



## Using Building Simulation to Teach High Performance and Integrated Design

### **Jacob Nathan Dunn, University of Idaho Integrated Design Lab**

Jacob Dunn recently graduated with his Master's of Architecture from the University with the AIA Henry Adams Medal of Honor for his academic excellence and extracurricular involvement. Currently, Dunn is a research scientist at the University of Idaho's Integrated Design Lab (IDL) in Boise, where he works on a daily basis with building performance simulation in both the realm of academic research and the professional world of sustainability consulting. His official title is "Architectural Simulation Specialist" and has worked on a wide range of simulation projects dealing with both new construction and deep renovation across multiple different system types. The simulation work can range from understanding architectural design load implications, to optimizing a passive solar strategy for a zone/building, to simulating complex distribution systems and HVAC types. Dunn also serves as a teachers assistant for various courses at the Idaho Urban Research and Development Center, the satellite graduate architecture program for the University of Idaho. He has helped deliver coursework for daylight simulation classes, run independent study courses, and facilitate integrated architecture studios with mechanical engineering students.

### **Kevin Van Den Wymelenberg**

Kevin Van Den Wymelenberg is an assistant professor at the University of Idaho and director of the Integrated Design Lab in Boise (UI-IDL). He has a Ph.D. in the Built Environment from the University of Washington. Van Den Wymelenberg opened the UI-IDL in 2004 and has successfully secured/completed over \$4.5M in funded research and outreach in energy efficiency for the Northwest Energy Efficiency Alliance, the United States Environment Protection Agency, the Idaho Power Company, the New Buildings Institute and others. Van Den Wymelenberg has consulted on several hundred new construction and major renovation projects with architects and engineers regarding daylight and energy in buildings since 2000. He has presented at many conferences including LightFair International and Passive Low Energy Architecture. He has authored several papers related to daylighting, visual comfort, and low energy design strategies. He is chair of the IENSA's Daylight Metrics Committee and the Governor's Energy Efficiency and Conservation Task Force in Idaho. He also represents the University of Idaho in the Center for Advanced Energy Studies' Energy Efficiency Research Institute.

### **Ms. Sherry McKibben, IURDC, University of Idaho**

Sherry McKibben is University of Idaho associate professor of Architecture and director of the University of Idaho's Idaho Urban Research and Design Center (IURDC) in Boise. Under her supervision, architecture students and faculty of the Center have undertaken many sustainable urban design and civic architecture demonstration projects with Treasure Valley communities—applying, advocating, and educating on Smart Growth and high performance buildings and sites. She founded the UI Integrated Design Lab and continues to work with Director Kevin Van Den Wymelenberg to educate students and professionals to promote energy efficiency and high performance. Sherry McKibben is also an architect and urban designer with the Treasure Valley architecture and urban design firm of McKibben & Cooper Architects/Urban Design. McKibben & Cooper specializes in sustainable urban design, architecture and site technologies. As a board member for Idaho Smart Growth, member of the Urban Land Institute, US Green Building Council, the American Institute of Architects, McKibben works to promote sustainability and is a devoted public speaker on these subjects. McKibben has a B.Arch. from the University of Oregon, a M.Arch. degree from Yale University, and is U.S. Green Building Council LEED accredited.

# Using Building Performance Simulation to Teach High Performance and Integrated Design

## 1. Abstract

The incorporation of building simulation into the integrated design process can add value to the multidisciplinary approach required for high performance buildings. While integrated design and building simulation are gaining traction in the building industry, a simulation-driven workflow between engineers and architects has yet to be clearly established. This paper documents an integrated upper-level architecture and engineering course that aimed to help define this workflow while focusing on the balance between aesthetics and performance. Architecture, landscape architecture, and mechanical engineering students from two different universities learned daylight and energy simulation to help communicate across disciplines in a semester long design studio. Extensive pre and post surveys were administered to the students to evaluate the course's effectiveness in using building performance simulation to teach high performance and integrated design. Insight was gained on how to introduce comprehensive simulation tools into the design studio, how to integrate mechanical engineering students more effectively into architectural courses, and how architects and engineers can work together around an energy model.

## 2. Introduction

In contemporary practice, two factors have a substantial impact on the way that we design buildings. The first, *integrated design*, is an old concept that has seen new popularity in light of the need for deep energy savings in new and existing buildings.

