

INTEGRATING BUILDING ENERGY SIMULATION INTO THE ARCHITECTURAL DESIGN PROCESS

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Abstract

Building energy simulation is an important tool for the study and development of energy efficient buildings. It is a tool that the Architectural and Construction Communities should employ to accurately predict and enhance the energy performance of our buildings, throughout their various lifecycle stages (from it's design formation, through to it's operation and management (**Website:"bs2003"**)). This paper attempts to review the extent 'Building Energy Simulation' (BES) tools are used by the Architectural Community. It also attempts to explore 'BES' as an analytical tool for 'building research' and evaluation of architectural design, by specifically focusing on it's current operation and implementation into the design process. In doing so, this paper attempts to identify a few current and on-going problems these tools face, and suggests possible solutions and methods on how to incorporate BES tools into the design process in order to enhance and optimize the energy efficiency of our built environment.

Keywords: architectural community, building energy simulation, design process, integration.

1. Introduction

“No one owns the air we breathe or the rain that falls. The Earth belongs to everyone, so we all have to respect it. When people ask me ‘what is the cost to do sustainable design?’ I ask them ‘what is the cost not to?’” (Wilson 2002).

There are various economical consequences of the decisions made during the design process. For instance, it may seem less expensive to design and construct a simple, building structure, where emphasis is only paid to the cost of the materials and of its construction. But when considering the long term and environmental costs, where emphasis is paid on balancing the initial cost of its construction, its environmental cost, and the cost to the users (i.e. usability, maintenance, etc.), the cost is then transferred from being not only an economical factor, but also a socio-economical factor. However, there are legislative laws put in place to help promote the good design of buildings, taking into account the rights and comfort of the users and the public, as well as the environmental impacts. Therefore, it is important to understand the physical properties and behaviour of buildings, in order to cater for it in their design.

To help the designer in determining these factors and properties, BES tools could be employed. These tools are used to provide environmental simulation data, which the building designer can then use as a basis of his/her cognitive analysis in determination of the building’s optimum environmental design, which can only be achieved by satisfying its predefined objectives, i.e. capital costs, operation, and maximizing daylight (Mourshed 2003).

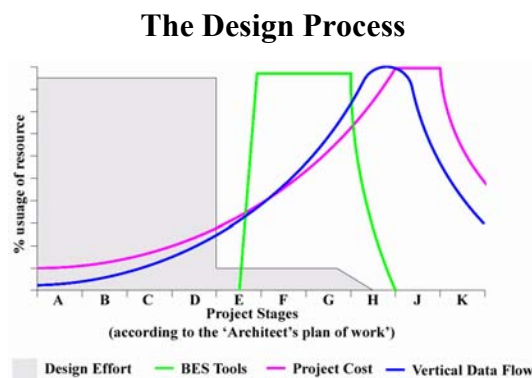


Figure 1: A diagrammatic illustration of the resource application throughout a typical project life of a building, structure, or environment (in current practice).

Projects which implement the use of BES tools, usually do so during the detailed design stage, when most critical decisions (i.e. building azimuth, mass, etc) that will effect the overall building efficiency, have been finalized by the lead designer. This neglects the verity that most energy savings could be achieved if BES tools are employed during the initial stages of design. As opposed to the current practice of using them (if at all) during the production stage to validate the design (**Mourshed 2003**).

BES tools are intended to transform the instinctive surmise at the initial design stages, into well-informed decisions, that will assist the overall development of the design.

2. Government Initiatives

Feb, 2004, the ODPM released a ‘white paper’, which highlighted the need to promote and improve the energy efficiency of buildings throughout the UK. This message has since been reinforced by the recent release of the revised building regulations – Part F (ventilation) and Part L (energy efficiency), which are planned to be in effect as of 6 April 2006. The ODPM and DEFRA have also set out targets to improve the environmental standards by 40% and/by saving one million tones of carbon (the main ‘green house’ gas).

In addition, recent government publications (**WhitePaper 26.04.04**) predict there to be a reduction of twelve million tones of carbon emissions by 2010, saving households and business’ three billion pounds per year on energy expenditure.

The EC Directive 2002/91/EC on energy performance of buildings comes into force in 2006. This directive enforces the requirement of energy certificates at the point of completion (new build), sale, rental, and for public display (**Cook 2004**).

In order to reach and over achieve the goals set out in the various government initiatives, the Architectural Community need efficient and easy to use tools to assist them in analyzing and understanding the full complexity of all the environmental aspects concerned.

