Early Decision Support Simulations for Operational Energy Assessment: A Literature Study

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Abstract — Most uncertainties of a building are generally addressed during its design phase. Though there are many software simulations available to help the architects on the energy requirements of a building, yet a very limited guidance are present for them at the early design phase which could help in prediction of the operational energy consumptions of a building. This paper traces the use of building simulation tools by the architects through time to be better informed on operational energy assessment of residences, by enabling them to identify and translate the early design inquiries into simulation tasks for prediction of the same. A brief literature survey is taken into account to co-relate the early design parameters with the simulation tools available at present. A summary of the comparison studies done on the available energy simulation tools is presented. Authors identifies various factors that affect the operational energy consumption in the later stages of a building as future inputs for the development of an appropriate simulation tool and relate the architectural elements to the tasks.

Keywords — Heating, ventilation and air-conditioning (HVAC), Building Information Modelling (BIM), Level of Development (LOD), Early Design Phase (EDP), Building Performance Simulation (BPS).

I. INTRODUCTION

The building sector is not only one of the major consumers of energy, it is also one of the largest contributors to the increase of carbon dioxide in the atmosphere, and hence, to global warming and climate change. In USA, building sector consumed nearly 40 percent of the total national energy use, which exceeded energy use in transportation sector. [1]. The Energy Statistics 2013 of India's National Statistical Organisation (NSO) showed electricity accounted for more than 57 percent of the total energy consumption during 2011-12 in India, and building sector is already consuming close to 40 per cent of the electricity [2]. In 2007, China's buildings sector consumed 31% of China's total energy consumption. China was also the second largest building energy user in the world, ranked 1st in residential energy consumption and 3rd in commercial energy consumption, according to reports [3]. These evidences along with several other confomations around the globe calls for in depth studies on optimization of energy use in buildings and development of effective tools for monitoring them.

Several factors have contributed to the growth of energy use in buildings, namely the increase in population, improvement of comfort level and the increasing number of energy using devices in buildings [4]. Scholars have noted primarily three major energy requirements in building: i) energy required for fabricating materials and equipment, ii) energy required for erecting materials, and iii) equipment and energy required to operate buildings [5]. It was estimated that the energy used in the construction of buildings is about 5% of global energy consumption, while energy consumption for operating buildings accounts for about 45% of the total global energy consumption [6]. At present, the research communities and building efficiency bodies have introduced various strategies to enhance and strengthen energy savings in buildings in form of codes of practice and building simulation. According to the Energy Conservation and Building Code (ECBC 2007) [7] published by Government of India, the building design community at large in India would have mandatory energy codes and standards that aim to reach low energy built environments both in residential and commercial sector.

Formulation of codes and their enforcements alone cannot lower the energy consumption of the new buildings to be constructed. Scofield (2002) [8] noted that despite some buildings having green credentials, some of the new buildings constructed was responsible for as much energy consumption and pollution as comparable to conventional buildings. This was so cause the environmental design decisions taken late in the design process was
only to validate design after critical decisions have already been made [9]. Early in the design, architects often make decisions regarding the building form, orientation, fenestrations and construction materials with little or no simulation support [10]. The integration of such design aspects during the early design phases is extremely complex, time consuming and requires a high level of expertise, and software packages supporting them are not available. At this stage, the architects are in a constant search for a design direction to make an informed decision so that the design may comply with the desired code of compliance of the area. An architect has to consider multidisciplinary design constrains at the initial stages. It is more evident for early design support especially for small projects like low height multi storey residential apartment buildings with area less than 1000 meter square. conditioned area (ECBC 2007), which lacks engineering support due to limited budgets. It is to be noted that during early design phases, 20% of the design decisions taken subsequently influence 80% of all design decisions [11]. Hence minimizing building loads during the early stage is a modern day necessity.

II. AIM

Building Simulation represents a possible solution to the complex problem of enabling comprehensive and integrated appraisals of design options under realistic operation conditions (Clarke 2001). Although new improvements of building energy modelling platforms and capabilities of Building Information Modelling (BIM) actuate architects and engineers to assess their design [12], but it is to be noted that building energy performance simulation do not have much use by the architects for making early stage design decisions, specially for residential apartments. The aim of this paper is to make a comprehensive study to investigate the gap of using existing energy simulation tools as design decision-making tool by the architects in the early design phase to make effective decision which would lower the operational building energy during life of the building.

III. ENERGY SIMULATION PROGRAMS FOR EARLY DESIGN PHASE

In AIA G202-2013 [13], Building Information Modelling Protocol Form, the Level of Development (LOD) stage definition has been developed by the American Institute of Architects (AIA 2013). It is to be noted that the main optimization of energy efficiency design decision should be taken in form of Building orientation, Natural ventilation strategies, Building layout and form and others. The effectiveness of design decisions taken during this phase has been elaborated by Krygiel et al. (2008) [14] in Green BIM. A literature survey has been done as to take note of some of the available simulation software which aims to simulate building energy requirements at this phase of building design.

