EARLY DESIGN SIMULATION TOOLS FOR NET ZERO ENERGY BUILDINGS: A COMPARISON OF TEN TOOLS

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ABSTRACT

Given the challenges to design Net Zero Energy Buildings (NZEBs), the use of Building Performance Simulation (BPS) tools during early design phases has been indispensable. In this context, we compare ten early design BPS tools. The aim is to define the potential of using and integrating the tools by architect during the design of NZEBs. The examined tools include HEED, e-Quest, ENERGY-10, Vasari, Solar Shoebox, Open Studio Plug-in, IES-VE- Ware, DesignBuilder, ECOTECT and BEopt. The comparison is based on two different criteria sets. The results describe tools limitations and major requirements to meet the NZEBs objective implications.

INTRODUCTION

BPS techniques can be supportive when integrated early in the design process. However, architects suffer from BPS tools barriers during this decisive phase that addresses more the building geometry and envelope. Despite the proliferation of BPS tools the barriers are still high. The design and decision area during early phases is characterized by barriers regarding architects' needs and design process. Current simulation tools are inadequate to support and inform the design of NZEBs during early design phases specifically. Most simulation tools are not able to adequately provide feedback regarding the potential of passive and active design and technologies, nor the comfort, used to accommodate these environmental conditions. Several studies show that current tools are inadequate, user hostile and incomplete to be used by architects during the early phases to design NZEBs (Lam 2004, Riether et al. 2008, Attia et al., 2009, Weytjens et al., 2010). In fact, architects are not on board concerning the use of BPS tools for NZEB design. Out of the 389 BPS tool listed on the DOE website in 2010, less than 40 tools are targeting architect during early design phases as shown in Figure 1 (DOE 2010).

On the other hand, the integration of BPS in the design of NZEB is challenging and requires making informed design decisions and strategic analysis of many design solutions and parameter ranges and simulates their performance. A recent study by the author has shown that architects' most important selection criteria for BPS tools is intelligence, as shown in Figure 2, that provides the opportunity to inform the decision making and allows decisions on building performance and cost (Attia et al., 2011). Architects indicated the lack of intelligence within the compared tools. The study revealed that architects and non-specialist users who want to design NZEBs frequently find it difficult to integrate BPS tools in the design process.

Therefore, to deliver NZEBs we must lower the barrier between building design and performance, ensuring the best guidance is available during critical decision making of NZEB design. Architects' decisions to design NZEBs should be informed. Many research investigations in literature describe the reasons of those barriers, but little effort has been done to develop the required methods and tools that can predict the building performance in use and support the design decision making of buildings.

In order to cross those barriers and achieve the aims identified earlier this research proposes selection criteria for NZEBs simulation tools and compares the ten tools against the proposed criteria. This study is part of a larger that aims to lower the barriers of integrating BPS during early phase in design and identify the gaps of BPS tools when dealing with the particular feature and target value requirements of NZEBs. This paper presents a comparative study of ten available BPS tools dedicated to early design stages. The comparison is based on two sets of criteria. The first set, are five criteria including usability, intelligence, interoperability, accuracy and design process integration of the tools.

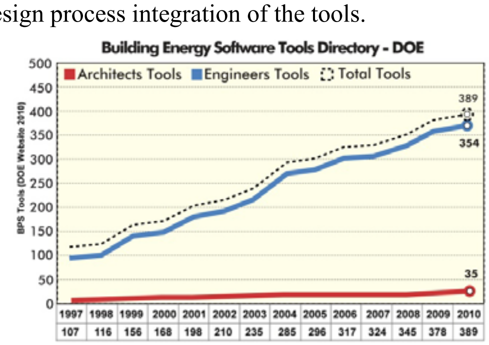

Figure 1: BPS tools between 1997 and 2010

The second set is a design matrix for early design stages of NZEBs. Also we selected early design tools with sufficient precisions to be used by architects.

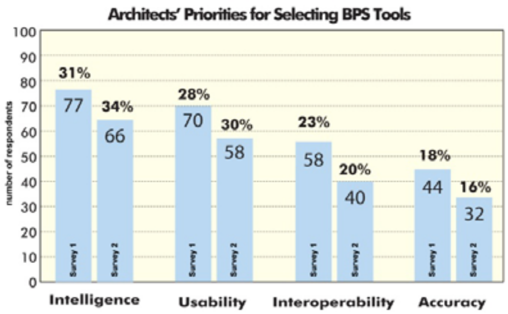

Figure 2: Ranking the most important features of a BPS tool

The following chapters will present an outline of the comparison. Firstly, we present some of the most important, drawbacks of existing early design tools in relation to the design process of NZEBs. Secondly, we present a basic cross comparison of the ten tools. Finally, recommendations for tools are given and improvements for future research are suggested.

