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Integrating Environmental Performance Criteria in Architectural Design Studios

Hazem Rashed-Ali, Ph.D.

The University of Texas at San Antonio, San Antonio, Texas

ABSTRACT: In recent years, the need to increase the environmental sustainability of the built environment has been clearly established, and an increasing number of built environment professionals are now aiming to design high-performance buildings. However, numerous studies have clearly indicated that achieving high-performance buildings, not to mention zero-energy or carbon-neutral ones, necessitates the integration of environmental performance criteria in the early stages of the design process, where they can be most effective. While a couple of decades ago such integration was difficult to achieve beyond the general design guidelines or rules-of-thumb level, both of which are inadequate to address the specific circumstances of each project, recent advances in building performance simulation tools now allow architects to effectively include building performance criteria in the early stages of their form-making processes. In the case of architectural education, an even more urgent need exists to introduce new generations of architects to the principle of integrating environmental performance criteria in the design process, and to train them to utilize the latest available tools to achieve this. This, however, requires a change from the traditional studio format in which projects are evaluated solely or primarily based on their form/image into one in which projects are evaluated comprehensively based on multiple criteria that include environmental performance as well as other relevant design objectives. The time limitations and wide range of issues typically covered in studios, however, make it difficult to also teach students the skills needed to effectively utilize performance simulation tools. This paper aims to provide a review of previous efforts to integrate environmental performance criteria in the design process in general and in design studios in particular, and presents a proposed collaborative seminar/studio model, which utilizes a seminar to introduce students to the different topics and building performance simulation tools necessary to understand and integrate issues of environmental performance in their designs. These performance considerations are then integrated into design projects in a studio, which runs concurrently with the seminar. In addition to describing the proposed model, the paper will also present results and conclusions from its first year of implementation in the University of Texas at San Antonio.

Conference theme: Building performance studies, zero energy, and carbon-neutral buildings
Keywords: sustainability, environmental performance, architectural education

INTRODUCTION

In recent years, the need to increase the environmental sustainability of the built environment has been early established. This growing interest in achieving more environmentally conscious buildings and communities necessitates an increase in efforts to more effectively integrate environmental performance criteria in all stages of the design process. This is made more significant by the fact that an increasing number of architects and other built environment professionals are now striving to design high-performance, zero-energy, and carbon-neutral buildings, and that achieving these high-performance objectives is not possible without such integration. Integrating environmental performance criteria into the design process is achieved through various methods which differ according to the stage of the design process they are intended for. All methods, however, aim to inform design decisions by an assessment of the expected environmental performance of the community, building, or building components, based on measurable criteria (e.g. energy consumption, harmful emissions, or other environmental impacts).

While performance criteria can and should be considered in all stages of the design process, numerous studies have clearly indicated that achieving high-performance buildings, not to mention zero-energy or carbon-neutral ones, necessitates the integration of these criteria beginning from the early design stages, where they can be most effective. This is particularly important because of the high impact that design decisions taken in these stages have over the environmental performance of buildings and communities. The ASHRAE Green Guide (Grumman, 2003) contends that "*it is much easier to have a major impact on the potential energy savings in a building … at the very early stages of the design process*" and that "*the available impacts diminish [in later] design and construction phases*". On the other hand, integrating environmental considerations in the design process faces several obstacles that frequently cause them to be overlooked. Mazouz & Zerouala (2001) identify some of these obstacles as the influence of iconic models, conceptual modes and pictorial movements that tend to transcend other design variables. Additionally, reliance on technical solutions to solve any building thermal or environmental problems adds to this tendency to overlook environmental performance considerations in design.

Integrating performance criteria into early design stages in particular is made more difficult by the wide range of issues and limited time available in these early stages. Therefore, integration of performance criteria in these stages has typically been limited to expert rules of thumbs and design guidelines that indicate to designers the optimum alternatives and/or acceptable ranges for relevant design parameters under certain conditions. Both of these methods, however, are based on average regional conditions, do not address the circumstances of a specific project, and do not offer the possibility of predicting the performance of that project (Morbitzer 2003). This makes them inadequate to achieve the desired goals of high-performance. However, recent advances in building performance simulation tools now allow architects to effectively include building performance criteria in the early stages of their form-making processes. These tools take into consideration the relationships between different design variables and allow for a more accurate assessment of the impact of specific design decision on environmental performance, thus increasing the validity of design solutions and reducing the cases in which detailed environmental assessments, in later design stages, indicate the need for major design changes, which are typically difficult to achieve at that time.