A. Tracing the Development

The ability of simulation programs to simulate a building reality in its future life provides a very effective-ive tool for improving the energy efficiency of buildings [15]. The benefits of using simulation tools are the following:

a) Evaluation of decisions making.

b) Optimization of building design and operation

c) Estimation of building impact on the environment

d) Compliance with building regulations

e) Establishment of new energy standards and benchmarks

f) Calculation of energy life-cycle cost.

By predicting the operational energy consumption of a building, for instance, simulation can help in reducing the recurring costs such as energy use and maintenance. Mora et al.,[16] laid emphasis on how computer support for conceptual design of building structures is still ineffective, mainly because existing structural engineering applications fail to recognize that structural and architectural design are highly interdependent processes. At present, analysis is used mainly for verifying and rationalizing decisions already made in the design instead of supporting the decisions instantly made by an architect [17]. Limitations in both tools and process pose challenges to the integration of simulation in early design and the conversion of 3D models between design and analysis representations. This is not well supported by existing data transformation mappings, and expertise is needed for its analysis [18]. Information at the conceptual stage cannot be sought at because most of the simulation tools necessitate detailed information about a building’s construction and services (Ellis and Mathews, 2001). Nicholas and Burry, (2007) [19] stated that the development of an interactive information exchange network with design and simulation analysis processes acting simultaneously is a barrier to the conventional practice. Methods for integrating simulation into the design process depend heavily on establishing effective strategies for exchanging information between design and analysis applications for rapid and flexible support to the iterative investigation of design alternatives. Attia (2012) contained a result of a field survey to create a benchmark representing the base case and threw light on the specific outcome where a benchmark simulation model that would be the basis of decision support tool.

B. The Role of Building Performance Simulation in Design

Building Performance Simulation (BPS) based computer models predict performance aspects such as energy consumption and thermal comfort in
buildings. Crawley (2003) described it as a substantial tool which can imitate the dynamic relationships of factors like heat, light, air, moisture, sound inside the building when the same building is exposed to climate, occupants, conditioning systems and hence predicting the energy and environmental performance of it. Before the computer revolution, architects relied on manual calculation. Clarke (2001) [20] summarizes the evolution from tools from traditional calculation to contemporary simulation in four generations from handbook oriented to computer implementations. Recently, computer programs have been used to analyse energy and evaluate the performance throughout building’s life cycle starting from it’s construction in which the steady state and dynamic methods represent the base for the computer programs. The programs does simulation of different tasks related to the operation of the building and has capabilities to manipulate a large amount of building and weather information. Following is the concept of simulation system as developed by Clarke (1982). The simulation programs has been used in connection with many aspects of building performance such as energy performance, lighting, HVAC system, air flow etc and can be divided into following three categories: the envelope load calculation tool, the system tool and the integrated simulation programs. Gibson (1982) [21] stated the performance concept in building should be thought in terms of the end as to which the building is supposed to do rather than the means of how it is being constructed. Clarke (1999) [22] assumed that only the integrated programs can take into account the dynamic behaviour of buildings. Crawley (et al., 2005) did a comparison of the most popular simulation programs from different aspects and noted that most of them require complete descriptions of building parameters, operation schedules and hourly observations of weather conditions for the building’s location.

Augenbroe (2006) [24] observed that for demarking the aspects influencing decision in design rationally, there should be connections between the design program and the design concept thereby establishing a clear design objective and organizing the performance thinking on that objective. Simulation in theory incorporates analytical processes, materials and component data, standards, design details, etc and makes it possible to be accessed to the professional. The BPS has reached a high maturation with a range of tools for building performance evaluation [25] in the last ten years. But yet the current tools are inadequate, user hostile and too incomplete to be used by architects during the early phases to design [26]. There is lack of BPS tools during decisive phase that is more focused on addressing the building geometry and envelope for the architect which may enable him to determine the operational cost of the energy consumption of the building in the whole life of the building. As pointed out by Attia (2012) [27] out of the 392 BPS tool listed on the DOE website in 2011, less than 40 tools are targeting architects during the early design phases. Morbitzer (2003) [28] summarized the different stages of the design process and difficulties embodied in them by examining the integration of simulation into the building design process. The influence of simulation based environmental design decision support tools in architecture was the subject of research for Donn (2004) [29] while Mourshed (2006) [30] delved into the optimization of architectural design decision making. The use of uncertainty and sensitivity analysis in BPS for decision support and design optimization was done by Hopfe (2009) [31]. With the aid of simulation tools at the early design phase many problems like increasing the designer’s knowledge on various energy consequences at the design phase can be sought out. Presently there has been a progress in terms of software development in form of ‘Virtual Building Environment’, ‘Single Project Model’, ‘Building Information Modelling’, and ‘Virtual Product Modelling’ by the vendors of alternate design systems such as Archi-CAD, Bentley, Autodesk, and CATIA. These simulation tools currently available are only proficient in performing decision already made by the architects before the energy assessment and, consequently there exists low level adoption of these tools by architects. Thus, the present generation of software provides building information modelling in place of building graphic modelling.