DESIGN PROCESS & TOOLS OF NZEB

The building delivery process has been traditionally a linear and sequential set of activities (Mahdavi et al., 1998 and Lam et al.,1993). However, the 'net zero' objective is a cyclic energy performance based design goal that embraces the integration of energy performance goals early in the design process. Architects are forced to expand their scope of responsibility beyond function and aesthetics. The design process of NZEBs shows that the design is not intuitive and energy performance requirements must be determined in the early design stages. Therefore, BPS tools are a fundamental part of the design process (Hayter, et al. 2001, Athienitis, et al. 2010 and Donn et al., 2009). During early design phases 20% of the design decisions taken subsequently, influence 80% of all design decisions (Bogenstätter 2000). In order to apply simulation during early design phases it is better to understand the current building design and delivery process of NZEBs because the effectiveness of tools are affected by process.

NZEB as performance-based design

The main concern of NZEBs design is the performance-based design (PBD) approach. As formulated by Kalay and Hayter et al., it emphasizes the design decision making in relation to performance (1999 and 2001). Similar to the evidence-based design (EBD) approach that emphasizes the importance of using credible data in order to influence the design process in Healthcare Architecture, the PBD has become a fundamental approach to evaluate the energy performance of buildings in Environmental Architecture. Experience with constructed NZEBs, shows that their design process is based on cyclic iterations and performance-based decision making that effectively integrates, early on, all aspects of building design, energy efficiency, daylight autonomy, comfort levels, renewable energy installations, HVAC solutions, in addition to innovative solutions and technologies (Hayter 2001 and Donn 2009). Architects workflow is iterative aiming to achieve the performance objective while conducting trial-and-error analysis. Designers evaluate different design combinations and parameters based on their performance during early design stages of NZEBs. To put the design process of NZEBs in perspective, designers have to meet with successive layering constraints with a performance based objective and define their work in a set of performance criteria, rather than work out the design traditionally in a prescriptive objective.

Tools for NZEBs

Consequently, the performance-based approach has implications on BPS tools. The performance-based design approach of NZEBs forces tools to address two issues early on: First maximize energy efficiency and secondly the delivery of needed energy with renewable systems. A critical look at the existing tools in relation to NZEBs design process shows that two main barriers exist in integrating the current BPS in this stage:

- First of all, the lack of informative support during the decision-making.
- Secondly, the lack of informed iteration based on evaluation.

Therefore, and in order to assess the capabilities of existing BPS tools we established a criteria for NZEB tools. The criteria intend to compare simulation tools and their suitability to cater for NZEBs design.

CRITERIA FOR NZEB TOOLS

The selection criteria for NZEB tools are based on two sets of criteria. The first set of criteria addresses the general tools mechanics, necessary to judge the tools usefulness. The second set is based on the specific tools features regarding the NZEB design.

NZEB Tools Mechanics

BPS tools selection criteria can be defined as the classification and description of tools' capabilities, requirements, functionalities, specifications, features, factors, etc. In the past, a number of comparative studies have been published and addressed the selection criteria of BPS tools. For this study we selected Attia's (2011) criteria that has been set to justify and classify the major tool capabilities. These five criteria are listed below (see Figure 3):

1. Usability $ Information Management of interface
2. Intelligence & Integration of Knowledge-Base
3. Accuracy of tools and Ability to simulate Detailed and Complex building Components
4. Interoperability of Building Modelling
5. Process Adaptability

Figure 3 Selection criteria &NZEB tools mechanics

NZEB Tools Matrix

The IEA Task 40/ECBCS Annex 52 is developing comprehensive qualitative and quantitative benchmarks that were established to compare the capabilities of simulation experts' tools (Bourdoukan P., et al. 2009 & 2011). However, for this study we screened the most recurring early design features in the design of NZEBs to compare the capabilities of architects' simulation tools. Early on during the conceptual stage, designers should address six main building design aspects including:

1. Metric: There are several definitions for NZEBs that are based on energy, environmental or economic balance. Therefore, a NZEB simulation tool must allow the variation of the balance metric.