In the case of architectural education, an even more urgent need exists to introduce new generations of architects to the principle of integrating environmental performance criteria in the design process, and to train them to utilize the latest available tools to achieve this. This, however, requires a change from the traditional studio format in which projects are evaluated solely or primarily based on their form/image into one in which projects are evaluated comprehensively based on multiple criteria that include environmental performance as well as other relevant design objectives. While several models exist for integrating environmental considerations in general, and simulation tools in particular, in design studios, the time limitations and wide range of issues typically covered in studios generally make it difficult to also teach students the skills needed to effectively utilize simulation tools.

Based on this, this paper aims to provide a review of previous efforts to integrate environmental performance considerations in the design process and in design studios. A proposed collaborative seminar/studio model is then presented and described. In this model, a seminar in utilized to introduce students to the different topics and building performance simulation tools necessary to understand and integrate issues of environmental performance in their designs. Students then integrate these performance considerations into design studio projects, which run concurrently with the seminar. In addition to describing the proposed model, the paper will also present results from its first year of implementation in the Department of Architecture, University of Texas at San Antonio.

1. PERFORMANCE SIMULATION AND DESIGN OF HIGH-PERFORMANCE BUILDINGS

It is now commonly accepted that the design of high-performance buildings requires the integration of performance criteria in all stages of the design process. This appreciation of the significance of performance evaluation within the design process is not new. Markus (1969) argues that measurement and appraisal of performance is central to the design process. More recently, Preiser and Vischer (2005) argue for a Building Performance Evaluation (BPE) framework for the planning, design, construction and occupancy of buildings in which quantitative and qualitative building performance criteria are used to inform all stages of the process and contend that this framework will allow decision makers to make more informed design decisions. With regard to environmental performance, Augenbroe (2005) proposes a set of environmental performance indicators (PIs), as unbiased measures of performance, which can lead to more rational decision-making and better dialogue between stakeholders in the building delivery process.

A variety of methods and tools currently exist for integrating performance criteria in the design process. Shaviv et al (1996), Garde-Bentaleb et al (2002), and Morbitzer (2003) all offer similar classifications of these tools including: 1) design guidelines and expert rules of thumb; 2) simplified calculation methods and simplified computer programs; 3) small scale modelling; and 4) comprehensive simulation programs. All of them, however, agree on the inadequacy of guidelines and rules of thumb and that computer simulation offers the best potential for effective design support. Clark (2001) further argues that simulation permits an evaluation of building performance that corresponds to reality and enables integrated performance assessment, while Malkawi (2005) contends that the use of performance simulation in architectural design is on the rise, and that the building industry is aware of the need for better integration of these tools into the design process. This increase in the use of performance simulation tools by architects and the relationship between their use and the design of high performance buildings is best illustrated by the numerous examples of high performance buildings in which such tools have been used. For example, Lerum (2008) analyses 8 case studies of high performance buildings, all of which utilize performance simulation in a variety of forms.

2. PERFORMANCE CRITERIA AND ARCVHITECTURAL DESIGN STUDIOS

The recognition of the need for better integration of environmental performance criteria in architectural design studios and the search for means of effectively achieving this is far from being a new concept. Recent increased concern for the environment, however, has given this area of research a renewed sense of urgency. Meunier (1980) argues for the necessity of introducing performance, measured in non visual ways, into the design studios through the application of simple scientific principles and the use of all kinds of testable models, both physical and mathematical. Brown (1980) makes an even stronger argument for this integration by contending that:

> *"The teaching of mechanical and electrical systems in isolation (distinct from design studio) reinforces the notion that technical courses are narrow, equipment oriented and independent. Broader environmental questions should be addressed relating to social and political. To accomplish this, mechanical electrical building design must be integrated with a synthetic building design process so as to combine programmatic elements in a way that is responsive to physical, social and political context."*

Throughout the years, several approaches can be identified for strengthening the integration of performance considerations in architectural design studios. Several prominent text books have been developed specifically to assist design studio students in taking environmental performance criteria into consideration within their design process. Brown and Reynolds' "*Inside Out*" (1982) aimed to provide students with exercises which require the design of a building and its site, evaluation of that design, and a redesign on the bases of that evaluation. Brown (1980) argues that the intent of "*Inside Out*" is to point out that all design decision, by intention or not, affect the thermal, luminous, sonic, and water environments in buildings, which in turn affect the natural environment. "*Sun, Wind, and Light*" (Brown and Dekay, 2000) was designed to be used by students in the schematic design phase and included various simplified analysis techniques that aimed to help architectural designers to understand the energy consequences of their most basic design decisions and to give them information so that they can use energy issues to generate form. More recently, the Green Studio Handbook (Kwok and Grondzik, 2007) aimed to inform students' designs through providing them with information about the what, how, and how big of various green design strategies to permit a go or nogo decision regarding the appropriateness and viability of a given strategy to be made during schematic design.

In another approach, several large scale collaborative projects have been implemented in the last two decades to develop curricular material that would enhance the integration of building systems' issues and more recently, environmental performance ones, in the design process. The Vital Signs Project (Vital Signs, 2002; Boak, 1999) aimed to achieve this by encouraging architecture students to examine architectural, lighting, and mechanical systems in existing buildings with attention to energy use, occupant well-being, and architectural space-making. Studies performed within the project resulted in 12 resource packages that address physical building performance issues such as energy use, the experiential quality of buildings and occupant well being. The Agents of Change Project (2005) provided training sessions for faculty and teaching assistants to train in methodologies of investigating actual buildings, conducting post-occupancy surveys, and developing exercises to implement at their home institutions. The Carbon Neutral Design (CND) Project (SBSE, 2009) is the most recent of these efforts. The project aimed to address the increasing sense of urgency of today's ecological challenges. The project was initiated by the Society of Building Science Educators (SBSE) in a joint effort with the American Institute of Architects (AIA) and its Committee on The Environment (COTE) to create and disseminate the resources and tools needed to integrate carbon neutral and zero-energy design into professional architecture programs and practice. As part of this project, SBSE implemented the Carbon Neutral Studio initiative in Fall 2007 to develop carbon-neutral teaching resources and tools; to pilot those resources and tools; and to develop a means to share educational resources and the studio outcomes for carbon-neutral design education. The initiative included the implementation of 31 carbon-neutral studios in universities across the US and Canada. One of these studios was the first implementation of the seminar/studio model described in this paper.

With regard to integrating performance considerations in design studios, Brown (1980) categorizes these approaches into: 1) general studio courses with clearly identified ECS content, 2) completely ECS oriented project studios; and 3) lecture courses strongly related to design studio processes. Similarly, Levy (1980) criticizes the traditional approach of separating studio and non-studio components of the curriculum and identifies two alternative model for overcoming its deficiencies: the total studio, in integration of design and all other areas of content happen in the studio, and the independent lab/studio, in which lecture courses aim to expand student motivation through experiential learning and problem solving, and employing and emphasizing creative design aspects, lab techniques, and studio methods.

Recent advances in building performance simulation tools, including their improved and more accessible user interfaces, enhanced application quality control, and better interoperability, more attempts at integrating performance criteria and simulation tools into design studios have been emerging. A survey of sustainability curricula in North American Schools of Architecture in the mid-nineties (Boak, 1995) identifies several software simulation tools, which were used in design studios at the time (some of which are still being used today). These include: G. Z. Brown's Energy Scheming, Murray Milne's Climate Consultant and Solar 5, Larry Degelman's ENER-WIN, Douglas Balcomb's ENERGY-10, and Leonard Bachman's Spreadsheets for Architects. Dekay (1999) describes an experiment in using Energy Scheming involving diverse approaches at different schools. The approaches included developing a Web-based "instructorless seminar", integration into lecture courses, and integration in studio. Dekay concludes that computer simulation offers a possibility for increasing students' ability to deal with greater complexity in a shorter time frame, especially with thermal and lighting issues.