C. Energy Design Decision Support Simulation Tools in Early Design Phase (EDP)

For the decision support in the energy efficient buildings energy simulations are of great importance. Hensen (1994) [32], Robinson (1996), Morbitzer (2003), Mahdavi et al. (2003) [33] and Obanye (2006) [34] proposed the use of that use of simulation in the early design stage (EDS) by both architects and engineers which can influence better design of energy efficient buildings. As the design process of the building design advances, changing design options becomes more onerous and time consuming [35]. Attia et al. (2011) [36] further elaborated on the wish list of the architects and engineers for determining selection criteria for BPS tools. These studies demonstrated the importance of an accurate estimation of energy needs and optimization of building solutions in early stages of design. The underlying logic of architect’s needs and expectations for use of energy simulations for design process has been addressed by these researchers. Various simulation tools are available to help us test the influence of different parameters such as energy use in operation phase [37], analysing the environmental impact [38], and others on the design and functioning of the building. Mostly simulation programs are intended to show the quality of the
building when it is finished while less attention is given to the optimization of the building in the planning phase. This means that in the early design phase of the project a licensed assessor uses the available information and the support of building designers to give a rough estimate regarding the fulfillment of individual demands—the so-called pre-assessment. Certain programs allow a preliminary score to be acquired on the basis of a smaller number of core criteria, which are assessed according to the usual procedure [39].

The integration of BPS tools into early design phase based on studies [40] are summarized as Geometry representation, Filling input, Informative support for decision making (guidance), Evaluative performance comparisons, Interpretation of results and Informed iteration. A study done by Attia (2011)⁴ [41] on the use of Building Performance Simulation (BPS) tools during early design phases aimed to note the potential of integrating the tools by architects. There were ten number of tools, namely HEED, e-Quest, ENERGY-10, Vasari, Solar Shoebox, Open Studio Plug-in, IES-VE-Ware, Design Builder, ECOTECT and BEopt, on which the study was conducted and the result was analyzed on usability, optimization, interoperability, accuracy and design process integration of the tools.

IV. DISCUSSION: APPROACHES TO RESOLVE THE INTEGRATION OF OBSTACLES FOR ENERGY SIMULATION IN EARLY DESIGN PHASE

Recent research has revealed that in practice, intuition and rules-of-thumb are preferred over energy simulation which is ranked amongst the lowest methods of decision support used by designers although simulation have the ability to evaluate climate and design-specific idiosyncrasies [42] There are a number of reasons why energy simulation has not been taken up as a decision support tool in early design. One of the basic reasons behind this being the tradition of using these tools by services engineers late in the design process usually for verification purposes. Another reason behind the fact is that the available energy simulations require detailed information, that is not available at the early design phase about a building’s construction and services before an analysis can be performed [43]. Inputs and outputs were largely numeric, and consequently the translation of model descriptions and simulation results often observed to lead an architect to a messy situation [44] where even the interface of the existing tools were observed to be complex and cumbersome [45].

V. TABLE 1

<table>
<thead>
<tr>
<th>Architect Oriented Simulation Program</th>
<th>Engineers &amp; Experts Oriented Simulation Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>No excessive data input requirement</td>
<td>Detail input of data is required</td>
</tr>
<tr>
<td>Suitable for small projects due to less cost</td>
<td>Is applied for all projects as cost is not a barrier</td>
</tr>
<tr>
<td>Implementation, analysis and validation to be made easy</td>
<td>Detail implementation, analysis and validation of the program run</td>
</tr>
<tr>
<td>Modification to be made easy at initial level</td>
<td>Experts can only modify them</td>
</tr>
<tr>
<td>To simulate the basic level parameters only</td>
<td>Maximum parameters is considered</td>
</tr>
<tr>
<td>Simulation time should be minimum</td>
<td>Simulation may take hours</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

The recent development of direct links between early design and analysis applications in both modelling and simulation software have given rise to many energy simulation tools in the said phase. The energy simulation tools, which exist, at present, are not used by architects regularly because they have shortcomings such like excessive data input requirement, complex user interface, and time consumed for the simulation. The architects prefer tools that are simple and easy to use. This paper has presented the need for energy oriented design system that is currently lacking, especially in Indian context, which when developed will address the design process centric approaches where simulation activities respond to early decision making. This decision making could be helpful to the architects to know the energy consumed by the residential building during its life. From the study the following points were identified to be taken up for future work.
Fig 2: Conceptual Design Elements Identified to Simulate to lower Operational Energy Consumption in Buildings

The nature of aggressive goals for energy consumption control in residential areas requires early creation of energy models during pre-conceptual and conceptual design phases.

REFERENCES