2. Comfort Level & Climate: The net zero energy definition is very sensitive toward climate. Consequentially, designing NZEBs depends on the thermal comfort level. Different comfort models, e.g. static model and the adaptive model, can influence the 'net zero' objective.

3. Passive Strategies: Passive strategies are very fundamental in the design of NZEB including daylighting, natural ventilation, thermal mass and shading.

4. Energy Efficiency: By definition, a NZEB must be a very efficient building. This implies complying with energy efficiency codes and standards and considering the building envelope performance, low infiltration rates, and reduce artificial lighting and plug loads.

5. Renewable Energy Systems (RES): RES are an integral part of NZEB that needs to be addressed early on in relation to building from addressing the panels' area, mounting position, row spacing and inclination.

6. Innovative Solutions and Technologies: The aggressive nature of 'net zero' objective requires always implementing innovative and new solutions and technologies. Based on those features we created a NZEB tools comparison matrix that provides an overview of the ten compared tool capabilities to support NZEB design (see Table 1).

RESULTS

This section presents the comparison results of the ten tools. For this article, main results that reflect the most important tools capabilities are selected. The complete results are presented and can be found in the final study report (Attia 2011). Table 1 shows the NZEB Tools Matrix, indicating what type of NZEBs features each tool can calculate.

NZEB Tools Mechanics

1. HEED: Usability (Medium)**:** The input process follows the wizard approach, which is simple, but lacks flexibility and is primarily based on text. The interface is simple with a restrained set of options, which improves navigation. Component properties are selected from predefined lists, but customised choices are more difficult to define. The output clearly supports benchmarking and alternatives comparison. Particularly, the building's performance is compared with a code complying and a more energy-efficient design. This improves the interpretability of the results by architects and facilitates the decision-making process. However, input filling and results interpretations are very challenging.

Intelligence (Medium): Based on few input parameters, the program automatically creates two reference cases, one meeting the California energy code and another more energy efficient. The easy comparison of design alternatives facilitates design decision-making. The tool also has a large and reliable database. Also the tool provides pre-design advices based on the climatic context. The tool does not allows parametric or optimisation analysis.

Interoperability (Low): The building geometry is restricted to shoebox geometry with maximum 10.000 sq. feet. The program does not allow any exchange with CAD, gbXML, BIM or other drawing tools.

Process Adaptability (Low): HEED is easy to use and requires minimal time to perform design evaluations. However, due to the nature of data-input, the low level of detail and limited building area the tool is only suitable for early design phases and does not allow connectivity with evaluation tools used in large buildings, by engineers in advanced design stages.

Accuracy (High): It uses an hourly heat balance technique for calculating the energy consumption. HEED was tested using the ASHRAE/BESTEST evaluation protocol.

2. e-QUEST: Usability (Medium): The interface is mainly textual and has limited visual appearances. The wizard approach impedes flexible use and navigation. The process of data-input follows a wizard approach. This facilitates the input process for a well-informed user, but lacks flexibility. The data-input is primarily textual, too detailed and not architect-oriented. Although the output supports easy comparisons of alternatives, it is often difficult to use in relation to design decision-making.

Intelligence (Low): The main intelligence features are related to the alternatives comparison capabilities and the embedded default values. If a non-experienced user changes any default value (in green), the tool highlights the changes in red. The tool does not allow optimisation analysis but allows restricted parametric analysis.

Interoperability (Low): The tool allows importing 2D CAD files, multi-zonal modeling and of modeling of inclined surface for pitched roofs. However, the tool cannot exchange 3D models in any format. The program does not allow any exchange with 3D CAD, BIM, gbXML or other drawing tools.

Process Adaptability (Medium): Most required input parameters are beyond the focus of early architectural design choices. Hence, the tool's usage is primarily oriented to schematic and detailed design phases. Engineers can mainly use the tool in large buildings in advanced design stages.

Accuracy (High): The simulation engine within eQUEST is derived from the latest official version of DOE-2. DOE-2 has been widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol.

3. ENERGY-10: Usability (Medium)**:** The interface is not visual, impeding flexible navigation. The input is mainly numerical and it is difficult to customize existing or create new components. Although the output provides an interesting comparison between the two simulated cases, several output graphics are neither intuitively interpretable for architects nor convincing to clients. An exhaustive list of output options is considered.