Since that time, however, several new software tools with more capabilities have been developed, many of which have been used by faculty in different settings. Similar to the categorization of approaches discussed earlier, two approaches to integrating performance criteria in design education, and to the use of software simulation tools, can be identified in recent literature. The first approach involves teaching the technical content in a seminar setting with a strong design focus, while the second involves integrating the technical content directly into the studio. Dangel (2008) offers an example of the first approach, in which a graduate seminar was used to teach building envelop design in a design project-based learning method. The seminar included a semester-long design project which formed the core of the coursework, and which allowed students to investigate concepts and principles and then test their feasibility and practical application in a design problem. The project consisted of a sequence of strongly-related design exercises. Dangel concludes that this model allowed students to experience that the presence of physical and technical constraints in the design process did not have to be a creativity-limiting factor, but could in fact constitute a liberating yet challenging aspect. The second approach is exemplified by Faoro and Means (2009), who collaborated in a performance-based integrated-design sustainability studio. The studio was divided into four sequential phases, each utilizing one or more software tools to inform the design process. The instructors concluded that sustainable design studios can provide an opportunity for performance-based design measures to be integrated into academic coursework, and that the metrics used to assess sustainable characteristics employ physical and ecologically based scientific facts in evaluating and promoting ecological literacy in the design of carbon neutral buildings.

While both approaches represent successful models that clearly have a lot of merits, they also both have some draw backs. The first approach, while allowing for in-depth study of the technical topics combined with the obvious benefits of direct application in a design setting, has the drawback of the limited time typically available for seminars especially if student are concurrently enrolled in a demanding design studios. This may not allow students the time needed to fully develop, and benefit from, the design project included in the seminar. The second approach, on the other hand, avoids this issue and achieves the direct integration of the technical content into the studio setting, yet again, the many topics/issues that need to be covered in design studios may limit the time available for covering the technical topics, especially the time needed to acquire the necessary software skills for students exposed to them for the first time. This may subsequently result in not achieving the desired level of utilization of the full capabilities of these tools.

To address these issues, the following sections describe a proposed collaborative seminar/studio model for the integration of environmental performance criteria into design studios, which attempts to combine the strengths of the two models described above while reducing their limitations.

3. A COLLABORATIVE SEMINAR/STUDIO MODEL

Integrating environmental performance criteria in the design studio process and teaching students the design of high-performance, zero-energy, and carbon-neutral buildings requires addressing a wide range of topics, strategies, systems, and technologies typically associated with various aspects of environmentally sustainable design. In addition, students should be introduced to state-of-the-art design decision support and environmental performance simulation tools, many of which have been designed specifically for architects and architectural students and are currently used by practitioners and researchers, as a means of informing their design decisions. To take full advantage of the potential these tools offer, however, students should be provided with hands-on experiences in using the tools, which they can then utilize both in their current studios as well as in their future academic and professional design activities. These experiences should also be used to demonstrate how sustainable design practices can significantly reduce the negative environmental impact of the built environment, while providing more comfortable, healthy and economic buildings and communities. Using these tools, studio projects can be evaluated not based on claims of performance, design guidelines, or rules of thumb but based on actual evidence that specific performance goals have been achieved. Architectural students should also be shown that the design of high-performance buildings does not preclude designers from addressing any other relevant design consideration and does not, as is sometimes claimed, necessarily result in low-quality architecture.