The Architectural Community

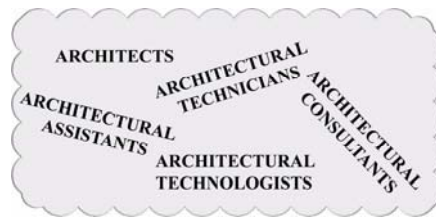


Figure 2: This diagram illustrates the disciplines which make up the Architectural Community.

Background

The current BES tools have evolved from the HVAC related programs of the early 1960's, which were developed to undertake 'non-trivial' building design analysis and appraisals (**Kusuda**), i.e. general thermal simulations based on hour by hour calculations. These systems were directly beneficial for the gas and electricity industries, which were thriving at the time (1960's).

Many of the simulation methods employed during this period are still in use today (i.e. DOE-2, BLAST, TRNSYS, etc.) (**Kusuda 2001**).

However, there is still the on-going need to improve the capability and accuracy of these tools, as well as the need to advocate their proper use (**Kusuda 2001**). From the experience of Kusuda, T, widespread availability of computer simulation tools could lead to the improper use of simulation. However, the author believes that widespread availability is essential in order to increase and enhance the awareness, production, and overall energy efficiency of our built environment.

3. Building Energy Simulation

Based on the modelling approach, BES tools can be categorized into two categories: zonal and computational fluid dynamics (**Mourshed 2003**).

Type 1: The Zonal approach

This approach can be sub divided into two other categories, the steady state or the dynamic approach. But generally, programs based on the zonal approach, are simplified in an attempt to reduce computation time and complexity.

The zonal approach, breaks down the object into zones, where each zone is considered to be in a thermal state (**Mourshed 2003**). However, this is not realistically representative of the true environment, but it does provide its results faster than the CFD approach (**Musy, Wurtz et al. 2001**).

Examples

EnergyPlus, Ecotect, TAS, ESPr, DOE

3.1. Type 2: The Computational Fluid Dynamic approach (CFD)

The CFD approach is the quantitative process of modelling fluid flows by the numerical solution of governing partial differential equations or other mathematical equations of motion (**Website:"csiro"**), mass, and enthalpy conservation.

3D space is divided into grids, where each node on the grid is given an initial value for different environmental parameters.

This approach represents real-life situations more accurately than the zonal approach. For this reason, there is a need to spend a lot more time and effort in simulation preparation.

CFX, FLOVENT

Due to the time and effort needed to implement CFD based BES tools, as opposed to its zonal counterpart, the zonal based tools could be considered to be the most appropriate tools to be employed by the Architectural Community during the initial design stages.

4. Variables

The accuracy of computer based BES models, are dependent on the appropriate use and validity of weather files in order to arrive at realistic representative climatic simulations (**Crawley & Joe Huang 1997**).

Variables

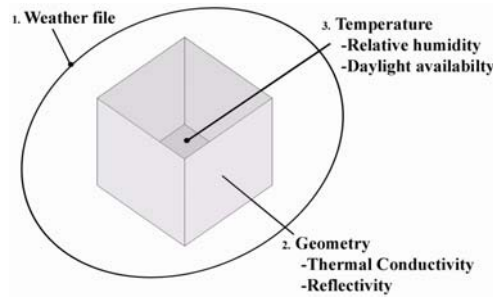


Figure 3: This diagram illustrates the main variables BES tool's take into consideration when producing simulations.

There are a variety of weather files available to be specifically used for BES programs. These range from locally recorded measured weather data, to pre selected 'typical' data sets.

- WYEC2 (developed by ASHRAE)
- TMY2 (updated by NREL)
- CWEC (developed by the WATSUN Simulation Laboratory')

TMY2 and WYEC2 data sets will result in predicted energy consumption and energy costs that are closer to the long-term average. The newer versions of these data sets are based on the improved solar models and more closely match the long term average climatic conditions (Crawley and Joe Huang 1997).

According to Crawley, D and Huang, Y, the use of TRY-type weather data sets should be avoided for use with BES based programs. TMY2 and WYEC are more appropriate weather data sets for use with BES tools (Crawley and Joe Huang 1997).

5. Problems And Possible Solutions

There are two main problems with using BES tools in the Architectural Industry:

Problem 1

Current available BES tools have their own individual file formats and there isn't a standard data representation among them. This makes it difficult to share information between tools, and thus disciplines.