Intelligence (Medium): Includes default components and extensive US context default values for HVAC systems, material properties and wall sections and library for material components. ENERGY-10 allows alternatives comparison and ranking of design strategies for different parametric and energy efficiency measures.

Interoperability (Low): The building geometry is restricted to shoebox geometry with no 3D representation and maximum 10.000 sq. Feet floor area. The program does not allow any exchange with CAD, gbXML, BIM or other drawing tools.

Process Adaptability (Medium): The required inputs are minimal and solutions are obtained quickly. However, the shoebox abstraction and area limitation of building geometry disconnects the simulation from the architectural design, restricting its usability in the conceptual stage.

Accuracy (High): The accuracy of ENERGY-10 has been demonstrated using the BESTEST procedure.

4. Vasari: Usability (High)**:** The tool is easy to use and flexible to navigate with many tabs and button including climate analysis, solar radiation and other analysis features imported from Ecotect. The interface has the same Revit modeling logic and is structured to focus on geometrical modeling and energy analysis. The input template is very limited and is in textual format. The out is very visual but still hardly interpretable to feedback or inform the design.

Intelligence (Low): Vasari allows alternatives comparison. The main intelligence of Vasari is lies in its ability to do parametric modelling. However, there are many limitation regarding construction, schedules and HVAC databases. The tool uses generic default settings with no possibility for modifications. The tool does not allows parametric or optimisation energy analysis.

Interoperability (High): Vasari and the conceptual modelling features have a background in parametric modelling and programming and allow organic massing. The tools has is a flexible parametric and geometric design tools, allowing a variety of 3D forms and templates with a architect friendly 3D massing and modeler tool. The tool exchanges models to full Revit Architecture, Structure or MEP as Vasari uses the same .rvt . gbXML models cannot be imported, but Vasari models can be exported as gbXML from the application menu.

Process Adaptability (Medium): The tool is very suitable for early design phases and especially site, solar analysis, and geometry and massing analysis. However, the main disadvantage of the tool lies its restricted energy analysis which does not allow it to be used in later phases or by advanced simulation experts.

Accuracy (High): Vasari uses Green Building Studio, which is based on DOE2 energy simulations. DOE-2 has been widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol.

5. Solar Shoebox: Usability (High)**:** Very simple one page interface and basic input features allows the designer to explore different passive strategies. The tool is fast and the output is interpretable. The results are reported in a yearly graph that shows the outdoor and indoor temperature. The indoor temperature range is based on adaptive comfort level, which is a unique feature. However, the tools should allow little input and output options.

Intelligence (Medium): The tool is powerful in allowing passive design modifications and design optimisations in relation to thermal comfort, but does not allow alternatives comparisons. The building parameters allow designing a shoebox direct gain passive solar building. The tool does not allow defining HVAC systems, parametric or optimisation energy analysis.

Interoperability (Medium): The tool is restricted to shoebox geometry and does not exchange any form with other tools. The program does not allow any exchange with CAD, BIM or other drawing tools.

Process Adaptability (Medium): Very suitable for early design stages while the IDF file can be used by advanced simulation experts in other environments.

Accuracy (High): The tools' analysis engine used is EnergyPlus. EnergyPlus has been widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol.

6. OpenStudio: Usability (Low)**:** OpenStudio is based on the intuitive, easy-to-use SketchUp, a popular drawing tool used by architects. The user spends less effort than to construct the geometrical data numerically in EnergyPlus, however, there is a confusing difference between building the geometry in the regular mode versus the thermal mode. The tools simulation output is basic and user must run the OpenStudio Result Viewer to get feedback for the predicted simulation. The Results viewer is a statistical tool with various output formats. However, results are hardly comparable, interpretable and are often difficult to use in relation to design optimisation.

Intelligence (Low): The tool has a very limited database for HVAC and constructions with no possibility to assign materials, constructions characteristics and Internal loads. OpenStudio does not allow alternatives comparison and ranking of design strategies for different parametric and optimisation analysis of energy efficiency measures.

Interoperability (Medium): The tool allows the quick creation of building form and massing. The tool exchange CAD files and embeds the geometry in the IDF file. The program does not allow any exchange BIM or gbXML tools.

Process Adaptability (Medium): The tool can be used by architects and allows the exchange of building models for more detailed input by experts.

