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Towards energy performance evaluation in early stage building design: A simplification methodology for commercial building models

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ABSTRACT

The paper analyses the benefits of the application of energy analysis in the early-stage building design, in particular for large commercial buildings. The research highlights the barriers that prevent this early integration and finally proposes the development of a methodology tailored around the optimization of energy efficiency during early-stage design. In general, the research aims to identify (a) the accuracy obtainable through progressive simplifications of the building model, (b) the most significant building parameters with respect to the model result accuracy and (c) the maximum number of simplifications able to ensure the respect of time requirements dictated by early-stage building design and to maintain an acceptable level of correctness. Here, as detailed example of simplification process, a case study of a large multi-storey office building is modelled starting with a previous detailed simulation performed through EnergyPlus and Openstudio software. The detailed model is then analyzed and progressively simplified. At each progressive simplification step, a comparison with the detailed results is given in terms of building energy needs and power curves of the system. The analysis is performed based on three different system hypotheses: a single-zone system and a variable air volume system with and without humidity control. The quantitative differences between detailed and simplified model are analyzed to determine the quality of the results of the simplified model.

1. Introduction

The daily operation of commercial and residential buildings comprises roughly one-third of the world's primary energy consumption. Because buildings are typically operated for many years, there is great potential for reducing global energy needs through improved building design [1]. Most of the energy consumed in buildings is the result of fossil fuel combustion, either directly or in the generation of electricity. One major path to reduce human impact on global warming is to design buildings and building renovations that have minimal energy demands and meet those demands with renewable energy rather than fossil fuels [2]. Computer modelling and simulation is a powerful technology for addressing interacting architectural, mechanical, and civil engineering issues in buildings. Building performance simulations can help in reducing emission of greenhouse gasses and in providing substantial improvements in fuel consumption and comfort levels, by treating buildings and their thermal systems as complete optimized entities and not as the sum of a number of separately designed and optimized sub-systems or components [3]. With conventional buildings and installations there is often no need for simulation, because standard methods and data provide enough information for design. In less simple situations, where complex building physics or complex installations are involved, a proper design cannot be achieved without the help of simulations [4]. Nonetheless, recently, there has been a strong push towards zero/nearly zero energy buildings (ZEBs/NZEBs). The nature of the aggressive goals of NZEBs requires the early creation of energy models during pre-conceptual and conceptual design phases [5]. Many existing energy simulation tools for buildings are very sophisticated and promise a high level of accuracy. Popular tools such as EnergyPlus and DOE-2 are quite effective at simulating final building designs and are typically used for demonstrating compliance with performance standards such as LEED. However, despite the proliferation of many building energy analysis tools in the last ten years, architects and designers are

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still finding difficult to use even basic tools [6]. Findings confirm that most building performance simulation tools are not compatible with architects' working methods and needs [7–9]. Although building energy simulation is a useful tool for predicting performance and comparing design options, most part of the energy simulations occurs too late in the design process [10]. In the traditional design process, the energy engineer carries on simulations, if at all, as a methodology for equipment sizing and code compliance only after the architect has completed the architectural design. Part of the problem is that existing simulation tools are not practical for the design process, however experiences with real buildings have shown that low-energy design is not intuitive and that simulation should therefore be an integral part of the design process [11,12].

During the design process a great number of decisions need to be taken. Typical design assessment criteria are costs, flexibility, energy efficiency, environmental impact as well as comfort, productivity and creativity of occupants. It is self-evident, that decisions at earlier phases of the design have a bigger impact on the building performance than measures taken at later design stages or during building operation [3]. It is believed that a more efficient use of building performance simulations during the early design stage would be very beneficial for the end result.

The building form, orientation, fenestration and construction materials are often decided early in the design by architects, with little or no support in terms of simulation software. Other design professionals are often brought into the project after the initial design stage, when many of the building design features and materials are fixed. It is essential to have building performance simulation tools that can assess the energy performance of a building during the sketch scheme design stage. In conceptual design it is important to be able to evaluate multiple concepts at the same time, and to quantify, rank-order, and even to be able to semi-automatically generate design alternatives. Qualification and quantification of variant solutions is here more important than detailed assessment of a single case. Therefore, in this approach the amount of model details can be generally low. These decisions are critical as they can determine the majority of a building's energy use profile. Unfortunately, energy modelling is rarely leveraged in the concept phase to provide information that could drive these critical decisions. This is a missed opportunity, since energy modelling in the concept phase can be a very powerful instrument for the entire design team [13].

