WEB-BASED COMPUTATIONAL DESIGN SUPPORT TOOLS

Use of Lighting and Energy Performance Simulation and Web-Based Visualization for Energy Integrated Architectural Design

STEPHEN K. WITTKOPF, YI CHUN HUANG
Department of Architecture, School of Design and Environment
National University of Singapore
Email address: akiskw@nus.edu.sg

Abstract. The paper proposes a new methodology how computational lighting and energy performance simulations and web based visualization tools can be employed to support energy integrated architectural design. By studying the current limitations of integrating simulation tools in the design process, the hypotheses of a *web-based design guide* attempts to establish computational simulation and visualization tools as a value adding part of the design process as well as contribute to the architect's understanding and concerns of energy relationships in buildings. The developed design guide attempts to address the identified limitations by making the actual simulations transparent to the designer physically and figuratively, the latter involving the studying of how to present data as useful information to the designer in post-processing techniques with special focus web-based visualizations.

1. Introduction

In architecture practice, energy performance of buildings has predominantly been viewed only as a technical requirement during submission. As such, it is not part of the design process but rather dealt with as an afterthought, not unlike letting the engineer determine the technical specifications of a column after it has been designed. Material science advances such as low thermal transmittance glass and insulation in cladding modules have allowed architects free reign in design and engineers to 'solve' the problems after the fact. This process is inefficient in terms of cost and overall energy invested in a building, not to mention allowing a non-progressive attitude towards energy conservation.

In defense of the industry practices, energy simulations have been developed in the realm of engineering and the resulting knowledge is not readily accessible to the architect in terms of employment. Simulation software, which are perhaps the most useful tool that can be integrated in the design process are hard to learn and require extensive engineering knowledge.

Given that architecture design is concerned with a multitude of factors and concerns, the architect often has to invest in a whole array of software to investigate the different areas of concern. This is highly uneconomical in terms of investment costs as well as the amount of training required to learn all the different packages.

The obstacles in implementing such new simulation tools limit their use in the local industry and consequently the understanding of their advantages and economic benefits by the general public. This in turn affects the willingness of developers or clients to bear the time and cost of conducting such simulations, a vicious cycle that prevents a practice from making use of the simulation tools. Studies in Singapore have shown (Wong and Lam, 1999) that only 1.6% of architecture firms use energy related simulation software and 0% of the users were trained in architecture.

This paper shall seek to propose how computational simulation tools can be more accessible and useful to the architect by examining these limitations, both in terms of the software itself as well as the method of employment.

2. Hypothesis

By identifying the current issues that limit the application of computational simulation tools in architectural design, the hypothesis of a *web-based design guide for energy integrated design* attempts to allow better integration of energy considerations in the design process.

By categorizing design decisions into high, mid and low levels that correspond to strategic, planning and technical resolution situations, we can appreciate the difference in time frames. Low-level decisions such as deciding the exact sizes of openings are decided in a matter of minutes or hours; it would be impractical to conduct a 5-day simulation at this stage. This severely limits the use of simulations in the design process until computational strengths advances a few fold perhaps in the near future.

The vehicle of a design guide is proposed to be able to allow the designer to make use of the information and knowledge afforded by computational simulations, while keeping the technical tasks transparent to the designer. The design guide is not just a summary of the quantitative data generated by the simulations, the data is post-processed and presented to allow quantitative comparisons; it is thus termed a *Design Guide*.

In the construction of an informational design guide, permutations of various design scenarios and typical energy related questions are developed, simulated, and the results post-processed to allow concise understanding of the various factors.

3. Methodology

To test the hypothesis, an experiment is designed to present a typical design scenario where the mentioned limitations of applying computational simulations are manifest. By first studying what the typical concerns and questions an architect has that can best be addressed with the technology of computational simulations, an example of the proposed informational design guide is developed, with specific focus on energy related and web-based visualization issues.

4. Typical Energy Related Questions

It is useful to develop a list of contemporary energy related questions that help guide design in the pre-parametric design phase to better understand and discuss the role and use of energy concerns in design. The reason for focusing on this stage is because the cost impact of design decisions at the initial stages are the largest while the cost to implement is the lowest.