Accuracy (High): (see Solar Shoebox)

7. IES VE-Ware: Usability (High): VE-Ware toolbar in Sketch-Up is simple with a restrained set of options, facilitating data-input and navigation. The tool incorporates many quality assurance features. The process of data-input is easy and quick. Building components and systems can easily be defined but only in the UK context, using simple drop-down menus with preset defaults. However, there is no possibility to go beyond the built-in choices, as no customised options are offered. The output results are not very suitable to support the decision-making process. This is mainly due to lack of visual presentation and too much textual and tabular information. In addition, feedback into the design software (Sketch-Up) is not possible.

Intelligence (Medium): VE-Ware allows alternatives comparison. The tool allows the input for HVAC, solar gains, shading, natural ventilation and dimming strategies. Also the tool allows the simulation of thermal comfort, comparisons of results and check the compliance with LEED and SBEM. However, many embedded hidden default values cannot be accessed.

Interoperability (Medium): The building geometry is modelled in Sketch-up, a familiar modelling environment to architects. However, the building model has to be imported to IES, interrupting the fluidity of the tool and enforcing the user to switch to another environment. The tools allows direct connectivity to SketchUp, Revit and ArchiCAD. gbXML and DXF models can be imported to VE-Ware.

Process Adaptability (Medium): The tool is adapted to different design phases and design users, allowing the flexibility in developing the model from early design to detailed design stages.

Accuracy (High): The IES APACHE Thermal Analysis system is the core thermal design and energy simulation component. APACHEsim has been tested with ASHRAE Standard 140.

8. ECOTECT: **Usability** (High): Ecotect has one of the most user-friendly interfaces that allows powerful visual analysis tool. The interface is structured around five tabbed views, but navigation and intuitive usage are restrained by a multitude of options. Despite ECOTECT's strength of visualizing output in the 3D-building model, the results of the thermal analyses (mainly charts), are often difficult to interpret. Also, an overwhelming amount of information is generated.

Intelligence (Medium): ECOTECT can display and animate complex shadows and reflections, generate interactive sun-path diagrams for instant overshadowing analysis, calculate the incident solar radiation on any surface. It can also calculate monthly heat loads and hourly temperature graphs for any zone. Default materials and properties are automatically assigned to building elements, strongly reducing inputs. Component properties can easily be modified and new materials can be created in the material library, but not all required properties are in the architect's language. ECOTECT does not allow alternatives comparison , code compliance or ranking of design strategies for different parametric and energy efficiency measures.

Interoperability (Medium): A built-in 3D-modeller facilitates the construction of the building geometry, but the geometry has to be remodelled from scratch. User can import 3D computer models in 3DS or dXF formats from several widely used computer aided design software such as AutoCAD, 3D Studio, Rhinoceros or Sketchup. ECOTECT has added the support for IFC and gbXML schemas.

Process Adaptability (Medium): ECOTECT primarily focuses on EDP. The tool is not adequate for detailed design, as it does not sufficiently support input from general to detail and lacks accuracy. Further, it does not allow straight comparisons between design alternatives.

Accuracy (Low): ECOTECT is lacking an energy analysis option. ECOTECT's thermal simulation results are not fully representative of reality, although this is perhaps not an issue in case of parametric studies investigating the relative effectiveness of design options. This is the main disadvantage of ECOTECT. This is due to the limitations of its thermal simulation engine, which is based on the CIBSE Admittance Method (CIBSE, 1999).

ECOTECT uses this method to calculate internal temperatures and heat loads.

9. DesignBuilder: Usability (Medium)**:** DesignBuilder's interface is well organized around several tabbed views. However, behind this structure, the designer is often confronted with too much information and too many options, impeding ease of use and navigation. DesignBuilder offers several distinctive input options, each requiring different levels of detail. Extensive templates and default values further allow a reduction of data-input, but custom data-input is difficult. Despite the interesting feature to perform parametric analyses, most output graphics are too detailed to architects and are not intuitively interpretable. Also, an overwhelming amount of information is generated. Consequently, the output results do not sufficiently support the architect's decision-making process.