The second, building performance modeling, is a new and constantly evolving technology that changes the landscape of design on almost a quarterly basis. The marriage of these two factors can empower design teams to make astute decisions about aesthetics and energy, while providing a framework upon which to manage an integrated design team. The advancement of these two procedural improvements are fixed and typically segregated within academia, whose structure and programs often fail to address the collaborative problems inherent within the professional practices of the building industry. Like the way of other fragmented portions of the design process, building simulation can also be limited by its current siloed nature in the design and engineering disciplines. Further effort needs to be made in defining the architect's role in using this type of tool in collaboration with engineers in the integrated design process.

This paper follows the implementation of an integrated architecture, landscape architecture and engineering studio that addresses the pedagogy of integrated design using building performance simulation as a vehicle for reintegration.

### 2.1 Motivation

Sustainability is the gestalt of our time. Whether the driving force is environmental, economic, or social in nature, more and more firms and publications are embracing these sustainable principles as part of daily practice. Energy efficiency has been

described as a link between this “triple-bottom-line,”<sup>12</sup> but often requires the most collaboration between disciplines and can thus be the hardest to achieve. The emphasis on energy efficiency has traveled beyond a ‘behind the scenes’ calculation for LEED (Leadership in Energy and Environmental Design) certification and is evident across many levels. It is now common for professional publications (High Performance Buildings, Greensource, etc.) to show both energy modeling data and actual utility bills, thus furthering the discourse on the evaluation of high performance design.

Additionally, accolades such as the AIA Cote Top 10 awards<sup>2</sup> now consistently show simulation data that support design team decisions through the delivery of superlative examples of sustainable projects.

## 2.2 Professional/Pedagogical Imperatives

The development of this interdisciplinary academic studio course was predicated on the following pedagogical imperatives.

### *2.2.1 The need to learn the integrated design process*

The challenge of low energy buildings is primarily one of integrated design, defined as the synthesis of climate, use, loads and systems resulting in a more comfortable and productive environment, and a building that is more energy-efficient than current best practices<sup>4</sup>. This particular definition of integrated design is more about the fundamentals of leadership, team dynamics, and design process than it is about any technical skill or training. In the end, a well-educated and knowledgeable designer practicing integrated design will be a skilled team member able to communicate their expertise and opinion as well as be able to ascertain and synthesize the ideas of other team members from other disciplines. These skills are difficult and expensive to learn in the field, therefore, it is becoming increasingly important to incorporate the education of how to work together early in academic curriculums.

The goal of educating future designers should then become more engaged between the silos of academic theory and practice. While this problem exists between many of the design and trade professions, it is particularly poignant between architectural practice and building systems designers, especially when taking into account the priority that has been placed on drastically reducing energy use over the next few decades<sup>3</sup> and looming discussions of carbon cap and trade. Building performance simulation has the potential to close the gap between the architecture and engineering “hand off” and serve to further integrate these two disciplines around a common performance model. Thus, architectural studios have to go beyond integrating civil and structural engineers into their classrooms<sup>12</sup>; studios must engage mechanical engineering students and other disciplines.

### *2.2.2 The need to learn building performance simulation in an integrated design setting*

Building performance simulation plays a critical role in almost all contemporary high performance projects and must be taught to both professionals and students. Utilizing

this technology not only has the potential to improve the process of design, but it can also improve the process of collaboration. Substantial integration of energy and daylight modeling, early in the design process, has the potential to redefine the disciplinary relationships for both academic and professional praxis. By using performance modeling as a vehicle, multi-disciplinary teams of university students can more effectively learn the process of integrated design and project delivery <sup>1</sup>. Incorporating performance modeling throughout the design process requires involvement from multiple professions across a project's lifecycle. For example, as architects employ energy modeling early in the design process to analyze building form and envelope to help reduce primary building loads, input is needed from the engineers to optimize these designs for implementation of high performance heating, ventilating and air-conditioning (HVAC) concepts.