Covering the needed wide range of topics while in the same time training students to utilize the latest performance simulation tools in the studio is made difficult by the time limitations of studios which do not allow students the necessary time to address all of these topics and, in the same time, acquire the skills needed to take full advantage of the simulation tools especially if they are exposed to them for the first time. The seminar/studio model presented in this paper represents an attempt to address this issue by introducing students to these important topics and tools in a separate seminar yet allowing them to directly

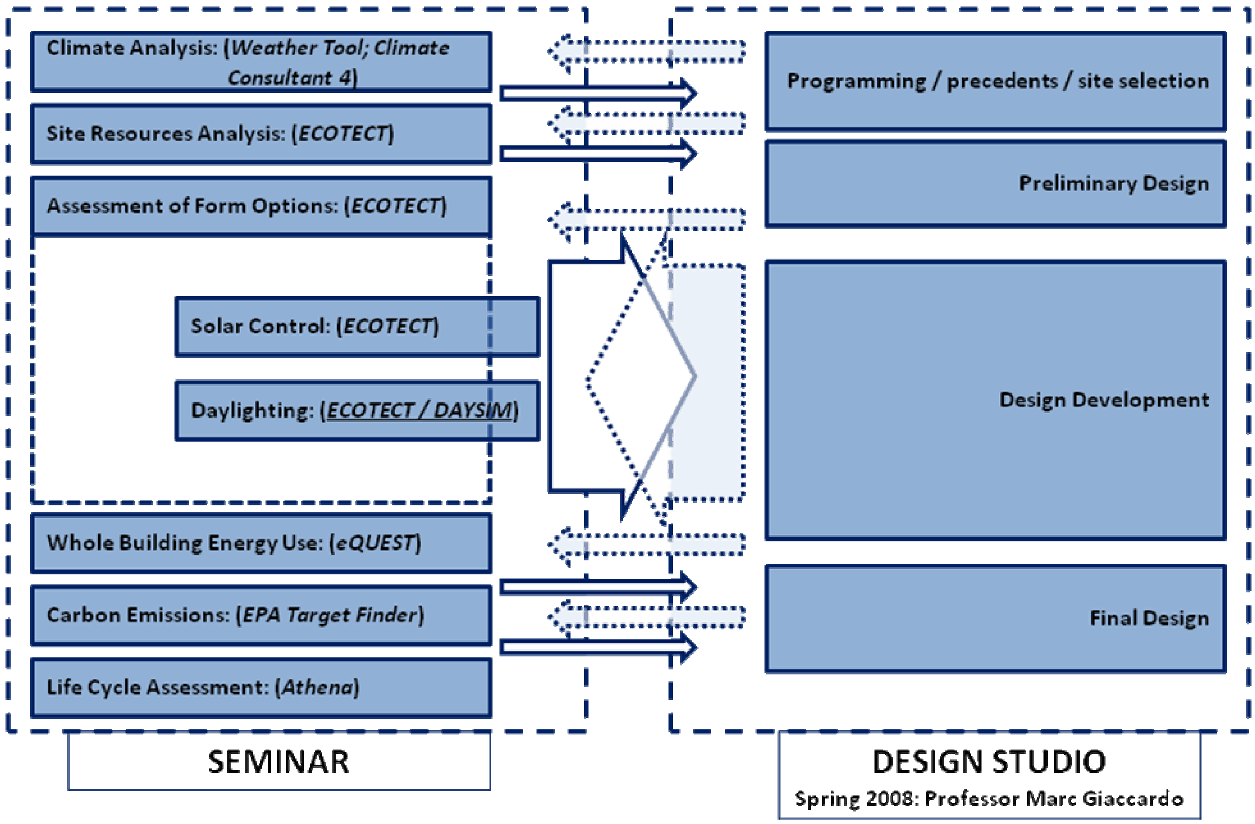

Figure 1: The proposed collaborative seminar/studio model.

apply the knowledge and skills they acquire in a studio setting. To achieve this, collaborative teams are formed between students in the seminar and in the studio, in which seminar student play the role of the environmental consultants within the design team. The goal of the consultants is to utilize the knowledge they gain in the seminar to provide the design studio students with the guidance, analysis, and support they need to inform their design decisions.

