

TEACHING AND LEARNING BUILDING PERFORMANCE VIRTUALISATION

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Abstract. Building performance simulation tools have indeed eased the task of evaluating a building's performance from the point of view of lighting design, heating and cooling loads, total energy loads, acoustic properties, natural lighting, ventilation, smoke and fire containment etc. However, to use these tools correctly, not only is theoretical knowledge required but also insight that can only be attained after substantial experience. For example, in order to evaluate the thermal performance alone, one needs to understand climatology, material properties, building physics, HVAC systems, internal and external gain factors, solar impacts, etc. to name a few. Hence, teaching students of Architecture how to use these tools, and also to interpret the results properly, is a tall order. This paper reports on insights gained through teaching courses on building performance simulations to graduate students in the Department of Architecture. The course content was varied each term and a different simulation software was used; namely: ECOTECH, Energy Plus and Design Builder. Data presented here will also contain feedback from the course students regarding the modelling process of the buildings, inputting the data, simulating their performance, and evaluating the results. Also, the difficulties faced during the various steps as well as the drawbacks of the tools will be discussed in depth.

1. Introduction

Simulation tools “serve as a kind of virtual laboratory” where experiments may be conducted without using actual material (Antao *et al.*, 1992). They allow architects and engineers to test their ideas and designs; predict the energy loads; and foresee the related environmental impacts even before they build their projects (Strand, Liesen and Witte, 2004).

Simulation tools can be divided into three categories: tools with high complexity and high precision; tools with low complexity and transparency; and tools with intermediate level of complexity and transparency. The first type is mostly used by engineers, usually after the architects have finalized their design; the second type can influence design from its inception, but their precision depends on the data input process. The third type can be used in conjunction with BIM tools and therefore have a positive impact on the building design process (Palme, M., 2011).

Simulation training is a must for architecture students who are unable to realize the gravity and extent of the environmental impacts of their design decisions. To benefit from such training they need to understand the simple laws of building physics and their behavior (Fuchs and Simon, nd). The primary objective of such training is to make the students understand how buildings operate and how building performance simulation (BPS) tools use fundamental mass and energy balance equations (Charles & Thomas, 2009).

For this reason most BPS courses are offered to senior undergraduate or graduate students, who are first taught basic concepts about buildings and HVAC systems. Some courses (e.g. on Energy Plus) also require background courses in heat transfer and thermodynamics. It is not possible to impart complete expertise on software use in a single semester; hence, the aim of BPS courses is to provide enough background information to the student so that they can understand ‘what’ is being simulated and not just ‘how’ to simulate it. (Strand, Liesen and Witte, 2004). The authors point out to the drawback of BPS with good graphic user interface (GUI) since architecture students can use them to produce their building models easily without having to understand the underlying principles or what to expect from the results. Although Soebarto (2005) also addresses problems related to the students’ lack of prior knowledge in the area of thermal performance of buildings, she emphasizes the need for a good graphical interface and less numerical input for architecture students.

Augenbroe *et al.*, (2008) argue that “a deeper understanding of the underlying simulation method is necessary to become a truly proficient user who understands the limitations of building simulation”. Hensen and Radosevic (2004) add that domain knowledge and simulation skills of the user are the main ingredients for professional and efficient quality assurance that is necessary for the reliability of the BPS results. Teaching students how to read the outcome of simulation results is easier than applying this knowledge to suitable design measures based on the correct prediction of these results (Reinhart *et al.*, 2012). In other words, the students should acquire enough domain knowledge and understanding of the basic principles in order to interpret the results in a meaningful manner (Bartak *et al.*, 2003).

This paper reports on insights gained through teaching BPS courses to students of the Building Science Graduate Program in the Department of Architecture. The aim is not to compare the workings of the 3 software but to present our observations regarding the difficulties faced by the instructors in teaching BPS software and those faced by the students in learning to use them. Feedback from the students was obtained through informal interviews.

2. Teaching Building Performance Simulations

BS581: Energy Analysis of Buildings was an elective course for students in the Building Science graduate program of the Department of Architecture. The majority of these students were graduates of architecture, while one had a mechanical engineering background and two were civil engineering graduates. The number of students was limited to 10 per term; however, one or two students invariably dropped out during the first few weeks because they realized that much effort and many hours would have to be spent to get a good grade. Hence, we had 6 students in our first course held in fall 2010, 7 students in spring 2011 and 6 in fall 2011.