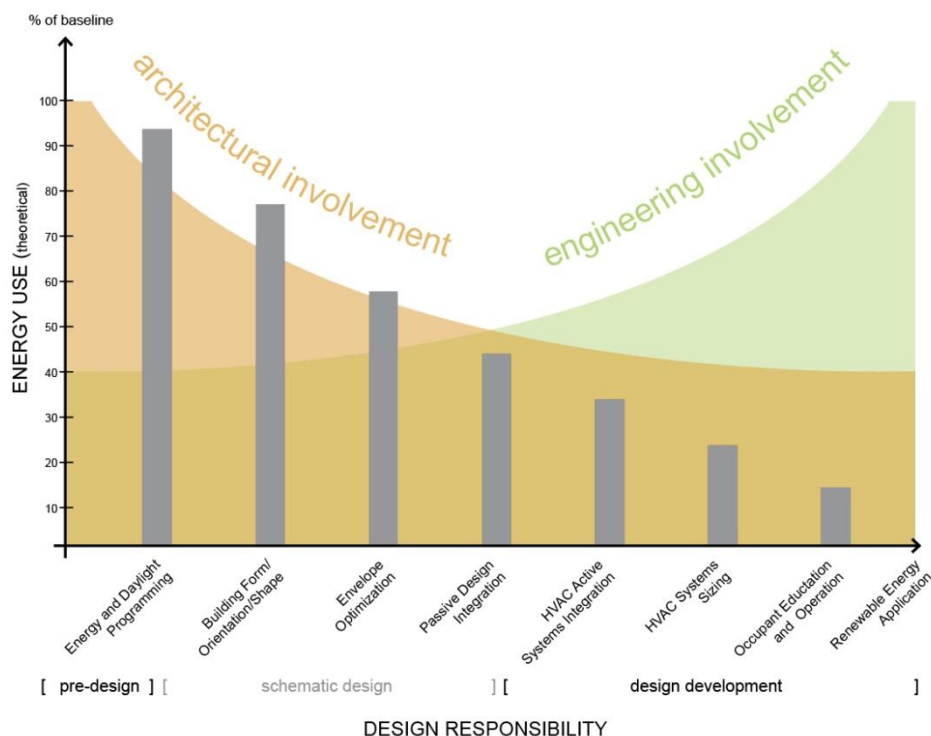
Engineering input at this stage of design is critical to ensure the consideration of alternative, high performance HVAC strategies as the design progresses from a schematic level. Everything from orientation, building form and envelope design, to insulation content, coefficients of performance, and sizing specifications can be considered concurrently by the two professions. Constant communication is required to ensure that design intent is pulled through the architectural design, energy model, and systems engineering and execution. Additionally, the energy and daylight modeling process can create large quantities of data that can only be understood through an integrated team approach. The resulting data are interconnected and require collaborative thinking to understand their full impact on energy consumption and occupant comfort.

Additionally, the use of building simulation within the integrated design process requires the definition of quantifiable goals and criteria to help guide a project, while providing scientific data used for the evaluation of these targets. It also provides meaningful and realistic imagery regarding the human visual and thermal experience of being in the proposed spaces. Just as we need to root design in physics and cost, we must start to root design decisions in energy and building science. The expression, "architects love glass," holds true in many cases and is the result of a breakdown in communication between the architectural concept of a project and its daylight, visual, climatic, and energy performance. A balanced energy and performance-based approach will prohibit the design of buildings that consume resources in an irresponsible manner, while also avoiding the opposite--windowless boxes that use little energy but do not create high quality environments for inhabitants. This balance can be difficult to achieve and thus it is increasingly important for architecture studios to place emphasis on the exploration of this elusive balance.

However, the status quo's usage of energy modeling often fails to achieve this higher level of integration and collaboration. This is in part due to the lack of integration between the tools themselves, mainly the disconnect of design tools from the simulation engines that perform complex analysis. Front end pieces of software are becoming more robust and integrated into contemporary architecture design and documentation tools, but we are still a long way off from having an integrated software suite with easy

movement between design, daylight, and energy analysis. Additionally, whomever is handling the energy model (architects, energy consultants, engineering firms, etc.) typically interfaces with the “design team” on a feedback loop that is too long and cumbersome to truly empower teams to make better informed design decisions about energy. A more simultaneous approach, where teams are working on the same model at the same time, is the ideal workflow for a truly simulation-guided integrated design process. Figure 1 is an integrated design workflow diagram that shows a simultaneous workflow between the two disciplines that is not cleanly separated. This flexibility is critical for providing the room to work together around the same energy modeling process in an effective and integrated manner. The building industry is starting to embrace the potential of this software, but little work has been done to define workflows between the disciplines and how it might affect the integrated design process.

*Figure 1 Integrated Design Workflow Diagram Incorporating Building Simulation<sup>22</sup>*



The course described in this paper is designed to address two major challenges in building design education. First, the team process by which architects and engineers face the challenge of synthesizing design throughout the disparate divisions of practice. Second, is the use of building simulation to guide decision-making through to the final building design.

### 3 Literature Review

This section reviews both existing pedagogical approaches to integrated building simulation within a design curriculum, including well established models of integrated

design in professional practice.

### 3.1 Academic

A similar pedagogical theme emerged in the literature for the few studios that incorporated building performance simulation into their courses: *students need to understand the balance between design and energy, aesthetics and performance*. The studios held that building performance simulation is critical to understanding the complex balance between energy and design and achieving energy efficiency buildings.