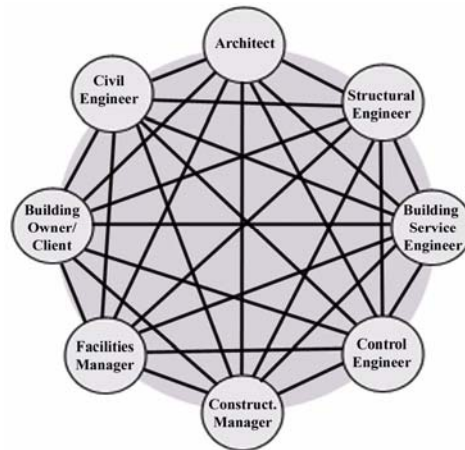


Figure 4: This diagram illustrates the various disciplines involved in the production of buildings as well as the complex paths of sharing information amongst themselves.

Possible solution

A possible solution, could be to use translators when sharing information between different programs (and disciplines). The downside to this method is that data could be lost through the translation process. So in order to maintain the integrity of the data, and enhance interoperability between the programs and the stakeholders, a neutral data standard is required.

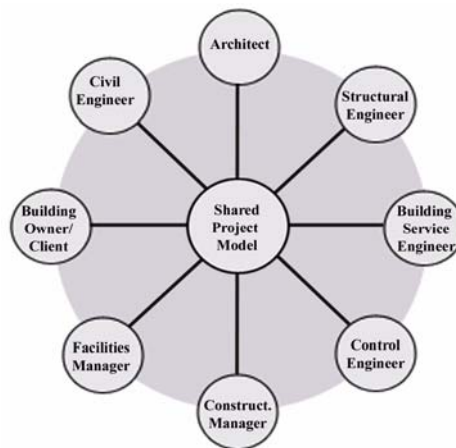


Figure 5: This diagram illustrates how the sharing and exchange of data amongst disciplines can be enhanced.

Example

Industrial Foundation Classes (IFC) promoted by the International Alliance for Interoperability (IAI) is a neutral file format, which is globally accepted for information exchange within the building Industry (**Website:Construction_computing**) .

Problem 2

A lot of focus is paid to the enhancement and development of the simulation engine, which slightly neglects the development of the user interfaces. As a result, the BES tool steams away from it's intended purpose and becomes less attractive to the architectural community.

Possible Solution

Provide new and/or enhance the existing user interfaces specifically targeting their individual disciplines.

Example

The architectural community can employ, Ecotect and/or Design builder (for EnergyPlus).

6. On-going Work

The following initiatives all intend to smooth the design process for the architectural community by focusing on decision making, integration, and interoperability issues.

Building Design Advisor (BDA)

Figure 1, illustrates that vertical data flow is increased when collaboration amongst disciplines is enhanced. Building Design Advisor (initiated in mid 1980's) has been developed to help enhance this collaboration process. It's primary function is data management and process controlling.

Process description

A climate is developed for each tool, which maps the generic representation unique to that tool. The BDA driver resolves any differences in format, units, and naming conventions between the representations of each application (**Papamichael, Laporta et al.**).

The building elements are assessed through the building browser, while the ‘decision desktop’ allows the user to compare and contrast design alternatives with respect to performance indicators addressed by integrated tools.

ArDot

The Research and development of ArDot was initiated by the Informatics Research Unit for Sustainable Engineering (IRUSE) and the National University of Ireland (**Mourshed 2003**).

ArDot is a user-centric decision support system that is embedded within existing Cad based software. It allows designers to analyse problems at any stage of the building’s design development (**Mourshed 2003**).

Process description

ArDot connects Cad based programs directly to BES tools. In order to investigate the complex relationship among conflicting design variables and objectives, ArDot employs optimization methods to search the design space and uses IFC’s as its primary file repository (**Mourshed 2003**).

Design Analysis Interface (DAI)

The Research of DAI was initiated by Georgia Institute of technology, Carnegie-Mellon University and the University of Michigan.

DAI aims to understand and implement the needs of the user by focusing on not only on integration issues, but also on the work flow between ‘scenarios’, ‘tasks’ and ‘users’.

7. Integration Into The Design Process

The Architectural Community are generally familiar with the concepts involved in basic environmental analysis. They therefore, usually implement basic ‘rule of thumb’ techniques in determining the environmental factors, i.e. the sun generally travels from ‘east’ to ‘west’ via the ‘south’.

BES as opposed to ‘rule of thumb’ methods should be employed by the Architectural Community, to accurately predict the energy and environmental performance of buildings

at all stages of the building's lifecycle: design, commissioning, operation and management (**O'Sullivan, Keane et al. 2004**).