The proposed model was implemented for the first time in the spring 2008 semester in the College of Architecture, the University of Texas at San Antonio. The seminar was taught as an elective titled: "*applications in Sustainable Design*", which was cross listed for both graduate and undergraduate students. The seminar was conducted in collaboration with a concurrent undergraduate design studio taught by Professor Marc Giaccardo. The seminar included 18 students (11 undergraduate and 7 graduate), while the studio included an additional 18 undergraduate students. Design teams were formed between students in the design studio and in the seminar. Seminar students played the role of environmental performance consultants, while studio students were asked to utilize the results of the performance analysis in informing their design decisions. A schematic diagram of this collaborative model is shown in figure 1.

The seminar consisted of a sequence of topics and related exercises and assignments, which were coordinated with the sequence of the design studio project. The structure of the topics and assignments in the seminar aimed to capture synergetic relationships between the different systems in the building and to gradually build up from the individual components to the overall building performance. For example: relations between site resources, building form and orientation, and occupant comfort; shading and daylighting; daylighting, HVAC, electric lighting; etc. The topics covered in the seminar included:

1- Climate analysis.
2- Analysis of site resources.
3- Performance assessment of form options.
4- Solar control and shading.
5- Daylight analysis and design.
6- Whole building energy use.
7- Building carbon footprints..
8- Design of photovoltaic systems.
9- Life cycle assessment of building materials.

As part of covering each topic, seminar students were introduced to one or more software simulations tools relevant for that topic. Students first applied these tools to a simplified design exercise to gain some experience with its use, then they used the same tools to perform a series of analysis tasks to the design projects of the studio students and provide performance-based feedback. In each of phase, students were required to meet specific performance targets, while at the same time aiming to achieve the overall performance target