In most buildings, energy concerns relate to the amount of energy required by a building in its construction, use and maintenance. While good design can positively improve the efficiency in all areas, the most effective and immediate effects are in lowering the energy consumptions during the use of a building. This energy consumption, or building load, usually refers to the energy required in the form of electricity to power devices that provide a physiologically comfortable environment, such as lighting and thermal comfort.

In the pre-parametric design phase, architects seek to understand the factors and effects of various options that can provide them with the most efficient methods to achieve such comfort. This includes considering how various design options and strategies such as layout, architectural elements and materials would affect the factors constituting comfort, such as temperature, humidity and wind speed in thermal comfort, and lighting illuminance, diffusion and glare in lighting comfort, and consequently the building load.

The focus then, is not on the quantitative aspects but on the qualitative performance and effects of each factor and how they affect other factors. With specific focus on energy performance, the questions seek to understand how the various design options and strategies would affect the various factors of thermal comfort and the building load, as well as each other. The task of understanding these relationships and qualitative effects comparatively is perhaps more difficult than accessing quantitative results and thus daunting to the architect who does not have a specialized training in energy topics. There are a large number of factors and considerations just to determine the overall building load and the permutations given how each factor may affect another are dazzling (Clark, 1985).

The questions on how a building design would perform in terms of energy can be categorized into three groups. The first is how each factor or element would qualitatively affect the building load directly. For example, how much air infiltration the building design allows that would directly affect the heat gain or loss in the building or the indoor wind speeds. This would affect the indoor temperature, humidity and wind speed and in turn the building loads in the form of air conditioning or heating. Other such factors include the proportions of the plan and massing, size of openings that allow solar and air infiltration, sun-shading devices, material properties, layout of thermal zones and equipment gains just to name a few.

The second group of questions pertains to the relationships between the different factors. For example, less window openings may lessen the solar heat gain in a building, but it also results in a dim room that may have to be lit up with more lamps. The lamps consume electricity, as well as give off heat that may increase the air conditioning load. Thus the architect needs to understand not just the individual elements, but also the various complex relationships.

The last group of questions relates to how to understand and analyze the data so as to form operative information to aid design decisions. This includes the visualization of the energy data; energy cost benefit analysis, as well as considerations on how to weigh between the programmatic, aesthetic and energy demands.

5. Experiment

The objective of this experiment is to construct an example of the proposed informational design guide that would aid low-level design decisions. As discussed earlier, low-level design decisions have to be made relatively quickly. If there are to be considerations for energy efficiency, the presentation and analysis of data have to be fast and concise.

The experiment considers the example of a design task where the architect has to decide on the choice of a façade design and the lighting scheme in a room, where the functional requirements, location of the room within a building and the general building materials have already been decided. The variables of the building envelope and artificial lighting scheme are chosen because they constitute most of the energy consumption in a building, and are relatively easy to manipulate. If the windows in the room are small, the heat gained in the room from solar radiation would be low, resulting in lower cooling costs, but there would be a need for more artificial lights, which contributes towards the overall energy consumption of the room. The task is thus to select the optimum combination of façade openings and lighting schemes.

In such a scenario of a low-level design decision, it would be unacceptable and not viable economically to spend days or even weeks to run experiments or simulations. Although the architect generally understands the relationship between the façade openings, cooling costs and lighting implications, there is a lack of quantifiable data for him to analyze and make an informed decision.

An informational design guide than, would include case studies of such typical design scenarios. The parameters and variables (in this case, window size and lighting scheme) are described and various permutations are simulated. The resulting empirical data are post-processed as charts or graphs and tabulated in the form of a matrix.

Such a matrix supplies quantitative data that enables decision-making, and the visual presentation of the data in charts, graphs and matrixes allow easy understanding and analysis by the designer within a short period of time.