The Architectural Community rely heavily on quantitative analysis' for decision making (**Mourshed, Kelliher et al. 2005**). But, in order to undertake more accurate and realistic energy and environmental analysis' in-house as a matter of routine, the architectural community need to have effective tools with user interfaces suited to their routine design procedures (i.e. cad based interfaces). Therefore, in terms of the usage of BES tools, it becomes a question of understanding the tool and not of implementing its use. Because once trained on inputting data and using the output, it may be common practise to implement (**Mourshed 2003**).

Design process

Architectural design is a very complex activity, juggling scientific, economic, social, and cultural elements, all at the same time (**Laaroussi, Zarli et al.**).

The first objective in design is to define an answer or solution to an unsatisfied need. The evolution of the chosen solution (at feasibility/sketch stage) is a consequence of various cognitive activities undertaken by the design team. BES tools aim to alleviate some of the complexities involved and assist the positive development of the design.

The design process' delivery is centred around the lead designer's extensive use of representation formats (diagrams, sketches, notes, layouts, and drawings) on various graphical medium (i.e. paper, post-its, physical models, Cad models, Visualisation, etc) (**Bertel, Freksa et al. 2004**). It is therefore important to computationally offload this information in a format that is understandable for the rest of the design team.

The architectural community, have a huge responsibility in the development of design. Depending on the scale of the project, the Building Service Engineer (who as part of their service, employ the use of BES/HVAC tools) during the initial design stages can serve as a resource to the architect, alleviating most of the work and enhance productivity and help direct the building creation towards energy efficiency.

Critical design decisions that affect the overall energy efficiency of a building are made during the initial design stages by the client and lead designer.

The design process: Current resource involvement.

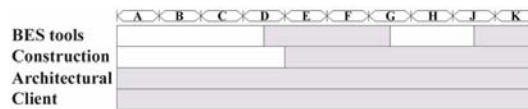


Figure 6: *Involvement of resources in Current practise (taking little attention to energy efficiency) The letters at the top of the chart represent the design stages.*

The shaded areas represent ‘involvement’. The shade colour is not emphasised because the involvement of the elements (BES tools, Construction community, Architectural Community, and/or Client) vary from project to project and is also dependant on the procurement choice.

Depending on the scope, type, and scale of a project, the Building Service Engineer is not brought into the design consortium until the architectural information (plans, elevation, etc) are near to be finalised.

20% of design decisions made during these stages (stages A to E in diagram) influence 80% of all later design decisions (**Mourshed 2003**). As a consequence of this and due to the fragmented nature of the design process, the opinions and views of the Building Service Engineer, which are critical in determining the optimum energy efficiency of the project, are not taken into consideration at the vital periods during the design process.

Why?

During the initial stages of design (feasibility), the client aims to minimise costs/fees, just in case the project is not feasible and doesn’t make it through the planning process.

Possible solution

The architectural community need to embrace intuitive BES tools in order to bridge the gap between disciplines, ideas and reality.

Enhanced involvement in the design process.



Figure 7: *this diagram illustrates the Involvement of resources during a fully collaborated design process.*

The architectural Community will only feel comfortable using such tools if the interfaces are designed to suit their techniques of design/drawing. Thus, reducing the time needed for training, and limit the need to contact other specialists. The possible political reasoning behind the stunted development of related software and their user interfaces, are:

1. The need for certain specialists will be reduced if such software advancements are made available to the architectural community
2. Some believe, that enhancing the abilities of these specialist programs and operators, is a better solution than providing 'short-cuts' for the Architect (**Website:"BLDG-SIM"**).
- 3.

8. Available BES Programs

For the past fifty years, a variety of BES tools have been developed and enhanced (Crawley, Hand et al. 2005). According to the opinions of the author and to the experience and views of the staff at Aedas Architects (quoted to be the 2nd largest Architectural Practise in the UK - according to the architect's journal), the most popular BES tools targeted at the architectural community, are Ecotect and Energy Plus.

Ecotect (1996)

Ecotect has quite a unique approach to conceptual building design, as it was entirely designed and written by architects and is therefore targeted at the Architectural Community (**Marsh 2003**).

Ecotect couples an intuitive 3D design interface with a comprehensive set of performance analysis functions and interactive information displays.

The latest version of Ecotect allows the user to work within an advanced modelling and visualization interface tailored to suit the design manipulation capacity required by the Architectural Community. It also has the ability to export building models to EnergyPlus (the very best analysis and validation software) (**Marsh 2003**) and Radiance.

EnergyPlus

Energy Plus paved the way for efficient interface design, by targeting certain groups of professionals, and by segregating the simulation engine from the user interfaces. This

allowed for the development and enhancement of the simulation engine to escalate and allow individual users to apply and develop their own interfaces that better suit their requirements.