Intelligence (Medium): The tool allows a range of input tabs and database including constructions, daylighting controls, and natural ventilation, double facade, advanced solar shading, internal comfort and HVAC components. DesignBuilder allows compliance with energy certificates in UK, alternatives comparison and parametric analysis of different design parameters.
Interoperability (Medium): DesignBuilder provides interoperability with BIM models through its gbXML import capability. This allows importing 3-D architectural models created in Revit, ArchiCAD or Microstation. Also, the building geometry can be constructed using the 3D-modeller.
Process Adaptability (Medium): DesignBuilder supports different levels of data-input, ranging from general to detail. As such, this tool is largely adapted to the different phases and users of the design stages.
Accuracy (High): (See Solar Shoebox)

10. BEopt: Usability (Medium): BEopt includes an interactive textual main input screen that allows the user to select from many predefined options, those to be used in the optimization. Once an optimization has been completed, each case contains input and output screen. The main output screen includes a results browser that allows to navigate among the results associated with each (optimal and non-optimal) building design simulated during optimization. For each building design, the browser will display detailed results regarding energy consumption, costs, and options, which facilities the interpretation of the output. If multiple cases exist in a project file, a combined graphs output screen will be available.

Intelligence (Medium): An options library spreadsheet that allows a user to review and modify detailed information on all available options including geometry and envelope. The main input screen allows a user to select from predefined options in various categories (e.g., wall type, ceiling type, window glass type, HVAC type, etc.) to specify options to be considered in the optimization. The user can create a benchmark for code compliance in a linked options library spreadsheet. Various cases are often used to analyze building performance as a function of climate. Cases can also be used to study how building performance is affected by economic parameters, PV system characteristics, or the options selected for optimization. Up to 20 cases can be defined, with case tabs displayed along the bottom of the screen. The tool is based and support the USA context and communicate in IP format.
Interoperability (Low): Similar to HEED the tool has a built in 3D modeller that allows the construction of residential building geometry. The program does not allow any exchange with CAD, gbXML, BIM or other drawing tools.
Process Adaptability (High): BEopt supports different levels of data-input, ranging from general to detail. As such, this tool is largely adapted to the different phases and users of the design stages.
Accuracy (High): BEopt calls the DOE2, TRNSYS, DView and eQUEST simulation engines and uses a sequential search technique to automate the process of identifying optimal building designs.

DISCUSSION & CONCLUSION

The aim of the assessment and comparison of ten early design simulation tools was to identify the gaps of BPS tools when designing NZEB. Thus, we were not looking for an abstract ranking of the tools; rather we were looking to form a snapshot of the current use of ten tools. The main finding of this study shows, except BEopt which is an optimisation tool, no tool has been developed to serve the NZEB objective. Each tool was developed for a different purpose and thus, has its own strengths and weaknesses. The common problems of the examined tools are explained according to the NZEB tools mechanics and matrix.

NZEB Tools Mechanics

By compiling the feedback of the ten examined tools (Figure 4) we found:
Usability: The representation of input parameters is a challenge in many tools. Also the representation of simulation output and its interpretation is a barrier. Analytical results presented in tables of numbers or graphs are often too complex, detailed providing an excessive amount of information. The output should better be displayed within the context of the 3D model. The use of default values is an advantage in many tools, however, input quality control is one of the missing features regarding usability.
Intelligence: As mentioned earlier in the introduction, Intelligence was ranked as the most important features among architects. Most examined tools still lack the intelligence (Figure 4) of supporting the designer with code compliant baselines and citable resources, e.g. database for construction, HVAC, schedules, etc. On the other hand, only few tools integrated code compliance and optimisation features. However, we remark that the