The course was divided into 4 parts: Building Physics; Climatology and related design strategies; Thermal modeling; and BPS. The first week was devoted to reviewing basic laws of building physics, solar insolation, shading, shadows; etc. The second part consisted of a lecture on climatic parameters and their effects on building performance; and the students were introduced to the Climate Consultant software. They were required to use this tool to analyse the climate of their project region and determine the recommended design strategies that would help them reduce the energy loads in their building project. The third part consisted of instructions and hands-on tutorials for producing the thermal model with a BPS tool; and the students were taught how to create the building geometry, specify materials and

create new ones; define thermal zones, internal loads, schedules and systems. The fourth part was related to carrying out BPS analyses and learning how to interpret the results. The students were then asked to improve the performance of their project by adopting appropriate strategies and then compare the resulting change.

2.1. CURRICULUM

This was a 3 credit-hours course that provided hands-on training on the energy analysis of buildings using energy simulation software. The course was conducted once a week from 1:40 to 5:30pm but the students were free to use the simulation lab computers for their projects any time during the whole term. The course outline for the 15 week term is presented in Table 1 below. The first hour was usually devoted to instructions and the rest to supervised practical work, except when the student had to present their projects at various stages of the coursework. For the hands on sessions, a simple building was modeled and tested for various parameters, such as: solar access, shadows, shading analysis, lighting design, thermal comfort, energy loads, etc. using weather files available in the tool's database. The students then had to transfer this knowledge, step-by-step, to their individual term projects in a region of their choice.

TABLE 1. Weekly schedule for course content, assignments and grading.

	Topics	Submissions /	Grade
1	Recap: Building Physics and Behaviour		
2	Climate Consultant V5.1 software		
3	Introduction to Building Performance Simulations	Presentation 1 <i>Climate analysis & design strategies</i>	25%
4	Geometry: 3D modelling tools		
5	Geometry: Editing tools and Zoning protocols		
6	Model Data: Construction/ materials data		
7	Model Data: Activities & Schedules; Internal loads	Presentation 2: Building model	25%
8	Model Data: Lighting & daylight control, Solar shading		
9	Calculations: Heating design		
10	Calculations: Cooling and ventilation design		
11	Calculations: HVAC data (heating, cooling, ventilation, DHW)	Presentation 3 Simulation model	25%
12	Calculations : Setting up and running simulations		
13	Calculations: Analysing simulation results		
14	Modifications and Re-calculations		
15	Final Submission	Presentation 4 Energy analysis	25%

2.2. SOFTWARE

According to Palme (2011) simulation tools can be called complex if they permit high levels of precision in modeling and calculations. They are declared to be transparent if they are clear on the values that a user has to insert as input to the tool. They are said to have high impact on design if it is possible to easily and rapidly modify the simulation model and get

the results. Simulation tools are confirmed as having low uncertainty if the results don't change significantly when input parameters are changed.

The three popular BPS tools; namely, ECOTECH, Energy Plus, and Design Builder, that were used in consecutive semesters, were all different from each other in the degree to which they possessed the above mentioned properties. Information on these three simulation tools is given in the following paragraphs:

ECOTECH is a simulation tool having medium complexity, high transparency, high design impact, but lower precision. Its GUI is very user-friendly and architecture students find it easy to model their buildings with this tool. The course students used Ecotech to model and simulate existing buildings that are claimed to be sustainable/ energy efficient.

Energy Plus is a highly complex and reliable tool that is used mostly by HVAC engineers. It has very low impact on design and is not as transparent as the other two tools. Course students used this tool to simulate a small house of their own design in a location of their choice.

Design Builder seems to have the best of both the worlds; i.e. it has a good GUI and also a reliable simulation engine. It has medium complexity, high transparency and impact on design, and low uncertainty. This tool was used to simulate individual projects again; some of which were existing buildings, others were designed by the students themselves.