The room measures 12 meters by 6 meters, and is 2.8 meters high, as shown in Figure 1. One of the 12-metre walls faces the south, and is on the edge of the building. All other walls are internal partitions. The room is located on an intermediate level, the floor is not in contact with the ground and the ceiling is not an exposed roof. The room is to be used as a seminar room or reading room, with a recommended lighting level of at least 750 lux. Artificial lights, when used, are fluorescent lamps. The occupancy load of the room is 48 persons. The room is used during normal office hours, from 9am to 5pm on weekdays and the thermostat for air-conditioning is set at 24 degrees Celsius during these hours. Air-conditioning is switched off during lunch, non-office hours and weekends. Other details such as material properties and heat dissipation from the occupants are also considered. The amount of openings on the south wall of the room is to be decided, together with a corresponding artificial lighting scheme. Three design options are initially proposed, a sash window, casement windows and a fully glazed curtain wall. (Figures 2, 3 and 4)

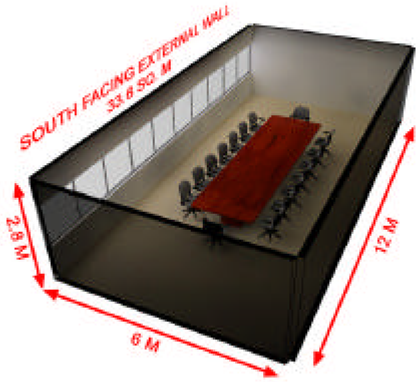

Figure 1. Setup of Experiment Room

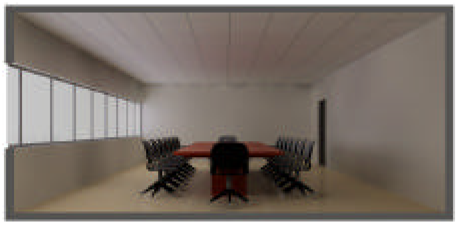

Figure 2. Option 1: Sash Windows

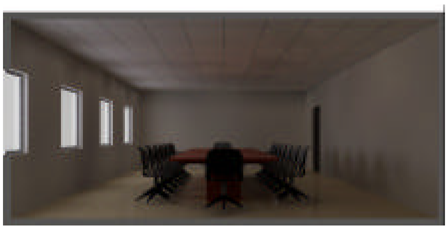

Figure 3. Option 2: Casement Windows

Figure 4. Option 3: Fully Glazed Curtain Wall

First, the lighting requirement of the room would have to be satisfied using a combination of day lighting and artificial lighting. Thus, in each of the three options of varying façade design, it is necessary to run a lighting simulation to determine the lighting level within the room throughout the day, and propose an artificial lighting scheme for each of the three options.

Second, with the empirical data collected by simulating the three options in forming the proposed artificial lighting schemes for the options, there may be conditions or situations for proposing new options. This illustrates the ability of computational simulations to offer new insight and design possibilities.

Third, once the lighting scheme for each option is worked out, all energy related elements are in place to conduct an energy simulation to calculate the amount of energy consumption in each scenario.

Fourth, all the façade design, lighting scheme and energy consumption data are post-processed. This includes converting the data into a web-based design guide, as well as arranging the options and scenarios into a matrix that would be easy to understand and compare. This is the final product that attempts to meet the overall objectives of the experiment, and is an example of the hypothesized informational design guide.

6. Experiment Results

6.1. LIGHT SIMULATION

The light simulation software Lightscape is chosen as the software to conduct the lighting related components of the experiment for the relative ease of use and credible accuracy. The geometry of the three design options are prepared using AutoCAD and imported into Lightscape. Each option is simulated for hourly day lighting conditions, a total of 13 times each (from 7am to 7pm, since the room is used for office hours from 9am to 5pm, a 2 hour buffer is given to before and after office hours usage). Table 1 gives an overview of the average lighting level on the tabletop, which is considered the working plane.

TABLE 1. Hourly illuminance levels in Lux by daylight only (CIE clear sky)

	07	08	09	10	11	12	13	14	15	16	17	18	19
1	338	496	553	577	588	590	597	660	651	628	573	429	0
2	163	238	266	277	283	284	284	282	279	268	245	184	0
3	686	994	1105	1151	1171	1174	1176	1167	1157	1115	1023	775	0

In proposing the artificial lighting scheme for energy efficiency, the objective is to use a combination of fluorescent lamps to reach the minimum required 750 lux.

