

EARLY DECISION SUPPORT FOR NET ZERO ENERGY BUILDINGS DESIGN USING BUILDING PERFORMANCE SIMULATION

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ABSTRACT

This paper aims to investigate the use of building performance simulation tools as a method of informing the design decision of NZEBs. The aim of this study is to evaluate the effect of a simulation-based decision aid, ZEBO, on informed decision-making using sensitivity analysis. The objective is to assess the effect of ZEBO and other BPS tools on three specific outcomes: (i) knowledge and satisfaction when using simulation for NZEB design; (ii) users' decision-making attitudes and patterns, and (iii) performance robustness based on an energy analysis. The paper utilizes three design case studies comprising a framework to test the use of BPS tools. Two types of data were collected, mainly preference and performance data. The preference data were used to collect information from participants using self-reported metrics. The performance data were used to collect information on the energy performance of the final design. The energy evaluations were compared with the results of a quantitative assessment of the overall design performance. Finally the results were compared and presented. The paper provides results that shed light on the effectiveness of sensitivity analysis as an approach for informing the design decisions of NZEBs.

Keywords: decision support, early stage, net-zero, design, simulation, architects

INTRODUCTION

Building performance simulation (BPS) tools have the potential to provide an effective means to support informed design decision-making of NZEBs. However, certain barriers block architects' use of BPS decision support for NZEB design during early design stages. The most important barrier is informing design decisions prior to the decision-making and early on in the design process [1-2]. The barriers to informing the decision-making and providing guidance to architects during the early stages of NZEB design have been quoted by a number of previous studies around the world [3-5]. Currently, simulation tools are mostly used in the later stages of NZEB design by specialists as evaluation tools, rather than by architects as guidance tools. In this context, this paper aims to evaluate the effect of a simulation-based decision aid on achieving informed design decision-making by architects during early stages of the design of NZEBs.

DESIGNING AND CONDUCTING THE STUDY

Two types of data were collected, mainly preference and performance data. The preference data were used to collect information from participants using self-reported metrics. The performance data were used to collect information on the energy performance of the final design. Three workshops took place in Cairo to examine the effect of using the BPS tools and sensitivity analysis technique in the design of NZEBs. The workshops were announced and three groups of participants were recruited.

Prior to starting the workshops, participants were asked to achieve proficiency in the use of geometrical modelling in DesignBuilder (DB) using the video tutorials provided online. Additionally, ZEBO, a Graphical User Interface developed for Egyptian, was installed and used by all participants [6]. At the beginning of the workshop, participants were given an introductory crash course in use of DB and ZEBO, requiring a time investment of eight hours. Throughout the crash course, participants were required to follow a guidebook checklist on how to carry out successful simulations. The checklist was developed after reviewing the work of Bambardekar [7] and Rocky Mountain Institute (RMI) [8] and was used to remind participants to use the minimum number of steps and to make the steps explicit. During the introductory tutorial participants were taught to: 1). create a simple building geometry model in ZEBO, 2). perform a simulation and sensitivity analysis exercise using ZEBO, 3). create a simple building geometry model in DesignBuilder, and 4). perform a simulation exercise in DesignBuilder, where the main building components as well as typical occupancy and equipment schedules were provided to the participants.

During the software instruction portion of the workshop, participants followed procedures as demonstrated by the checklist and instructor to create a model. The RMI Building_Model_Checklist was used to remind participants about the minimum steps of the simulation and to make them explicit [8]. The checklist offered the possibility of verification and instils a kind of discipline of higher input performance. The use of the checklist was established for a higher standard of baseline performance.

CASE STUDIES FRAMEWORK

This section describes three different design case studies for NZEBs in which simulation was used to test and measure the ability to achieve informed decision-making for design. Three design workshops were organized early in 2011 in Cairo to design and develop three case studies. We provided all participants with rudimentary software training and asked for volunteers for more in-depth study of the BPS tools package. The aim was to provide opportunities for all participants to attain basic proficiency in using the software package with the help of a checklist developed to enable them to better understand the complexities of performing simulations. This introduction to BPS is meant to build a common-ground for future investigation of design decision-support by BPS during the design development of the case studies in the workshops.