This higher design acumen typically began with a redefinition of the approach to design and sustainability. These types of studios reached beyond using a building's "appearance" as the main metric of evaluative performance for design. Here, the primary substance of education moved beyond the all too common objective of perfecting expressive, individual form-making. This made way for a new, tangible approach to sustainability where students used a scientific, evaluative approach that relied on climate, energy, comfort, *and* aesthetics to inform design. The design teams within these new studios need scientific, empirical, and quantitative feedback on how design decisions affect energy consumption and other performance factors such as human comfort. Building performance simulation made this type of relationship accessible through linking a building's aesthetics to its performance through the provision of both qualitative and quantitative data.

The Society of Building Science Educators (SBSE) created a database of studio projects that document teaching methodologies that align with the Carbon Neutral Design (CND) Project<sup>18</sup>. The CND project was created by the SBSE in response to the magnitude and urgency of the ecological challenges that face architectural educators and professionals. The project's goal was to disseminate the resources and tools needed to integrate carbon neutral and zero-energy design into professional architecture programs and praxis. The studio initiative includes a network of 50 professors from around the world and about 30 carbon neutral studio projects. The web database displays a matrix that documents each professor's studio project, course objectives, software approaches, and resources according to the different areas of focus throughout the design process. These areas of focus include frameworks and goals setting, site, envelope, passive strategies, and even energy simulation.

Upon researching several different projects within the matrix, multiple patterns started to emerge that illuminated different strategies used currently within academia regarding building performance simulation. First, most of the projects were seminars, not studios, and the majority of courses did not use any type of simulation software to verify or explore different energy implications of design strategies. The projects that did utilize a performance modeling approach typically focused only on a fragment of the building energy picture. Some approaches explored early massing approaches, some were concerned with envelope analysis, and others with passive design measures, etc.

However, no courses on the website utilized a continuous software approach across a holistic design project that focused on whole building daylight and energy optimization. Additionally, none of these projects attempted to integrate an architecture studio and

mechanical engineering project together, which precluded the exploration of the effect of HVAC systems and their relationship to the rest of the project design. There was also a disconnect between the software tools used in the studios and the industry tools used in professional practice, which are geared toward providing documentation requirements needed by certification programs such as the LEED standard. In some cases, Ecotect<sup>6</sup> was the only software utilized for both daylight and energy analysis, when much more accurate tools exist for these types of simulation. However, the professors involved sometimes had perceived limitations of students capabilities or lack of experience with the more advanced and challenging software.

From the CND Project's website, Professor Hazem Rashed-Ali utilized a similar approach to the course, documented herein, in an undergraduate studio at the University of Texas in spring of 2008<sup>17</sup>. The seminar was called, "Applications in Sustainable Design," and integrated eQUEST into the course to provide annual energy use intensity (EUI) data and disaggregated energy end use (heating, cooling, lighting etc.) monthly consumption graphics. Additionally, a Radiance<sup>6</sup> daylighting model was also utilized (via Ecotect interface) to integrate detailed daylight analysis within the course. Even though an iterative approach was not taken, the results from the model were compared against EnergyStar's Target Finder<sup>10</sup> benchmark buildings to identify potential design modifications and strategies. The instructor cautioned that although eQUEST is a graphic user interface that has a schematic design "wizard" available for ease of model definition, taking advantage of all of its capabilities requires extensive energy modeling experience.

In more recent examples, Iowa State University has explored integrating parametric performance evaluation tools into an architecture seminar in 2011<sup>14</sup>. The approach focused on reshaping the student's process of design by incorporating energy performance as a design parameter. The iterative simulation strategy utilized a combination of parametric evaluation software and thermal calculation spreadsheets for analysis. The dynamic nature of the analysis drove the students to explore more detailed aspects of building physics and quantitative sustainable design practices. Both studios studied this approach in the context of urban infill design and situated performance within larger contextual issues of environment, and culture. The students developed design strategies and guidelines for mixed-use typologies in the first studio and extended this research into net-zero infill projects for US automobile business strips. The studio's approach reinforces the need to integrate performance-oriented design into current pedagogical practices to effectively address energy and sustainability issues faced by architecture today.

In terms of curriculum approaches, the University of Minnesota has explored developing new graduate-level courses that integrate architecture and landscape architecture around energy and water conservation. The courses were designed to explore the tools and resources that can integrate net-zero<sup>20</sup> energy and water strategies and metrics in the early design of campus buildings and landscapes. The curriculum has developed five courses that range from one week workshops, to seven week design studios, to 15-week seminars. One of the main goals of the curriculum is to "identify and apply

integrated performance metrics and assessment methods and tools,” and it does this mainly through the incorporation of the IES VE<sup>6</sup> software. The software plays a critical role in the integrated approach of the courses, and provides a flexible, modular simulation platform with a wide range of simple and advanced analyses. The IES VE software provides an easy to use front end for Radiance and can handle advanced HVAC system design and calibration. The University of Minnesota curriculum serves as a good example of how critical the right software choice can be for the integration of simulation into architecture programs.