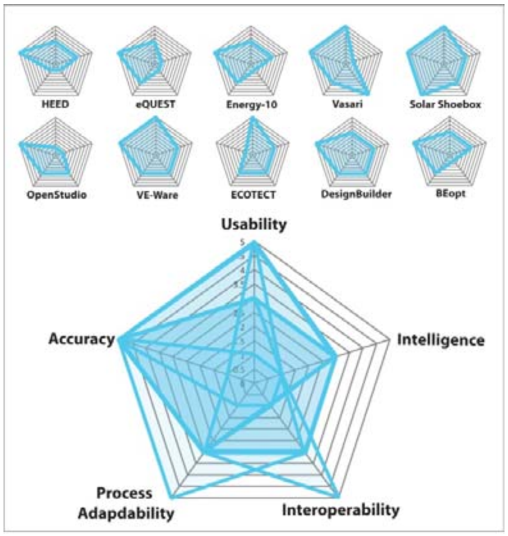

Figure 4, Results of the NZEB Tools Mechanics

Table 1, Results of the NZEB Tools Matrix

NZEB Criteria	HEED	eQUEST	Energy 10	Vasari	Solar Shoebox	Openstudio	IES VE-Ware	ECOTECT	DesignBuilder	BeOpt
Metrics	•	•	•	•	•	•	•	•	•	•
Energy	•	•	•	•	•	•	•	•	•	•
Environmental (CO_2)	•	•	•				•		•	•
Economic	•	•	•						•	•
Embodied Energy										
Urban Scale NZEBs										
Comfort & Climate	•	•	•		•		•	•	•	•
Climate Analysis	•	•	•	•			•	•	•	
Static	•	•	•	•			•	•	•	•
Adaptive					•					
Comfort Visualisation					•			•	•	
Passive Solar	•	•	•	•	•	•	•	•	•	•
Geometry, Massing				•	•	•	•			•
Daylighting	•	•	•				•		•	
Natural Ventilation	•		•				•		•	•
WWR		•	•				•		•	•
Thermal Mass	•		•				•		•	•
Shading Devices	•	•	•			•	•	•	•	•
Energy Efficiency	•	•	•	•	•	•	•	•	•	•
Envelope Insulation	•	•	•	•	•	•	•	•	•	•
Glazing Performance	•	•	•	•	•		•	•	•	•
Envelope Air Tightness	•	•	•				•	•	•	•
Artificial lighting	•	•	•				•		•	•
Plug Loads	•	•	•				•		•	•
Infiltration rate	•	•	•		•				•	•
Mechanical Ventilation	•		•						•	•
Cooling System	•	•	•	•			•		•	•
Heating system	•	•	•	•			•		•	•
Renewable ES	•		•		•		•			•
Photovoltaic (PV)	•		•		•		•			•
Building Integrated PV										
Solar Therm. Collectors			•				•			•
Innovative Solution & Technologies					•		•			•
Mixed Mode Ventilat.					•					
Advanced Fenestration							•		•	
Green Roofs							•			
Cool Roofs	•									
Double Skin Facade									•	
Solar Tubes										
Phase change materials										

more intelligent the tool become, the more it becomes exclusive and local serving a certain countries' context. Moreover, most tools provide only post design evaluations and comparisons. There is a lack of pre-decision and post-design informative support (parametric analysis and optimisation). Even after reviewing the evaluation results, frequently architects ask: What to do next based on the simulation results. More post-processing guidance should be provided in the future. In addition, the optimisation of geometry and envelope in relation to RES systems is still a challenge in all tools.

Interoperability: The seamless geometry exchange is a present problem among all examined tools. Almost no tool allows an easy exchange of geometry.
Process Adaptability: The idea of integrated teamwork and sharing the same simulation model within and simulation package to cater for different design stages and different users (architect/engineers) was successful in a few tools. However, much research is needed to expand the process-coverage of simulation packages to earlier conceptual stages.
Accuracy: Accuracy of most tools was satisfactory and the simulation models were widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol.

NZEB Tools Matrix

The following feedback is structures and based on Table 1.
Metric: Most tools provide energy metrics to assess the design performance and less provide CO_2 emissions and economic matrix. However, almost no tool (except BEopt) operates from a NZEB balance paradigm allowing the user a variety of balance metrics.
Comfort & Climate: Only some tools provided climatic analysis features allowing contextual site and solar analysis. More importantly, no tool provided choices for the comfort models. Most tool do not even mention the comfort and does not the user to investigate this very important performance criteria. In addition, most tools are lacking the visualisation of outputs relative to comfort.
Passive Strategies: In fact, passive solar gets insincere and inadequate support from the examined tools, it's potential is not being utilized including passive design strategies for geometry and massing. Most tools operate from an energy efficiency realm where buildings by default are mechnically acclitised and consequently the design aim is to increase their efficiency. While not many tools help to verify the passive design strategies (thermal storage, heating and cooling) of comfortable buildings with no HVAC systems.
Energy Efficiency: Many of the examined tools provide capabilities to evaluate the energy efficiency target values required for designing a NZEB.
Renewable Energy Systems (RES): A very important problem to analyse when the building designer considers integrating PV systems in the NZEBs, is the sizing and physical settings of RES. Most of the examined tools do not allow the simulation of the most important renewable technologies for integration in NZEBs design. No tool allowed the architect planner to compare possible renewable supply solutions at the same site for instance, grid connected photovoltaic systems, BIPV, wind power plants and solar thermal systems.
Innovative Solutions and Technologies: According to Table 1, most tools could not simulate advanced solutions and technologies including mixed mode ventilation, advanced fenestration, green roofs, cool

roofs, double skin facades, solar tubes or phase change materials. In NZEBs, many innovative technologies are used and thus the examined tools could not provide feedback for such solutions.