From the initial data generated earlier, we can observe that the lighting level is low and varies only slightly for most part of the day. The drastic change only occurs early in the morning and in the evening, where it tapers off to 0 lux in the evening. This suggests that we may propose a two stage lighting system where the first set of lamps is used to light up the room for most of the day, and a second set is switched on when the first is in sufficient in the evenings.

6.2. PROPOSING NEW OPTIONS

From the lighting simulation, it is observed in the third option of a fully glazed curtain wall that the illumination levels are slightly high (exceeding the recommended illumination levels) even when the artificial lights are not switched on during the day. Thus the simulation suggests that the illumination in the room may be too bright and that there could be a provision to reduce the lighting levels. Given the design condition in this option that the façade is a curtain wall, the method to reduce daylight levels in this room is proposed to be sun-shading fins. This demonstrates the benefits of simulation tools in revealing unexpected conditions and suggesting new possibilities. The assessment of glare has not been considered for the experiment, neither the impact of different materials. This could be looked into in future research.

Using four external sun shading fins 300mm in depth that casts a 1215mm shadow on the façade at 45 degrees (43.4% of the elevation), a new option room_04 is proposed and tested for the illumination levels throughout the day.

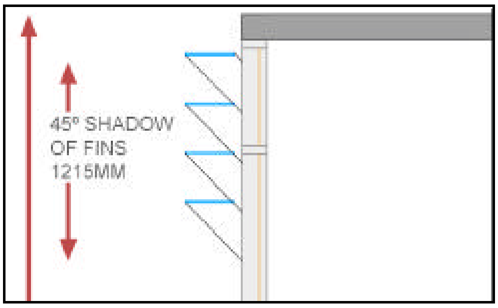

Figure 5. Adding Sun Shading Fins.

With the sun shading fins, the daylight levels are reduced and the illumination levels in the room are nearer to comfort levels (below 1000lux). The lower daylight levels also result in extended periods when a set of lamps is needed to augment the illumination. Otherwise, the proposed lighting scheme is similar to that when there are no sun-shading fins.

6.3. ENERGY SIMULATION

EnergyPlus, representing the latest development in energy simulation software, is then used to simulate each of the four options to calculate the overall energy consumption of each option. In simulating each design option and analyzing the energy consumptions by the air conditioning systems and artificial lighting, EnergyPlus considers factors such as the environmental conditions (based on the Singapore weather data), solar heat gains with respect to physical properties such as building construction and orientation, as well as internal heat gains due to occupancy and heat generating devices.

The parameters of each option is prepared in the EnergyPlus input format and processed by algorithms to produce hourly data. This includes hourly indoor and outdoor temperatures and cooling loads for one year under various conditions of being vacant or occupied, with and without optimized lighting. To make sense and use of the EnergyPlus simulation output data, there is some form of post-processing necessary to enable an understanding the results. Spreadsheet software is commonly used to organize such numbers into charts or graphs.

Figure 6 depicts a common representation for temperature and energy consumption data as graph plots, in this case for the design option of a glazed curtain wall with sun shading fins (Room 4). Figure 7 enables comparison of the temperature curves between the four design options, whereas Figure 8 compares the contribution of the various components in all the design options towards the total energy consumption.

It is obvious that the presentation of the results using conventional means as demonstrated thus so far is tedious, requires much space and still demands user effort, as all the charts and graphs need to be lined up to enable qualitative comparison. Another aspect that should not be neglected is the appearance of the architectural space itself, which can be generated as a photorealistic rendering, as shown in Figures 2,3 and 4. In order to provide even illumination on the horizontal work plane it is also useful to check where supplementary artificial light is needed, preferably by presenting the daylight penetration using false color rendering of the illuminance levels, as shown in Figure 9. A compressed version of all useful representations as output from light and energy simulation software is shown in Figure 10.