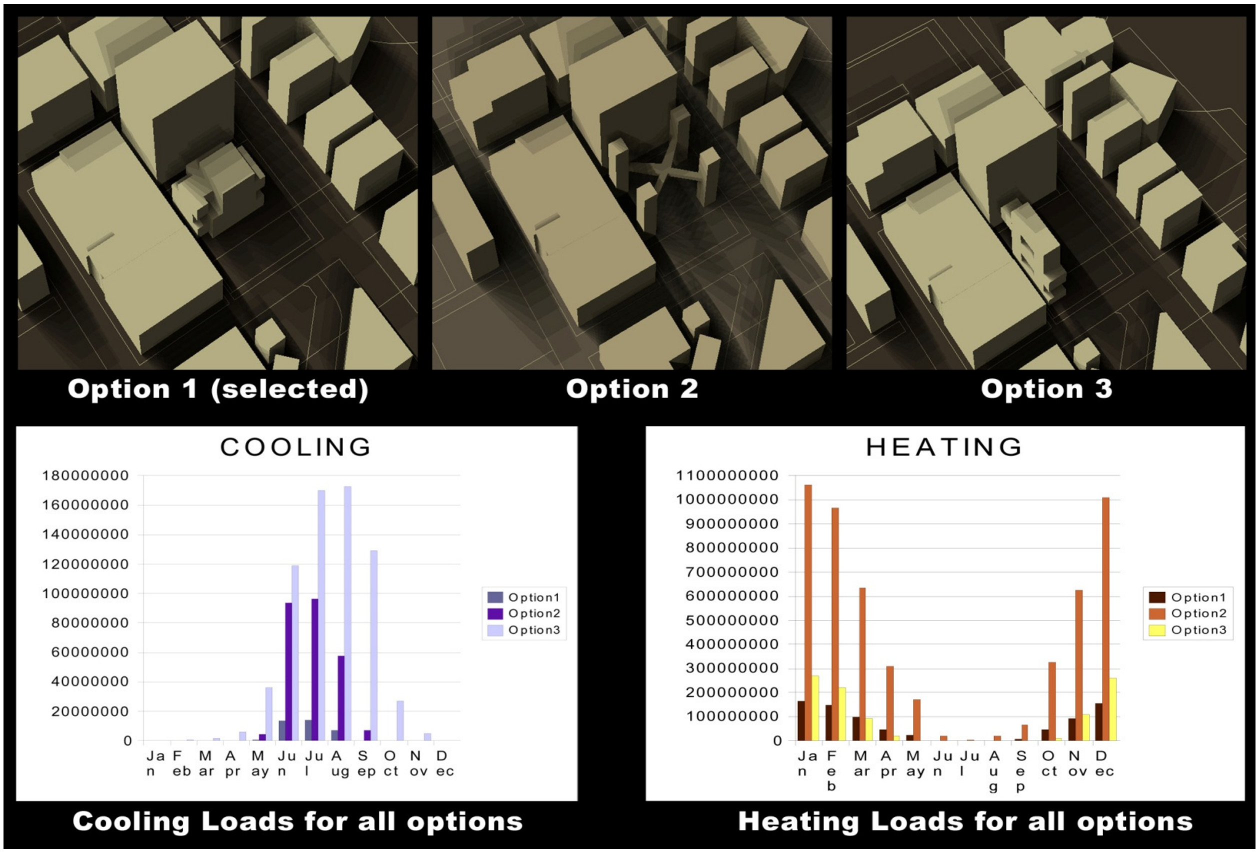

Figure 2: Using ECOTECT to compare the performance of project form alternatives.

of carbon neutrality for the whole project.

Most of the performance analysis tasks conducted within the seminar/studio utilized the simulation tool ECOTECT. ECOTECT is a complete building design and environmental analysis tool that covers the full range of simulation and analysis functions required to truly understand how a building design will operate and perform through allowing designers to work easily in 3D and apply all the tools necessary for an energy efficient and sustainable future (Autodesk, 2009). During the seminar, ECOTECT was used to analyze the resources of the projects' sites, by conducting solar access and shadow range studies, to compare form alternatives, by simulating the cooling/heating loads of each option, to design shading devices, and to perform daylighting analysis. ECOTECT's Weather Tool was also used to perform climate analysis. Other software tools and databases used within the seminar/studio include Climate Consultant 4 (Milne, 2008), used in climate analysis; Radiance and DAYSIM (NRC, 2004), used to simulate daylighting performance, eQUEST (Hirsch, 2003), used to perform whole building energy use simulations; EPA's Target Finder (EPA, 2008), used to estimate the building's carbon footprint; and the life cycle assessment tools BEES (NIST, 2007) and EcoCalculator (Athena Institute, 2008). Figures 2, 3, and 4 show examples of student work in some of the analysis tasks performed. Figure 2 shows an example of using ECOTECT to compare different form alternatives for a design project based on the resulting cooling and heating loads, figure 3 shows an example of a daylighting simulation modelled using ECOTECT and then rendered in Radiance, while figure 4 shows an example of a whole building energy use analysis performed using eQUEST.

4. EVALUATION OF FIRST IMPLEMENTATION

In general, the first implementation of the proposed model proved to be successful. Both the design projects and the performance assessment reports produced by the seminar students exhibited a good level of understanding of the principles, strategies, and systems involved in the design of high performance buildings. While some of the design projects did not manage to achieve the goal of carbon neutrality, mainly because the needed photovoltaic system was too large to be integrated in the buildings as required, they still resulted in high-performance buildings with carbon foot-prints 20 – 40 % lower than their conventional counterparts (according to the Target Finder tool).

Student feedback was also generally very positive especially form the seminar students. While students commented on the large amount of work involved in the seminar, compared to other electives in the program, they all seemed to appreciate the unique skills and experiences they gained from the seminar. Many also commented positively on the team-working experience