3. Learning Environmental Simulations: the students' perspective

In the following sections the students' perspective has been presented for each of the three different software. The students who have commented here were those with the highest motivation and understanding and who were the most hardworking ones. And yet they had to struggle with the many facets of the software.

3.1. ECOTECH

It was quite simple and easy to model with Ecotech, especially if the building plans are imported as 2D drawing files. Some inputs from the database are not used for the simulations, so for detailed calculations the model has to be exported to more professional software; such as Energy Plus. Faster renderings can be obtained for design changes in the visual tab; these changes are directly transferred to the thermal model also. The simulation results before and after the changes can be saved and compared, which makes it easy and speedy to test the design options. The thermal simulations do not last for more than a few minutes, although they do depend on the complexity and size of the thermal model.

There are too many options for the input variables to choose from, but they can also be left at default values; which simplifies the modeling and simulation processes. If there are errors in the thermal model Ecotech gives you an error message, but if you choose to ignore the message it continues with the simulation. This may give you a result but you may not be sure if it is erroneous or not. On the other hand, error messages are easier to understand and therefore easier and faster to rectify; such as the faulty orientation of the surface normals, or the inter-zonal adjacencies errors due to conflicts in primary and secondary material assignments (once you understand what they are).

3.2. ENERGY PLUS

With Energy Plus it is possible to model complex systems and run the simulations with accurate results, but far too much time is required to model the building components. While there are a number of extensive controls for a very detailed simulation for the experts, a good graphical user interface for modeling the components is required, particularly for architects. The only graphical modeling option available is to use Open Studio plugin for Google Sketchup, which has flaws and bugs that make the process cumbersome.

Energy Plus interface answers the needs of mechanical engineers and code compliance specialists, as it has all the necessary components for defining the building geometry, envelope properties and zones in the model; internal loads, day-lighting, solar gains; infiltration, ventilation and multi-zone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; environmental emissions; economic evaluation; climate data availability, results reporting and validation. Most of these components are also required by architects, who intend to carry out building simulations themselves, in addition to tools that provide qualitative feedback in graphical form both for design evaluation and presentation.

Besides learning the simulation components of the software it is necessary to spend time on learning how to utilize the outputs (simulation results) either on their own or in combination with other software tools for architectural design evaluation and presentation. During the course most of the time was spent on getting accustomed to the Energy Plus user interface and the relationship of different components within the software even though assignments were given each week to practice these components.

Additionally, the error messages were output as text documents by Energy Plus and an interpretation was necessary by a more experienced user for a better understanding of the problem. As a result of the time spent on understanding the user interface and bugs inherent in the Open Studio plug-in there was no time left for evaluating outputs data on the simulations results. It would be better to spread the course content over two semesters.

3.3. DESIGN BUILDER

The software was used as a tool for creating and developing design concepts and for assessing the performance of the building designs. It is an analysis and simulation tool that can be used effectively at any stage of the design process; from the concept stage where just a few parameters are needed to capture the building design, to a much more detailed model for the final design. Design builder can be used for all types of architectural projects, whether residential or public place or under construction, both by designers and builders, to avoid mistakes in the project. Additionally, it can be used as a teaching and learning tool to recognize many of the details of how buildings are efficiently operated, due to the contextual and environmental interaction between the building and its surroundings.

This tool is also useful in evaluating the performance of existing buildings; e.g. the African satellite control centre in Gharyan, Libya; shown in Figures 2 and 3. When this building was simulated and analysed for a range of environmental performance aspects (energy consumption, carbon emissions, comfort conditions, daylight luminance, maximum summertime temperatures and HVAC component sizes) using ASHRAE or Energy Plus dynamic thermal simulation built-in engine, it became possible to realize the failures and deficiency of the existed design/building that could have been avoided to make it more efficient. One of the main disadvantages of this tool is the limited number of weather data files in the database. It is not possible to find weather data for many cities in the world and one has to use the weather data of the closest location, which may be quite different from the local conditions. For example: the building in Figure 1 is located in Gheryan (Libya) but

since weather data for this city is not available, data from the closest city, i.e. Tripoli, was used for the simulations and hence, approximate results were obtained.