A previous studio offered by the University of Idaho executed a comprehensive design studio that used energy goals and benchmarks to help inform the concept and direction of an upper-level graduate architecture studio. For the past four years, the studio has used Ed Mazria’s Architecture 2030 Challenge<sup>3</sup> to organize the studio’s goals and approaches to designing projects that range from net-zero field campuses to engineering labs and educational buildings. Home Energy Efficient Design<sup>6</sup> (HEED) or IES VE was used to quantify energy performance and help inform the design process. Ecotect and AGI3<sup>6</sup> were also used for any daylight and electrical lighting simulation needs. This course helped define some of the parameters and strategy of the course documented in this paper.

All of these examples recognized the need to integrate performance simulation early in the design process and each has started to address the lack of protocols and guidelines for execution. The examples reinforced the need to organize studios around energy goals, to connect design with performance, and emphasized the importance of choosing the right simulation software. Currently, this choice has a large impact on the length of the feedback loop between design and performance documentation. The course described in this paper utilizes a workflow that was not encountered in the literature review. While some of the courses emphasized the need for integration across disciplines, none fully embraced the integrated design process in a multidisciplinary studio that incorporated mechanical engineering students. Simulation, in this respect, can be a powerful tool to help bridge the communication gaps within both conventional and integrated design processes. Additionally, it emphasized the role of simulation beyond early design exploration and deeper throughout the design process. The studio was designed around the idea that simulation practices and strategies should not be developed within the silos of architecture, landscape architecture, and engineering. Instead, a workflow needed to be developed that capitalized on the collective knowledge of all three disciplines and how they work within the integrated design process using building performance simulation.

### 3.2 Professional

Building simulation is slowly becoming common practice. This type of analysis first gained popularity through its use to document energy savings for LEED certification efforts and is also used for energy code documentation. This is still the most typical way to use simulation, but more firms are exploring how to use these powerful tools to support design throughout all stages of a project. This allows teams to use building



performance simulation to drive design, versus only using it to document design decisions for third party certification programs. It is rare to see an energy efficient building that has not used building simulation in a meaningful way throughout its conception.

The rising popularity of building simulation is also marked by the fact that a new position in leading architecture and engineering firms has emerged: the energy analysis/modeler. Firms are starting to dedicate resources solely to run daylight and energy simulations to support their internal design process and in some cases, meet client expectations. Consulting firms have embraced simulation for energy analysis purposes and engineering practices sometimes use simulation to help size and design mechanical systems. Energy codes and high performance building standards already require a certain level of familiarity with energy modeling techniques and terminology and will require more prowess in the future. The building industry is starting to embrace the potential of this software, but only a few documents have been produced that adequately define workflows between the disciplines and how it might affect the integrated design process. Typically, energy modeling is conducted exclusively by the engineering discipline for documentation purposes, and it remains inaccessible for architects to use as a design tool. This section of the literature review focuses on the review of those professional approaches to integrated design and their varying emphasis on building simulation processes.

The guideline-oriented document titled “Roadmap for the Integrated Design Process”, created by Busby Perkins+Will and Stantec Consulting, serves as a comprehensive professional guide to developing both an integrated team and process<sup>15</sup>. The document provides a means to explore and implement sustainable design principles on a project while staying within budgetary and scheduling constraints. It follows the design through the entire project life, from pre-design through occupancy and into operation. This document speaks about the importance of utilizing an iterative design process that allows for feedback loops and mechanisms to evaluate all design team decisions. While it briefly mentions energy modeling as one of these mechanisms to evaluate design decisions based upon energy consumption and life cycle costing analysis, it does not go into detail about how to incorporate modeling into this integrated process. The document does spell out the role of energy modeling in the different phases of the integrated design process, but it lacks the specifics on how the team can use simulation to help solve a variety of different design problems and help solve communication issues within the disciplines.