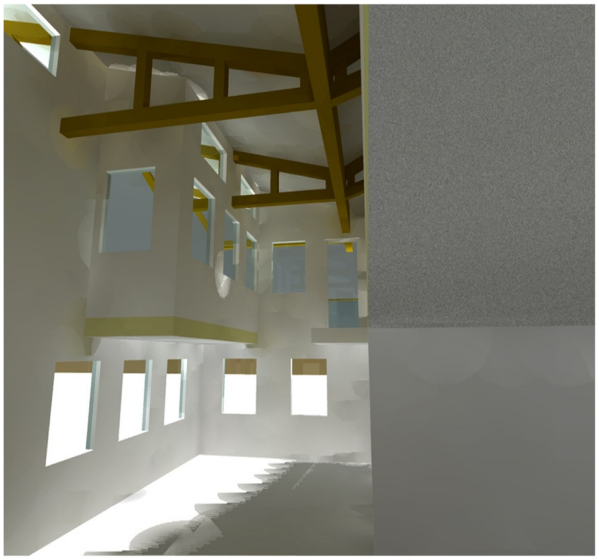

Figure 3: Daylighting simulation using ECOTECT and Radiance

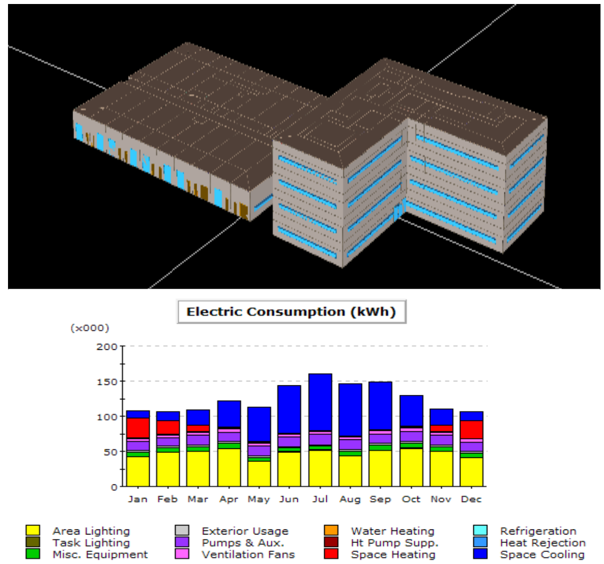

Figure 4: Whole building energy use simulation using eQUEST

they went through during the semester.

On the other hand, several issues have been identified which require improvement in future implementations of the model. Most of these involve organizational and scheduling issues which resulted from the different day/times in which the two courses involved were offered. In this respect, several students commented on the need for more organized meeting times between the two groups of students. In addition, some of the groups also faced difficulties in communicating and exchanging the required work during the semester. Most of these however resulted from personal and group-dynamics issues in these groups. Finally, the issue of how to evaluate the design studio students with respect to the success of their design in meeting the performance targets also needs to be further explored and examined.

Based on all of this, we can conclude that the model implementation experiment was successful in general and resulted in effectively introducing a much larger number of students to the issues and tools needed to achieve high-performance and carbon-neutral designs and to the tools needed to achieve this goal than would have been possible using only the studio format. Future implementations of the model should prove more successful by building on the positive experiences of the first implementation and avoiding or minimizing any negative aspects.

CONCLUSIONS: MODEL EFFECTIVENESS

Based on the experiences of the first year of implementation, the following can be concluded with regard to the effectiveness of the proposed model in assisting students in designing high-performance and carbon-neutral buildings in architectural design studios:

On the one hand, the use of simulation tools clearly allows for far exceeding the accepted objective of minimizing loads, through the use of passive design guidelines and rules of thumb, and providing PVs with no verification of achieved performance. On the other hand, it is difficult for studio projects to credibly claim/achieve zero energy and/or carbon neutrality both because of the limitations of the schematic design stage (lack of time, details, etc.) and the difficulty of accounting for the potential savings of advanced mechanical and electrical systems, or any potential integrative solutions to optimize the performance of both envelop loads and systems. While the simulation tools we have available now do allow for accounting for such savings, this requires a level of experience beyond that of architecture students.

However, the proposed format does allow measurable performance improvements targets for whole building energy use in the studio projects to be set and verified. As the simulation will be based on average mechanical and electrical systems performance, performance improvement targets should be limited to potential improvements resulting from building form, orientation, envelop improvement etc. (in the range of 20 – 30% from average usage), which still represents a significant improvement. Similarly, aggressive performance targets can be set for each of the element systems (shading, daylighting, etc.). These goals can be derived from existing or proposed building performance standards and initiatives (ASHRAE 189, 2030 Challenge, LEED®, etc.). For example, one of these goals could be to achieve the LEED® target with regard to space daylighting. These targets will probably also fall short being of zero-energy for the same reasons discussed above.

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