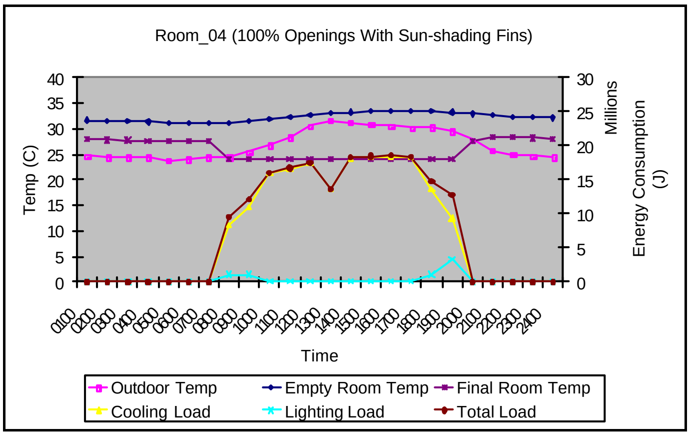

Figure 6. Temperature and energy consumption for glazed curtain wall with sun shading fins

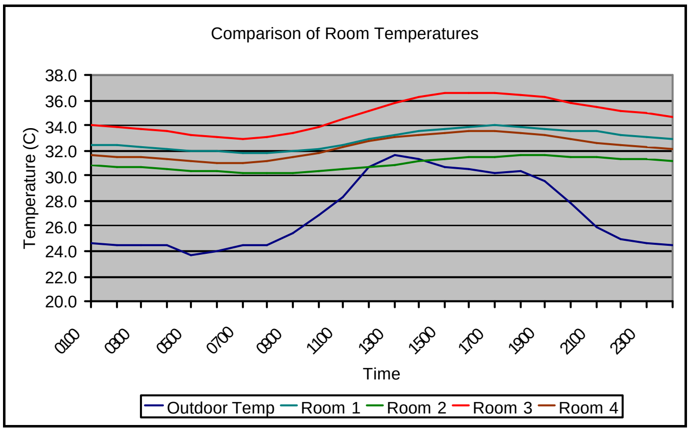

Figure 7. Comparison of room temperatures in all four design options

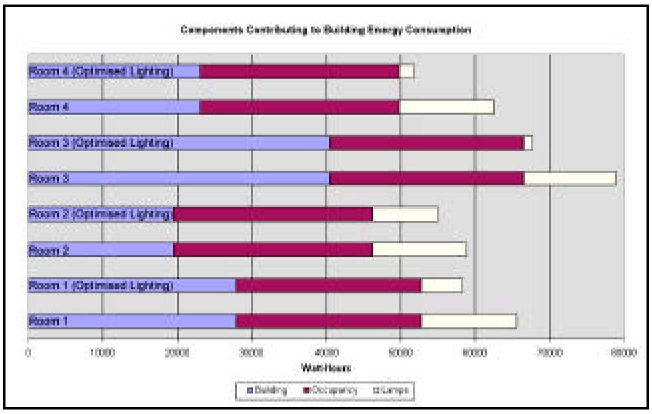

Figure 8. Components contributing to the total building energy consumption

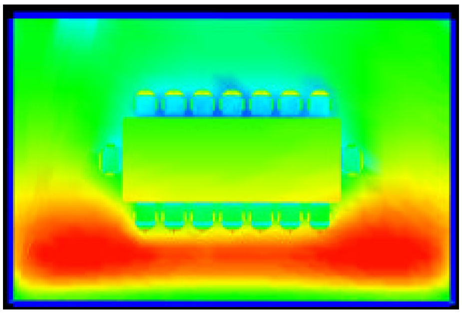

Figure 9. False color rendering of room 1 at 14hrs

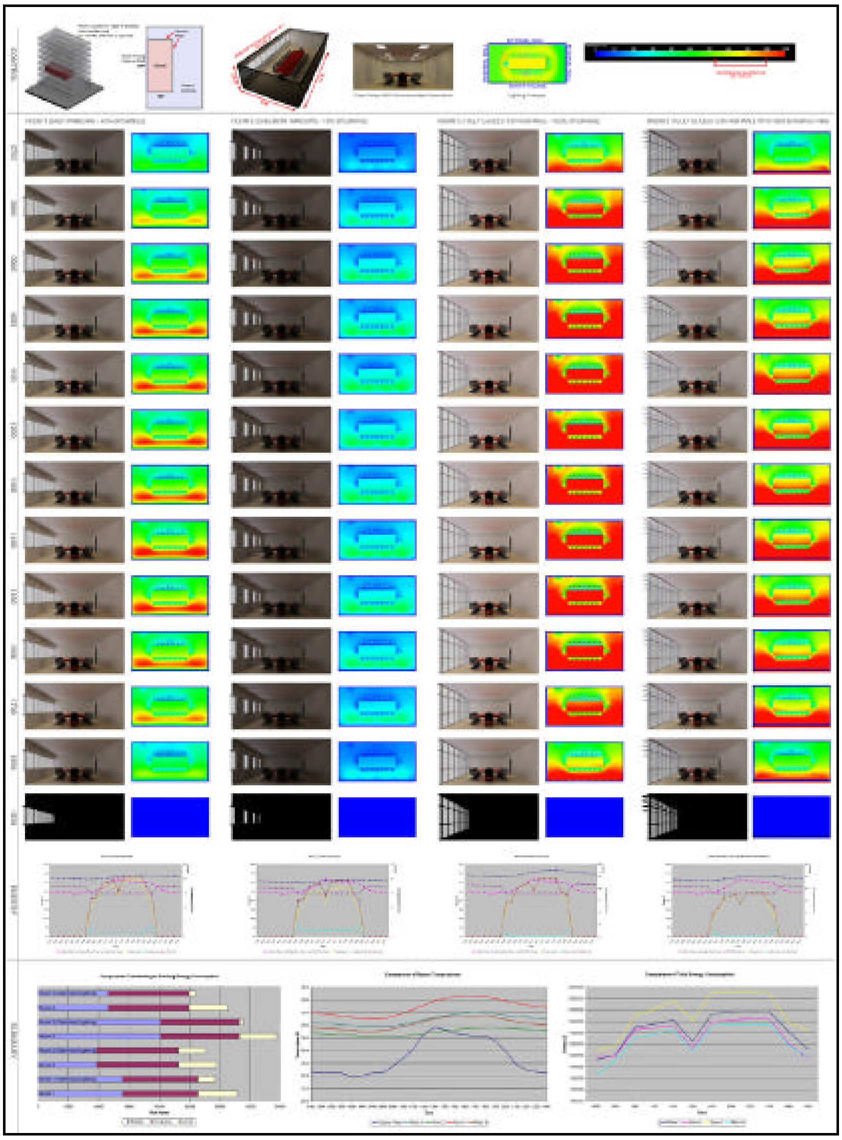

Figure 10. Matrix of different outputs from light and energy simulation

6.4. THE WEB-BASED DESIGN GUIDE

It is evident that although the simulation produces a variety of comprehensive results, it is still not easy to qualitatively understanding the implications of the data when presented in a series of numerical tables. Post-processing is the manipulation of these results, including but not limited to using contemporary visual aids to present the data such as bar charts and graph plots. However, such traditional methods of visualizations tend to be efficient only in presenting specific aspects (of limited variables) and are limited when trying to present many variables to appreciate the complex relationship between many data sets. Since the objective is to address a more holistic understanding, the structure of a matrix where various quantitative data are arranged to facilitate qualitative comparisons is proposed. Post processing should also cater for anytime and anywhere access through the Internet.

Flash, a popular software for developing interactive web pages, was used to integrate the different representations into one interactive, easy to use and comprehend, interface. Figure 11 shows the index page. The page layout caters for access to the four design options, with 4 corresponding key icons arranged in a column on the left, pointing to adjacent photorealistic rendering of the spaces. The index page also displays a summarized comparison of the energy consumptions and provides space for additional information below this chart.

Figure 12 is an example of the content displayed upon selecting one of the design options on the index page. The renderings of the other design options have been displaced, but the key icons on the left still allow switching between them. Each page for the 4 design options comes with a representation of the temperature and energy consumption curves (compare to Figure 6).

An interactive sliding bar below the photorealistic rendering allows the user to manipulate, access and understand the information easily by adjustment the time variable. This slider snaps to the hour and all apparent representations are dynamically updated correspondingly. First of all, one can browse through the hourly renderings of the selected design option, whereby the renderings fade into each other to demonstrate the changes qualitatively. Secondly, a vertical time marker, also dynamically linked to the interactive slider, moves along the time axis on the temperature and energy consumption chart to cover the remaining hours of the day, not unlike a translucent curtain. This allows easy reading of the chart. Third, the false color rendering changes according to the time, representing the change in illumination levels of daylight. Compared to the photorealistic rendering of the space, one can easily observe how the ratio of daylight and artificial light in the contribution towards illumination in the room changes dynamically during the day. During periods when there is enough daylight and the artificial lighting is switched off, the photorealistic rendering reflects the luminaries fading out and the energy consumption graph shows no lighting load.