Another disadvantage that may be mentioned is the limited drawing and modelling capabilities when dealing with free form roofs and walls; the software does not have a wide range of tools that facilitate dealing with such non-traditional shapes. Non-traditional forms are handled by drawing two-dimensional sections that are extruded but often require fragmentation to get the desired shape. However, there were no problems in calculating and simulating the free-forms as the software can deal with all physical and textural properties of the materials. Since shapes can be predefined as building blocks, outline blocks, or component blocks it is possible to include or exclude some of these components while simulating the building. It should be noted that simulation time of detailed models may exceed 8 hours, based on the number of zones and surfaces in the project. The simulation results vary a lot by varying such factors as the gender and age of occupants and occupancy schedules; activities, clothing and metabolic rates; machines and equipment being used. Since all these factors contribute to the internal gains in a building and influence its energy loads, they have to be entered carefully and diligently for each space. On the other hand the zone multiplier option reduces the need to input data and define schedules separately for similar zones.

4. Problems in Building Performance Virtualizations

Architecture students take considerable time to understand the difference between an architectural model used for design representation and a thermal model used for simulations. Old modelling habits are difficult to break for these students, who eventually learn to forgo the level of accuracy they are used to and simplify their models. The realization usually comes after the first simulation run when they see that the complexity of design retained needlessly in the thermal model extends the simulation time unnecessarily.

This attitude can be seen in the models displayed in Figure 2; the one on the left is the architectural model of the project; that in the center is the first thermal model created in Design Builder, with as much detail as the architectural model; and the one on the right is the rectified final thermal model. In this project the student had to check the feasibility of adding a double skin façade to the tallest block, as part of her thesis study. The first thermal model was created with all the other blocks in the project and the thermal simulations took more than six hours for a single run. But when the thermal model was rectified by excluding all the blocks that were not sharing a wall with the block to be simulated, the simulation time was reduced to less than five minutes.

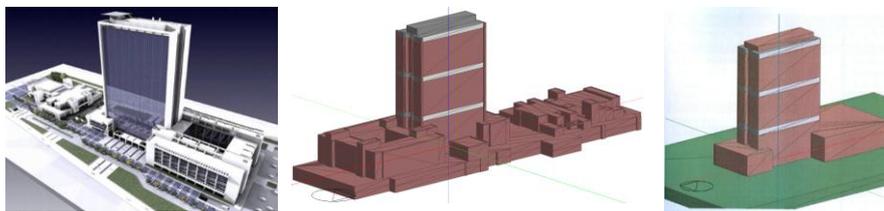


Figure 1. Models of an existing building complex (from left to right): Architectural model of the project; Thermal model emulating the architectural model; and the rectified Thermal model (Design Builder model by D.Ölmez).

This was also the case in the Gheryan project (Figure 2), where every non spatial component (such as exterior columns) was also modeled as a component block, thus increasing the simulation duration. This attitude is exhibited on the individual building level also, where each room on each floor is modeled as a separate zone. The ground floor plans of the initial and rectified thermal models of the Gheryan project are presented in Figure 3, where the first detailed thermal model (on the left) had 22 zones. These were reduced to 17 thermal zones by combining similar zones with hanging partitions, thus reducing the simulation duration from eight hours to a few minutes only.

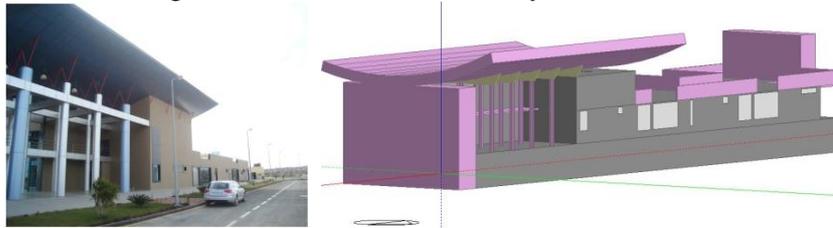


Figure 2. Design Builder thermal model of the African satellite control centre in Gharyan, Libya (Architect: H. Hadia).