Needs related to the design process can be easily identified in time and accuracy. Accuracy is an essential prerequisite to every analysis used to support decision-making in every field, if the analysis is not accurate the results could be misleading and the decisions made based on those results could be non-optimal or even completely wrong. The problem becomes significantly more relevant during the design process of buildings, where decisions taken can concern a relevant amount of energy and can affect the building for a large number of years. To worsen this issue is the difficulty to change wrong decisions made during previous design in subsequent design phases or even during management phase.

Accurate energy analysis requires time, up to several weeks in more complex cases, and the more accurate the analysis must be the more time it will require. This is in contrast with the necessity to minimize the time requirements of the analysis so that it can be compatible with design times, but to do so simplifications of the building model and a simulation methodology are needed, with the drawback of a loss in accuracy.

Existing software requires detailed inputs and promise excessively high accuracy. At the early stage such extreme accuracy and detail is unnecessary and in fact unrealistic, as details are often sparse and uncertain, simulation time is limited, and major decisions are not yet finalized [1].

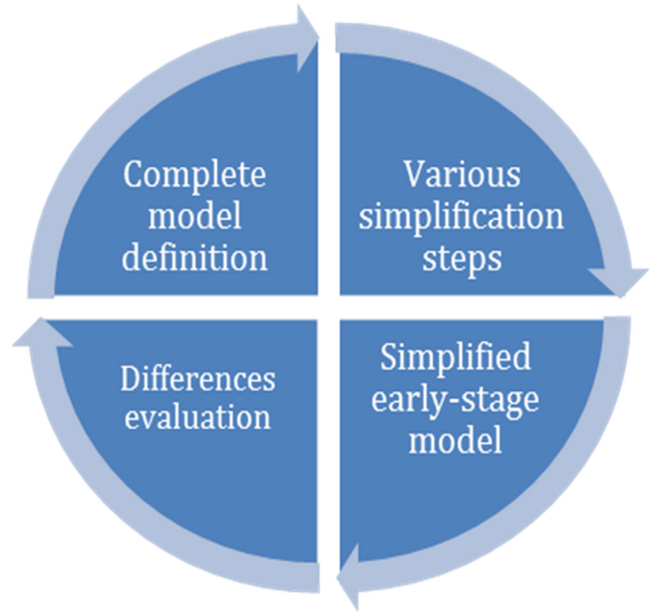

Fig. 1. Simplification process.

The strategy behind this work is the definition of a methodology to simplify the building description and able to convert a detailed building model into a simplified model requiring only a limited number of inputs. The methodology is defined in eight consecutive steps, as further detailed in Section 2, each concerning one major aspect of building model description to evaluate its impact on simulation results. For each simplification, its implementation in common practice has been considered and the simplification step is defined trying to minimize the difference in results while also limiting the number of inputs required, focusing on information available during conceptual and early-stage design.

In the second phase of the research the defined methodology is tested and improved through its application to an adequate number of case studies. Lastly, based on the results of the previous analyses, the methodology is to be implemented into a design tool able to generate the building model and run simulations from a limited number of input data.

The aim of the work is to deliver fast results to designers to assist in the decision making process during the first hours of design. The primary objective is not an exact performance prediction of the final building design, but to be able to identify which design factors has the highest impact on energy use relative to the others. Although we restrict the detail in the inputs, the computational model is still sophisticated, being based on the EnergyPlus simulation engine. It is also interesting to note that, by using a complete simulation engine like EnergyPlus, we are able to generate an IDF file of the simplified model, which can then be integrated and expanded in the following design phases.

All the case studies will be developed following the same pattern as seen in Fig. 1: a complete building model will be implemented in EnergyPlus and assumed as the "base case model"; from there the simplification methodology will be applied. For each step, output differences from the base case in term of energy and power loads are to be analyzed to identify the total differences generated by the simplified model.

This phase of the research concentrates on the analysis of large commercial buildings in Italy, as it is believed total costs better justify the inclusion of this kind of studies. Commercial buildings are also generally more energy intensive, leaving more room for the implementation of energy saving solutions, and less suited to standard energy saving solutions compared to residential structures.