Since the design option icons on the left are constantly visible, one can easily switch over to the any of the other designs for comparisons. In this case the software remembers the adjusted time; if the time slider was set to 3pm for room design option two, then the other design option, when selected, will appear at 3pm accordingly. This results in less distraction when comparing between options.

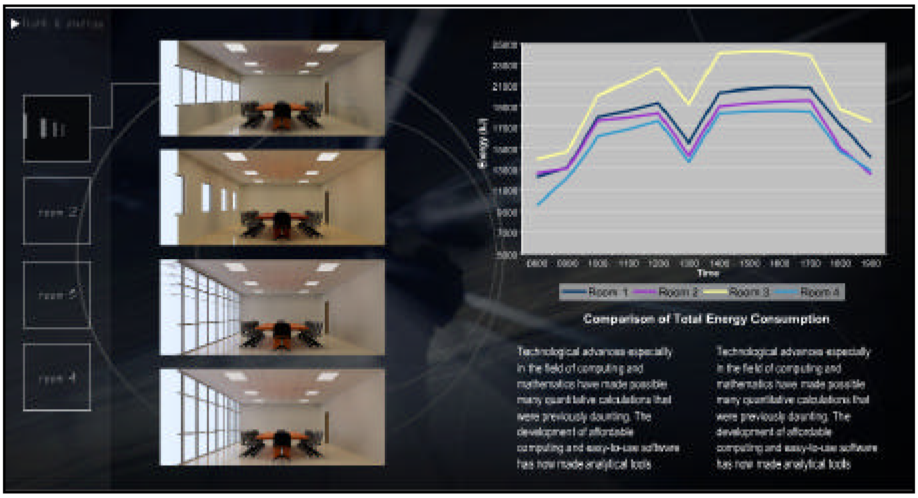

Figure 11. Index page of the design guide with overview of the four design options

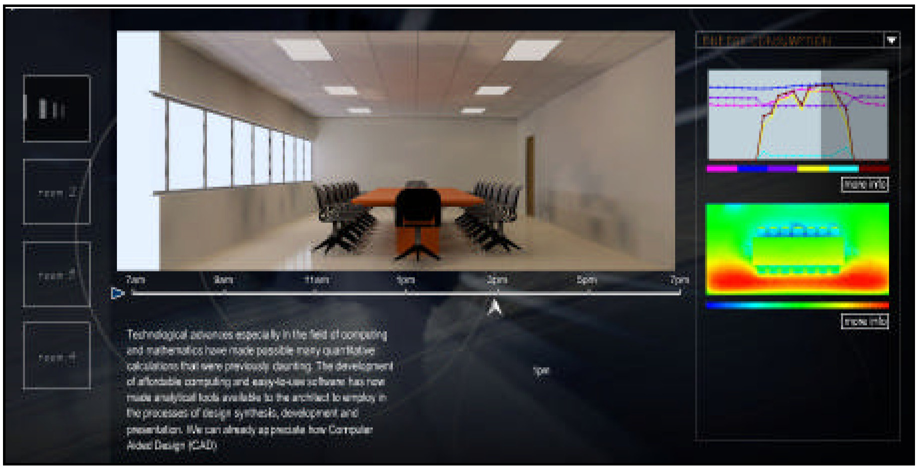

Figure 12. One design option with further information according to the adjusted time

7. Discussion

In reviewing the results of experiment, the developed *web-based design guide* shows potential in fulfilling the objective of allowing fast and concise interpretation and understanding of knowledge made possible by computational simulation and web-based visualization tools.

The second, and more importantly, is to show how the prototype structure of the *web-based design guide* can integrate simulation output from tools such as Lightscape and EnergyPlus. This allows the maximum harnessing of the advantages of computational tools, as well as providing a holistic way of utilizing the information as opposed to the piecemeal understanding when conducting the simulations separately.