Conclusion

There is a strong feedback from the design community that most those tools are not much accessible and therefore rarely used, during the phases of planning and preliminary design of NZEB. Also in the current design practice, multiple tools have to be used during the design process of a NZEB. On the other side, the comparison analysis shows that for NZEBs more input is required for early design rather than late design. In fact, more input is shifting to the beginning. Architects are obliged to get access to simulation programs that model building physics rigorously. Therefore, we should invest more in early design application and tools. The result shows that each one of these tools would be more complete and more functional for NZEB with the addition or improvement of certain features.

Regarding the tools mechanics, intelligence and usability should receive more attention. There is need to improve existing tools to become more effective, efficient & informative tools rather than evaluative tools. To support the design decision, tool developers should provide tools for architects to better manage the NZEB complexities on an urban scale.

Regarding the NZEB objective, we found that:

- We need tools that focus on carbon beside energy
- We need better, citable, queryable and searchable resources databases
- We need to allow simulation passive design strategies
- We need tools that allows minimum efficiency, basecases and code compliance calculations
- We need to address comfort in tools more explicitly
- We need to allow design and optimisation of renewable energy potential of a site versus whole energy system
- We need allow the simulation of innovative system design solution and technologies

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REFERENCES

Athienitis, A., Attia, S. et al, 2010. Strategic Design, Optimization, & Modelling of Net-Zero Energy Solar Buildings, EuroSun 2010, Graz.

Attia, S., et al. 2009. “Architect friendly”: a comparison of ten different building performance simulation tools. Proceedings of the IBPSA Conference. Glasgow, Scotland

Attia S. 2011. State of the Art of Existing Early Design Simulation Tools for Net Zero Energy Buildings: A Comparison of Ten Tools, Technical Report, Architecture et Climat, Louvain La Neuve: Université catholique de Louvain.Available from: http://www-climat.arch.ucl.ac.be/s_attia/attia_nzeb_tools_report.pdf [Accessed April 2011].

Attia, S. et al., 2011. Selection criteria for building performance simulation tools: contrasting architects' and engineers' needs', Journal of Building Performance Simulation,, First published on: 12 April 2011

ANSI/ASHRAE Standard 140-2001, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, 90 pages, ASHRAE, Atlanta, GA 3032

Bogenstätter, U 2000, Prediction and optimization of life-cycle costs in early design’, Building Research & Information, vol.28, no.5, pp.376-386.

Bourdoukan P., and Delisle, V.,2009, A qualitative benchmark for comparison of simulation tools used to design net zero energy buildings, IEA SHC task40, ECBCS Annex 52

Bourdoukan P., and Delisle, V.,2011, A quantitative benchmark for comparison of simulation tools used to design net zero energy buildings, IEA SHC task40, ECBCS Annex 52

DOE, U. S., 2010b. Building Energy Software Tools Directory [online]. Available from: http://apps1.eere.energy.gov/buildings/tools_directory/ [Accessed 1 March 2011].

Donn, M., et al. 2009. Simulation in the service of design – asking the right questions, Proceedings of IBPSA 2009, Glasgow, 1314-1321.

Hayter, S., Torcellini, et al. 2001. “The Energy Design Process for Designing and Constructing High-Performance Buildings,” Clima 2000/Napoli 2001 World Congress.

Kalay, Y., 1999, Performance-based design, Automation in Construction 8 (4), 395–409.

Lam, K P, et. al, 2004. Energy modelling tools assessment for early design phase. Research report, Portland, Carnegie Mellon University, Pittsburgh.

Lam, K.P., et al. 1993. A study of the use of performance-based simulation tools for building design and evaluation in Singapore. in IBPSA. Kyoto, Japan.

Mahdavi, A. 1998. Computational decision support & the building delivery process: A necessary dialogue. Automation in Construction 7: 205-211.

Riether, G., et al. 2008. Simulation space. A new design environment for architects. eCAADe Proceedings . Muylle M., ed., Antwerp, Belgium

Weytjens, L., Attia, S et al. 2010. A comparative study of the ‘architect-friendliness’ of six building performance simulation tools, Sustainable Buildings CIB 2010, Maastricht, Netherlands.