A literature source that does illuminate the specific role of simulation into the integrated design process comes from BetterBricks and the Northwest Energy Efficiency Alliance. The recent document, “Integrating Energy Engineering & Performance Modeling into the Design Process<sup>16</sup>” is a guide that looks at how to incorporate building simulation throughout all phases of design. The document spells out the scope of building performance modeling, areas of focus, potential useful outputs, and how it can be specifically used for the integration of different building systems. The document’s structure is broken down into a series of questions that building simulation can be used

to analyze and solve amongst the different disciplines of the project. The document also presents this information in the light of an integrated design process that incorporates rigorous energy engineering activities. These activities extend beyond modeling and include goal setting/benchmarking, measurement and verification, post occupancy analysis, and other energy related activities. While the engineering/modeling function is part of the project team, it is not necessarily part of the design team. It can be part of the mechanical engineer's scope or may be performed independently. Regardless, the main job of the energy engineer is to continuously champion issues concerning energy performance and simulation of the building. The document serves as a good starting point to help design teams understand how simulation can be used throughout the entire design process in an integrated fashion, but does not get into specifics of implementation or workflow concepts.

Finally, the AIA published in September of 2012, a web document titled "An Architect's Guide to Integrating Energy Modeling in the Design Process." The document argues that a working understanding of the energy modeling process is critical for architects to fold this capability into architecture's fundamentally integrative work. Unfortunately, this document had not been published before the execution of the course described in this paper, as the resource serves as a comprehensive high-level guide to why architects should care about energy modeling. The resource covers everything from common misunderstandings of energy modeling, to how architects should reframe the design process discussion, to surveys and inventories about different tools and applications. The document also discusses implementation strategies and budgetary considerations, which helps to situate energy modeling within the context of architectural practice. However, the document does not provide much detail on specific workflow concepts between the architect and the engineer.

Many modeling guides talk about the process as if it were done by the "architect, energy consultant, or engineer," but not how the different entities work with each other around an energy model. A major goal of this paper is to contribute to these workflow concepts and to help guide the roles of each discipline within a simulation-driven integrated design process.

#### 4. Methods

This paper documents the process of executing a simulation-based integrated studio for graduate architecture students, landscape architecture students, and upper-level mechanical engineering students from both the University of Idaho and Boise State University. The studio was based in the University of Idaho's IURDC (Idaho Urban Research and Design Center), which provided the parallel studio for the two architecture disciplines. One mechanical engineering student from the University of Idaho and two mechanical engineering students from Boise State University also participated in the studio as a part of a three-credit independent study. The studio formed three multi-disciplinary, cross-collegiate teams to work on designing a high performance, 20,000 square foot recreation center along the Boise River, in Boise, Idaho.

The students had little to no experience with the software packages used for the course, which included OpenStudio version 0.6.0<sup>6</sup>, EnergyPlus version 6<sup>6</sup>, and Radiance<sup>6</sup>.

Emphasis was made on teaching the students how to use the tools to interact with each other's disciplines, and to drive an iterative design process throughout all stages of the project. Radiance and EnergyPlus were chosen for their reputation as having accurate simulation engines and capacity for advanced analysis. Flexibility, depth, and breadth of analysis all factored into the choice of software for the course. Usability and speed were also a key criteria and the recent attention that has been given to OpenStudio by the Department of Energy has rapidly improved its accessibility by architects in early stages of design. Additionally, the development of OpenStudio as a front end for EnergyPlus, and now Radiance, provides new opportunities for the integration of the two analysis engines. Despite the complexity of learning and executing EnergyPlus, it served as an ideal choice because of its ability to provide detailed analysis throughout the entire design process between both architecture and engineering disciplines. The student could conduct a series of comprehensive architectural and engineering analysis within the same model and software.

#### 4.1 - Methods - structure

The following sections briefly describe the different phases of the studio and how building simulation was either learned or applied throughout the integrated design process. A detailed flow diagram can be found online as part of a presentation given to the SBSE<sup>24</sup>.

##### *4.1.1 Pre-design (three week duration)*

For almost the full first month of the course, the students did not touch a simulation program. Instead, pre-design work was broken into a series of intensive workshops that focused on preparing materials used to support the upcoming charrette that marked the culmination of this initial design phase. The first set of workshops introduced the students to professional models of integrated design while study building precedents.

Next, benchmarking and goal setting exercises introduced the students to consumption data from national databases such as the Commercial Building Energy Consumption Survey<sup>9</sup> (CBECS) and regional tools such as Energy Star's Target Finder and the Commercial Building Stock Assessment's (CBSA) body of research. A landscape architecture-integrated workshop approached site and climate design in an inseparable manner and focused on teaching the students the difference between inventory and analysis. Next, energy programming workshops kicked off the student's immersion into the energy code and concentrated on emphasizing energy and lighting performance criteria as an integral part of programming. Finally, an HVAC workshop gave the students a survey of basic building systems and their energy efficiency potentials, while producing schematic diagrams and narratives of different system concepts.