It is noted that there are some slight discrepancies in the lighting level readings but this is acceptable within parameters of the experiment. Since the emphasis is to enable qualitative comparisons, the tolerable limits for variance within the empirical data are hence slightly increased. Other parameters have not been considered, such as glare and the impact of building materials.

Simulations need time and effort to conduct, both of which mid to low level design decision scenarios cannot afford. The idea of a design guide was to communicate design considerations based on simulation outputs of standard architectural examples. The knowledge gained from this should be transferred to individual design proposals. The empirical data presented gives the user a more detailed understanding of particular aspects in how they affect the design. The presentation of a comparative matrix also enables a more concise understanding of the relationships between the different aspects. The development of an interactive design guide juxtaposing qualitative and qualitative data in an interactive manner deals with the issue of how to process data into information.

An acid test in establishing computational tools as useful value adding methods in the process of design would be its ability to offer not just insights but also new design possibilities. In the case of simulating a fully glazed curtain wall and subsequently introducing sun shading fins, computational simulations may bring up problems or situations that may be overlooked when using traditional design methods or guesswork. By presenting accurate empirical data and visualizations of the design options or intentions, the tool has demonstrated the ability to lead the designer to new possibilities.

8. Conclusion

The developed *web-based design guide* thus fulfils the three objectives of the hypothesis and demonstrates that computational simulation and visualization tools can be integrated with and value adding to the design process. The experiment thus reinforces the position that computational simulation and visualization tools do not merely improve work efficiency or accuracy. These new tools offer new insight, enable better understanding and can even lead to new design possibilities, though better control and management of design decisions. By concentrating on how the tools can be qualitatively used in the design process, the web-based design guide also identifies areas of possible research that are most pertinent to the designer, in an attempt to guide the development of design tools from technological tools that can be more beneficial to the design process.

Acknowledgements

This research is sponsored by the Academic Research Fund of the National University of Singapore, from which one author is a postgraduate part-time research assistant, and currently pursuing the Master of Architecture degree by the Department of Architecture. We would also like to thank Prof. Lam Khee Poh and Dr. Wong Nyuk Hien for their support on general energy performance simulations and in particular for providing the Singapore weather data.

References

Augenbroe, G., Winkelmann, F.: 1991, Integration of Simulation into the Building Design Process, J.A. Clarke, J.W. Mitchell, R.C. Van de Perre (eds.), *Proceedings, Building Simulation '91 IBPSA Conference*, pp. 367 – 374.

Bazjanac, V.: 2001, Acquisition of Building Geometry in the Simulation of Energy Performance, *in Proceedings of Building Simulation 2001 IBPSA Conference*, pp. 305-312.

Clark, J.A.: 1985, Energy Simulation in Building Design, Adam Hilger, Bristol.

Mahdavi, A. and Pal, V.: 1997, On the Problem of Operative Information in CAAD, *CAAD Futures 1997*, Kluwer Academic Publishers, Munchen.

Wong, N.H. and Lam, K.P.: 1999, A Study of the Use of Performance Based Simulation Tools for Building Design and Evaluation in Singapore, NUS, Singapore.

Lam, K.P., Mahdavi, A., Ullah, M.B. and Ng, E., 1997, Mapping of the Sky Luminance Distribution and computational Prediction of Daylight Performance, *National University of Singapore Research Report RP-950015*, Singapore.

Papamichael, K., Pal, V.: 2002, Bridging the Gap Between Building Science and Designing Studios, in *Proceedings of CAADRIA 2002* , Malaysia.

Witte, Michael J., Robert H. Henninger, Jason Glazer, and Drury B. Crawley.: 2001, Testing and Validation of a New Building Energy Simulation Program, *in Proceedings of Building Simulation 2001 IBPSA Conference*, pp. 353-360.

Wittkopf, S.: 2000, Digital Light Simulation. In *Professional Lighting Design, Nr 14*, Guetersloh, Germany.

Wittkopf, S.: 2001, I-Light, a Web Based Learning System for Architectural Lighting Design, in *Proceedings of ANZASCA 2001*,Wellington, New Zealand.