Most participants participated in a previous introductory workshop on BPS tools in 2010 [9]. Before or parallel to that, all participants were instructed in various analysis techniques, including reading a sun path diagram, analysing thermal comfort, using the Database of Egyptian Building Envelop (DEBE) [10], and using the Weather Tool and Climate Consultant for climate visualization. Weather Tool is a visualisation and analysis program for hourly climate data. It recognises a wide range of international weather file formats as well as allowing users to specify customised data import formats for ASCII files. It also provides a wide range of display options, including both 2D and 3D graphs as well as wind roses and sun-path diagrams. The tool allows generating full psychrometric and bioclimatic analysis, which is a unique mechanism for assessing the relative potential of different passive design systems. Solar radiation analysis can be accurately determined and optimum orientations for specific building design criteria. The tool allows comprehensive pre-design climate/site analysis. Climate Consultant is a graphic-based computer program that displays climate data in several of ways useful to architects, including temperatures, humidity, wind velocity, sky cover, solar radiation graphics and psychrometric charts for every hour of the year. Climate Consultant 5.0 also plots sun dials and sun shading charts overlaid with the hours when solar heating is needed or when shading is required. The psychrometric chart analysis shows the

most appropriate passive design strategies in each climate, while the new wind wheel integrates wind velocity and direction data with concurrent temperatures and humidities and can be animated hourly, daily, or monthly.

RESULTS

The effects of the use of BPS and sensitivity analysis, was evaluated by means of three design case studies using a control trial and extended usability testing for preference and performance indicator. The following paragraphs identify the influence of BPS knowledge on the decision-making attitudes and patterns. Then the results of the scenario questionnaire are reported. Then the improved design through the energy performance comparison of the three case studies using BPS tools is verified. Finally, the outcome of the open-ended questions and workshop discussions together with associated material and observations are presented. An extended paper has been published including detailed analysis results [11].

Satisfaction: Using self-reported metrics, the background knowledge and understanding of NZEBs design and the satisfaction with the use of BPS decision-support were determined.

Knowledge: Evaluating the effectiveness of BPS tools in informing design required an understanding of the participants' pre- and post-simulation knowledge. Respondents completed pre- and post-simulation surveys to assess the value of the BPS tools to further the participants' understanding of NZEBs' design influences and their relation to the use of simulation. In order to assess participants' knowledge about NZEB design issues, participants were asked "How would you assess your ability to design NZEB?" Table 1 shows the paired t-test analysis of pre- and post-responses, showing a statistically significant increase. A significant increase in knowledge uptake was recorded for the three groups. Moreover, the repetition of this increase in all three group samples is strong evidence that the use of BPS increased the knowledge uptake. This indicates participant perception of growth in informative knowledge of the basic tenets of decision-making.

Table 1, Pre- and post-test analysis

ITEM	PRE-TEST	POST-TEST	MEAN	T	P	N
	MEAN	MEAN	DIFFERENCE			
HOW WOULD YOU ASSESS YOUR ABILITY TO DESIGN NZEB? (EECA)	5.40	7.30	-1.900	-5.01	0.0007	10
HOW WOULD YOU ASSESS YOUR ABILITY TO DESIGN NZEB? (FOFA)	4.00	6.13	-2.130	-8.66	0.0318	23
HOW WOULD YOU ASSESS YOUR ABILITY TO DESIGN NZEB? (OPEN)	3.57	6.68	-3.110	-8.88	0.0001	19

Satisfaction (After-Scenario Questionnaire): The After-Scenario Questionnaire (ASQ) developed by Lewis (1995) was used to measure three fundamental areas of usability: effectiveness (question 1), efficiency (question 2), and satisfaction (all three questions). The results indicate a low level of satisfaction regarding the ease of completing the design using ZEBO and other BPS tools for all groups. Similarly results indicate a low level of satisfaction with the amount of time taken to complete the design using ZEBO and other BPS tools. The explanation for this low rating for both questions can be found in Sections 4.4 and 4.5. On the other hand, participants' satisfaction with the information support was reported to be high. Surprisingly, the patterns of answers of the three groups almost match. These findings have unlimited generalizability because the sample size for the factor analysis was relatively large (52 participants). Also the resulting factor structure was very clear.