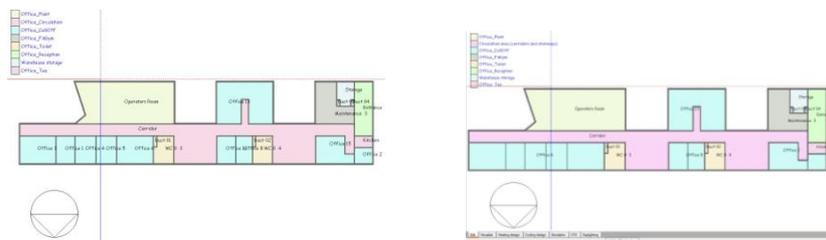


Figure 3. Number of zones in the 1st model reduced by combining similar zones in the 2nd model for the African satellite control centre in Gharyan, Libya (Architect: H. Hadia).

One basic problem is that students tend to forget the knowledge they had acquired during their compulsory undergraduate environmental courses; perhaps because they are not required to use that knowledge in their design projects by the design studio instructors. Hence there arises the need to repeat the fundamental laws of building physics and climatology. Since very little time can be devoted to these topics it is not possible to bring up their knowledge to the level required for understanding the validity of inputs and outputs and interpreting the simulation results.

One other problem is that once the students have won the struggle to produce a thermal model that can be simulated without getting an error warning, they are quite comfortable in submitting a 30 page printout of the simulation results without the need to understand them. They apparently feel that they have achieved what they set out to do and are therefore, very unhappy when they cannot obtain a high grade in the course.

5. Conclusion

The user friendly interface of most simulation software facilitates the modeling and running processes. It is seemingly quite easy to evaluate a building's performance or calculate its energy loads by clicking on a few buttons and choosing the various inputs from readymade lists. Whether the choices are informed or not, pressing the run or calculate button will always present the user with a result. However, the result may or may not be realistic, but it

requires considerable experience on the user's part to detect a mistake in the input or output. Since most students do not possess enough knowledge or expertise, they are prone to accepting whatever comes up on the screen, without questioning the validity of the result. Hence, the need to increase domain knowledge cannot be overemphasized; just as the need to understand the difference between a thermal model and an architectural model is crucial.

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References

- ANTAO, B.A.A., BRODERSEN, A.J., BOURNE, J.R. AND CANTWELL, J.R., 1992. Building intelligent tutorial systems for teaching simulation in engineering education. *IEEE Transactions on Education*, Vol. 35(1)
- AUGENBROE, G., BROWN, J., HEO, Y.S., LI, Z., .KIM, S.H., MCMANUS, S. AND ZHAO, F., (2008), Lessons from an advanced building simulation course. In *SimBuild 2008, 3rd National Conference of IBPSA-USA*.
- BARTAK, M., DRKAL, F., HENSEN, J., LAINI, M., SCHWARZER, J. AND SOUREK, B., 2003. An approach to teaching and research of simulation for environmental engineering design, In *Proceedings of 3rd International Conference on Advanced Engineering Design*.
- CHARLES, P.P. AND THOMAS, C.R., 2009. Building performance simulation in undergraduate multidisciplinary education: learning from an architecture and engineering collaboration, *11th International IBPSA Conference Proceedings*, Glasgow, UK.
- FUCHS H.U. AND SIMON, M. (n.d.) Teaching Building Simulation with the help of general purpose dynamical modelling software, Technicum Winterthur, Switzerland
- HENSEN, J.L.M. AND RADOSEVIC, M. 2004, Some quality assurance issues and experiences in teaching building performance simulation, *IBPSA News*, Vol. 14(2) pp 22-33
- PALME, P., 2011. What architects want? Between BIM and simulation tools: an experience teaching ECOTECT. In *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association*, pp. 2164-2169
- REINHART, C.R., DOGAN, T., IBARRA, D. AND WASILOWSKI SAMUELSON, H. (2012) Learning by playing: teaching energy simulation as a game, *Harvard University GSD*.
- SOEBARTO, V., 2005, Teaching an energy simulation program in an architecture school: lessons learned, *9th International IBPSA Conference, Montreal*.
- STRAND, R.K., LIESEN, R.J. AND WITTE, M.J., 2004. Resources for teaching building energy simulations, *SimBuild 2004 IBPSA-USA National Conference Proceedings*, Boulder.