EnergyPlus is a BES program for modelling the heating, cooling, ventilation, lighting, and energy flows relating to a building.

This program builds on the features and capacities of building loads and system thermodynamics (BLAST) and DOE-2 programs. However, it also includes many innovative simulation capabilities, such as the ability to incorporate modular systems and plant integrated with heat balance based zone simulation, thermal comfort, photovoltaic systems, and multi-zone air flow.

9. Conclusion

Dynamic Interactions

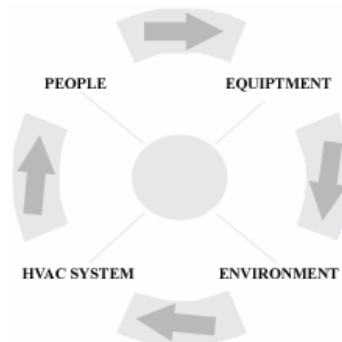


Figure 8: This diagram illustrates the interaction of variables that the architectural community takes into account when designing.

The architectural and construction communities are in the forefront of the development of our built environment. They make the decisions which address the complex interactions (**figure 14**) between people, the environment, and the building systems that service them (**IBPSA 1997**).

It is evident that the impact of decisions is greatest in the earlier design stages, and BES tools are rarely used to support the production of design alternatives, or help make informed choices between different design options.

The architectural community should be able to interactive with BES tools at all stages during the life of a project, in order to calculate the performance of the systems in place and foresee the requirements for the next stages of design. The lead designer should then be able to make informed decisions based on the analysis of the simulation of results **(Hensen. J 2004)**.

BES is a tool which is aimed to assist the architectural community in making these informed decisions. Therefore, the Architectural Community need to embrace the use of these tools and bridge the boundary between HVAC engineers in order to enhance our built environment.

10. A Glimpse Of What The Future Holds!

The author envisages that Sustainable design will be a lot cheaper for the client because the initial stages of analysis will be undertaken by the architectural community.

The author also believes that the future holds an ultimate system which will make the production of the optimum energy efficient buildings, environments, and structures, much easier, by embodying the following factors within the Architectural Design Process, as well as, be featured in the BES tools that the Architectural Community will use as common practise.

Collaboration

The author envisages that there will be an advancement in the organisation of data management. Where all disciplines and programs will be able to issue all building information to a central data model and be able to extract all updated/current information from that model regardless of what software they use., because this model will arrange all data in a way as to enable the various disciplines/program operators to extract the information they require. This will lead to the full collaboration within the design process between disciplines. Interoperability is a major factor in this development.

Interoperability

The author sees IFC's being fully incorporated as a standard repository for all software programs, which will enable the seamless sharing, exchange, and transfer of building information among various disciplines and the programs they employ.

User interface

The most important human sense that is utilised by the architectural community when undertaking design and understanding the environmental impacts (from the results produced by BES tools), is 'VISION'.

The organisation of the visual precepts, influence the segmentation of the environment into objects, categories, and classes. Therefore, when developing a user interface for the Architectural Community, the 'visual sense' will need to be the main aspect embraced and form the basis of its development.

The author believes that the ultimate user interface will be based on virtual reality and visualisation.

Virtual reality



Figure 9: Illustrates two team members of the Barlett School/Aalborg University, altering a virtual urban landscape in real time.

The next step will be to incorporate the use of a simulation engine behind this user interface, in order to visualise the environmental effects.

Generative design

Architectural design tasks very rarely have a single solution, as certain decisions are sequenced in a variety of ways. These solutions often have to be determined before finalising the chosen decision, in order to justify it's choice (**Bertel, Freksa et al. 2004**).

The author believes that the most efficient way to lessen the cognitive complexities within the design process, lies in BES tools producing generative designs based on their simulations.

Generative Design

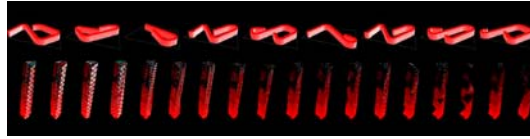


Figure 10: This figure illustrates a computational form finding (sample) generated from contextual constraints and design space exploration. Produced by "The Advanced Modelling R&D Group" at Aedas Architects.

E-Commerce

The author envisages that there will be the constant updating of weather files, libraries, and information via e-commerce to make sure that there is a continuous update to current and on-going advancements in technology. The author also believes that the time for change is coming soon, due to the raise in awareness amongst professional disciplines, education establishments, and most importantly – the public.

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