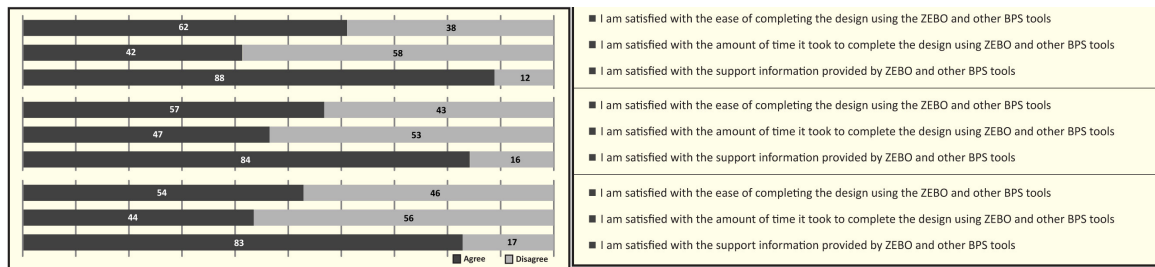


Figure 4, The After Scenario Questionnaire Results of the EECA, FOFA and OPEN groups respectively

Decision-making attitudes and patterns: Another self-reported usability metric was a post-workshop questionnaire that was administered to participants regarding how far using ZEBO and other BPS tools informed their decision-making and led to higher reliability and robustness of the NZEB design. Participants were asked to fill in an online questionnaire with six questions.

Informed decision-making: Figure 5a and 5b show that participants' questionnaire responses vividly indicate agreement with the statements "guides your decision-making" and "informs your decision-making". With regard to the "guiding" question, Most of Group 1 respondents strongly agreed or agreed while few were undecided. The results of Group 2 and Group 3 were similar. In total, 71.2% of participants recognized the importance of BPS tools in guiding the decision-making of NZEBs design even though 6.0% of all three groups disagreed with the statement. With regard to the "informing" question and as shown in Figure 5b most of participants recognized the importance of BPS tools in informing the decision-making of NZEBs design and none of the questionnaire respondents disagreed with the statement. In Group 1, 2 and 3, almost all respondents strongly agreed or agreed with the statement while few were undecided.

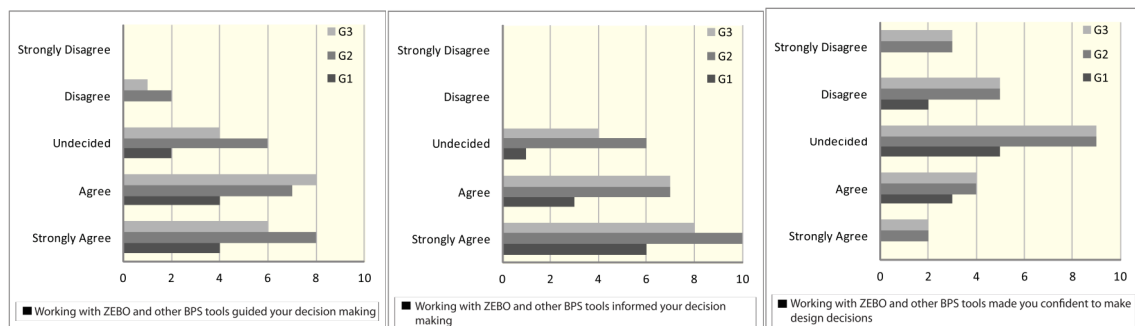


Figure 5, Participants' responses to a question related to guidance of decision making, informed decision making and confidence in decision making

However, as shown in Figure 5c, participants disagreed with the statement "makes you confident about your decision-making". In total one third of participants disagreed that the use of ZEBO and other BPS tools made them confident about their decision-making in NZEBs design while almost half of respondents were undecided. In the open-ended questions and discussion respondents indicated that the simulation process and the results have to be well presented and understood, so that they can gain confidence from the information.