As mentioned previously, the workshops focused on creating materials that were to be used to support the design process approached during the charrette. A charrette is an

intense period of design planning or activity, often collaborative in nature. It served as a vehicle to engage professionals and push students to produce at least three fairly developed design schemes to inform their first round of simulations. The charrette took place over the course of six hours and provided at least one professional from each discipline to work with each of the three student groups throughout the day. The professionals played a key role in helping guide the student's communication with the other disciplines. The charrette was critical in reinforcing the need for students to design quickly and iteratively at a pace that would carry throughout the rest of the course. Additionally, it introduced the students to a multidisciplinary working environment commonly encountered at the onset of professional integrated design projects. The professionals that participated during the charrette were invited to the mid-project and final critiques to follow the projects through their completion.

#### *4.1.2 Conceptual design (three week duration)*

The conceptual design phase marked the first usage of building simulation software in the course. The goal of this phase was to analyze the large-scale design moves produced by the energy charrette and evaluate their maximum potential for deep energy savings. During this phase of the course, the students conducted comprehensive daylight and energy simulation on each of the three design schemes. The analysis produced a wide variety of performance metrics for the students to analyze and synthesize in addition to the more traditional evaluative criteria for early conceptual design (i.e. program functionality, capturing views, proportionality, etc.).

In terms of learning the software, the architecture students studied daylight design and simulation in a parallel daylighting course. The energy simulation piece, however, was taught during studio through a kickoff workshop and multiple follow up sessions.

Typically, the first hour of most classes were devoted to learning how to use the simulation tool to conduct various forms of analysis relevant to the focus of the studio during that particular week. This format remained consistent throughout all phases of the course and disrupted the balance between tool learning and design education in the course.

Daylight simulation focused on single point in time analyses that quantified overall percentages of "daylit" space according to performance criteria developed earlier in the course. Daylight visualization and glare analysis of different spaces were also developed by the students. In terms of energy, simplified HVAC systems were utilized in lieu of fully developed systems to focus attention on loads analysis and relative energy consumption comparison between the different design schemes. Combining the daylight and energy analysis provided insight into the performance of the different scheme's shape, form, orientation, and glazing ratios in ways not encountered before by the students.

At the beginning of this phase, students first were required to choose which design scheme to carry forward. Their decision was to be informed by the simulation results, but the goal of the studio was to emphasize the balance between performance and

other values. Two out of three of the groups did not choose the design with the lowest energy consumption as predicted by the models. These students made a judgment call to develop a design scheme that had the potential to be both architecturally relevant and energy efficient. Regardless of their choice, the conceptual design exercises still provided insight into how their designs used energy and the inherent conflicts between their chosen schemes' aesthetics and performance. Moving forward, simulation provided a way to help these groups mitigate the energy penalties incurred by their original design moves.

Once a design scheme was chosen, the student groups engaged in more detailed analysis that focused on deep load reduction and benchmarking energy savings.

Baseline HVAC systems were defined according to the ASHRAE 90.1 code's modeling protocols and served as a reference point for energy efficiency studies. Students executed daylight and energy analysis of envelope performance parameters including glazing ratios, glazing specifications, shading, daylight harvesting, and insulation optimization. Additionally, the student disciplines had to work closely together to define efficiency measures that focused on the operative parameters of the building type such as temperature setpoints, setbacks, and operational schedules. This information was used to complete one full design iteration, where student groups were given the chance to use the simulation results to make minor or major changes to the design scheme carried forward from the conceptual design phase. One student group completely changed their design, while the two others made slight tweaks and refinements based on their iterative simulations.

#### *4.1.3 Schematic design phase 2 (three week duration)*

The schematic design phase of the course was broken down into two different portions.

The first focused on the detailed analysis of passive design measures in the gym with the goal of eliminating the need for mechanical cooling. To approach this goal, students used building simulation to quantify hourly distributions of temperature ranges inside the gym without a mechanical cooling system. This metric served as a baseline to benchmark the effectiveness of various passive design measures employed by the students in the gym. Aggressive daylight harvesting, natural ventilation, and thermal mass coupled with night purge strategies were designed, explored, simulated, and optimized. Extensive metrics were output from the simulations in an attempt to provide the students with the information needed to determine the impact of their design decisions the performance of the system. These metrics included measurements of mass surface temperature, air temperatures, advanced comfort metrics such as percentage people dissatisfied (PPD) and predicted mean vote (PMV), airflow, cooling capacity, etc. In the end, a judgment call had to be made on the final number of hours that exist beyond the expanded comfort zone of the space and whether or not it warranted a lack of mechanical cooling.

