented based on modeFRONTIER, a commercial multi-purpose, multi-objective and multi-disciplinary optimization platform. The search for the optimal solution was done through the Pareto frontier method. Static and dynamic energetic behavior, costs and the environmental impact were analyzed for various building configurations; and significant input variables were identified based on their influence on the response of the "whole building system."

For each input variable, a "library" of alternative solutions were defined, and all technical information required for the simulation (type and thickness of its layers, thermal transmittance, specific cost and environmental impact indicators, etc...) were listed for each option.

TEST CASE: OPTIMIZATION OF ENERGY, THERMAL COMFORT AND ECONOMIC PERFORMANCE

The analysis of a 9-story building to be refurnished has been developed as follows:

1. On-the-spot investigation of the building characteristics, check of energy bills to verify the current energy consumption, and surveys among users about the actual comfort conditions.

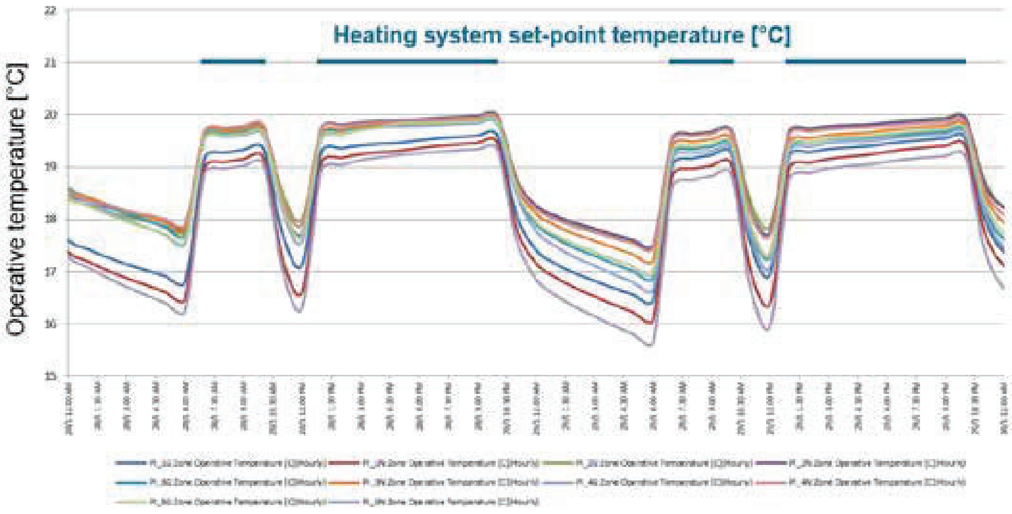

Fig. 4 – Simulated indoor operative temperature in the actual building during two days in January with a set-point of 21°C

2. Identification of redevelopment goals and alternative options to achieve them.
3. Evaluation and preliminary cost/benefit comparisons of different design solutions.

The goal was to identify key areas of improvement for owners; such as, reduced energy consumption, increased comfort, aesthetic requalification and the implementation of new services such as air conditioning.

The added value of this approach lies in the tight integration of design and management aspects (choosing, sizing, monitoring and controlling) starting from early stages of the design process. And the use of advanced techniques to support the analysis and comparison of a large number of solutions supports the decision-making process.

One peculiarity of this approach is that, it does not recommend a single optimal solution, excluding in this way other interesting alternatives, but it offers a set of options that can be objectively compared to each other based on their technical and economic performances.

System comparison and multi-variable optimization

As an optimization problem is faster to solve if the model is "simple", variables were limited (in number and variation) and the model was simplified in order to make simulations run quickly. Only the middle floor of the 9-story building was modelled (Figure 2), the latter was divided into thermal zones (Figure 3), and analysis was focused on optimizing the:

- Type and thickness of the insulation coat.
- Type of transparent enclosures (windows).
- Heating and cooling system.
- Three objectives were established for optimization (minimization).
- Primary energy for heating and cooling calculated on a yearly basis (standard design year).
- Total cost of refurbishment.
- Pay-back time in relation to a reference solution.

Firstly, the model of the plane was calibrated and validated for energy consumption and indoor temperature. i.e., the graph in Figure 4 shows that the tenants feel the cold as they are not able to reach the desired perceived comfort temperature, even with a heating set-point temperature of 21°C because of a much lower operating temperature. This phenomenon is further accentuated during shutdown (10 hours a day).

The next steps were:

- Evaluation of a campaign for the Design of Experiments (DoE) to create a first dataset of "attempted solutions" to support the optimization algorithm.
- Optimization in order to efficiently search and identify optimal/attractive configurations.

The graph in Figure 5 shows configurations that are potentially interesting and their pay-back time related to savings in terms of primary energy.

Optimal configurations are characterized by a good trade-off between a reasonable investment and a good capability to reduce costs related to energy consumption (i.e. investments on energy systems or external wall insulations have a reasonable payback time whilst replacing windows are characterized with a longer payback time).

CONCLUSIONS

It has been shown that the implementation of a software process can strongly support "sustainable" building design by making it possible to progressively evaluate and optimize energy performance, indoor thermal comfort, environmental impact and costs. By providing the scientific evidence of the benefits, this kind of approach can help spread sustainable design within the construction sector.

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