Reliability and robustness of design: Figure 6a shows that participants' questionnaire responses indicate disagreement with the statement "allowed you to achieve the NZEB design target". In total more than half the participants disagreed that the use ZEBO and other BPS tools allowed them to achieve the NZEB design target while one third were undecided

According to Figure 6b, more than two third of participants agreed that the use ZEBO and other BPS tools is essential for NZEB design. More than half participants agreed that the use ZEBO produced reliable and robust NZEB design while one third of respondents were undecided (see Figure 6c). To avoid any ambiguity of the terminology the term reliable and robust was explained before the questionnaire. For most participants having to use ZEBO or DesignBuilder which are graphical user interfaces for EnergyPlus was sufficient to produce reliable and robust NZEB design.

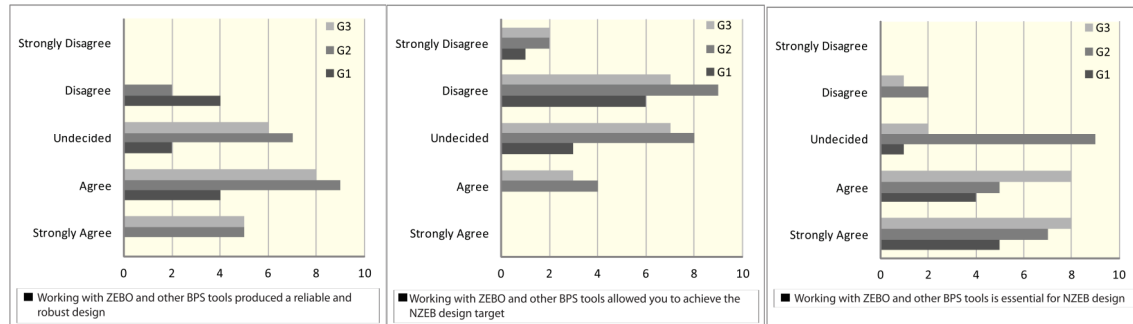


Figure 6, Participants' responses to a question related to the achieving the NZEB, importance of using BPS for NZEB design and BPS tools and the reliability and robustness of NZEB design

Verifying the effect of BPS: This section presents the combined effect of BPS on design, knowledge and energy performance improvements of the design projects. The impact of BPS is compared and summarized in Table 2. As shown in Table 2 and described in section 4.1.1, a significant increase in knowledge uptake was recorded for the three groups. Also the new design incorporated optimised changes which were compatible, acceptable to the designers. Their introduction was a result of sensitivity analysis and parametric variation of the different design parameters listed below:

- The geometry was redesigned to reset the mass correctly with orientation close together.
- The solar protection was redesigned so that it maximizes the shading of openings and envelope.
- The openings ratio and glazing type were significantly improved in the third design round.
- Extra envelope insulation was added so that all envelopes thermal performance improved by at least 50%.
- The PV & ST sizing and architectural integration was optimised in all designs

DISCUSSION AND CONCLUSION

The use of BPS tools and the sensitivity analysis technique in the design of NZEBs demonstrated a strong correlation between increased usage and achieving informed decision-making. The main purpose of using BPS tools was to assess their ability on informing the decision making by using a simple parametric tool (ZEBO) and a detailed comprehensive tool (DesignBuilder). The aim of the study was not to compare those tools or expose participants to a broader composition of tools; rather it was assess the mechanics and process of using BPS tools to inform the decision making. In order to evaluate BPS and sensitivity analysis as a tool for informing decision-making, participants completed several questionnaires assessing their informative effectiveness. The questionnaires reveal participants' perceptions of the simulation's informative importance in their design decision-making. Specifically, the open-ended questions and group discussion addressed the value of and barriers to the use of

simulation as a decision-support method. To validate the study findings a formal energy analysis measure was employed in this respect. A group discussion was also used as an informal triangulation to facilitate the validation of the survey results reported below:

1. There is a relationship between BPS usage and better energy performance outcomes.
- 2). Parametric Analysis features were found to promote informed decision making.
- 3). The case studies revealed a significant difference in knowledge levels before & after.
- 4). NZEB design ambitions should be tempered by the complexity of design and design process.
- 5). A more pre-decision approach is required to meet the uncertainty of decision making of designers.
- 6). Value of usability testing and other user experience measurements (self-reported metrics) is high as a research methodology.
- 7). Four factors that promote or inhibit the uptake of BPS as decision support in architectural practice: a) Interactional usability, b) Decision support (informative), c) Users' skills d) Contextual integration.

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