The second portion of the Schematic Design Phase 2 focused on advanced HVAC modeling and its integration into the architectural design of the project. At this point, the engineering students were doing most of the advanced HVAC definition of the model,

while the architecture students had to work closely with them on making diagrams concerning HVAC space and placement within their drawings. Additionally, this is where the graphic user interface of OpenStudio was too limiting and thus, a text-mode interface had to be carried forward to design the geothermal loop zonal heat pump system with dedicated outside air and heat energy recovery. The engineering students also experimented with rightsizing exercises and sizing both baseline and high performance pumps, fans, amongst other types of mechanical equipment.

#### *4.1.4 close out (three week duration)*

The final deliverables for the students included both a critique and a book that comprehensively documented their entire simulation based integrated design process. Consequently, the students were given three weeks to close out their projects. The first week was focused on conducting the final round of simulations and making last minute design changes. The second focused on preparing graphics for the critique, which included both a PowerPoint presentation to cover process and physical board presentation, complete with finalized drawings and energy metrics. The last week was given to the students to complete and turn in their final book, which served as both a grading/portfolio piece for the students and record of the course's first execution.

#### 4.2 Methods - evaluation

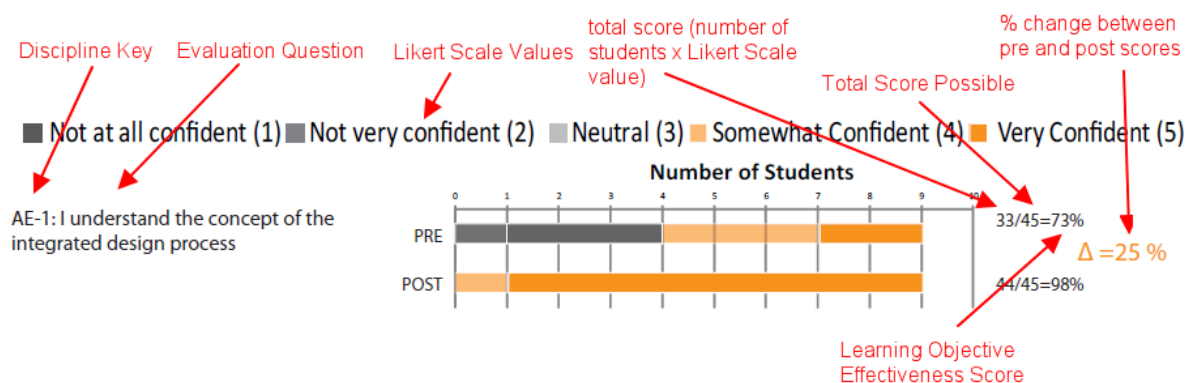
After the course, extensive surveys were administered to the students post and prior to the course to measure perceptions about their own discipline, the other disciplines, and confidence surrounding their professional efficacy. This type of evaluation strategy was based on a methodology conducted on an integrated studio of architects and civil engineers by Sinead MacNamara of Syracuse University<sup>13</sup>. The University's Office of Professional Research and Development in the School of Education designed the comprehensive evaluation plan to include pre and post student surveys, written materials reports, tests, and classroom observations from all parties involved. The survey questions focused on the student's perceptions of their discipline as related to a variety of attributes, as well as their personal and cross-professional perceptions according to the same attributes. A thorough and comprehensive evaluation plan was critical in both refining the course in future applications, in addition to informing models for widespread dissemination of the teaching methodology.

The evaluation plan for the course described in this paper focused mostly on a pre and post student survey, as well as the final grading of a book designed by the students to document their process throughout the semester. Additionally, comments and evaluation forms were solicited from the architecture and engineering professionals and used to help inform simulation workflow between the students.

The survey administered 47 common questions answered by each student disciplines. It also contained seven architecture-specific questions and ten engineering-specific questions. The discipline-specific questions focused on the relationship between the two professions in both a design and professional context. Questions explored how well

the students thought they could work with the other discipline on a project and how their design decisions affected architectural or engineering considerations. Each question revolved around determining their self-assessed proficiency around a particular skillset, or their opinion about either their own, or fellow student's, discipline. The questions were designed around the learning objectives of the course and presented the student with a statement upon which he or she gauged their confidence from "not at all confident" to "very confident" on a five-point Likert Scale of confidence ranges. These qualitative answers were also associated with a number from one to five. These number values were then multiplied by the student responses to get a "total score" for that particular question or learning objective. This "total score" provides insight into the student's level of understanding for that particular question. A pre and post "total" score starts to measure the amount of learning and effectiveness of the course. Figure 2 below shows an example of one of the questions, its format, and pre/post scores.

*Figure 2 Evaluation Question Example<sup>7</sup>*



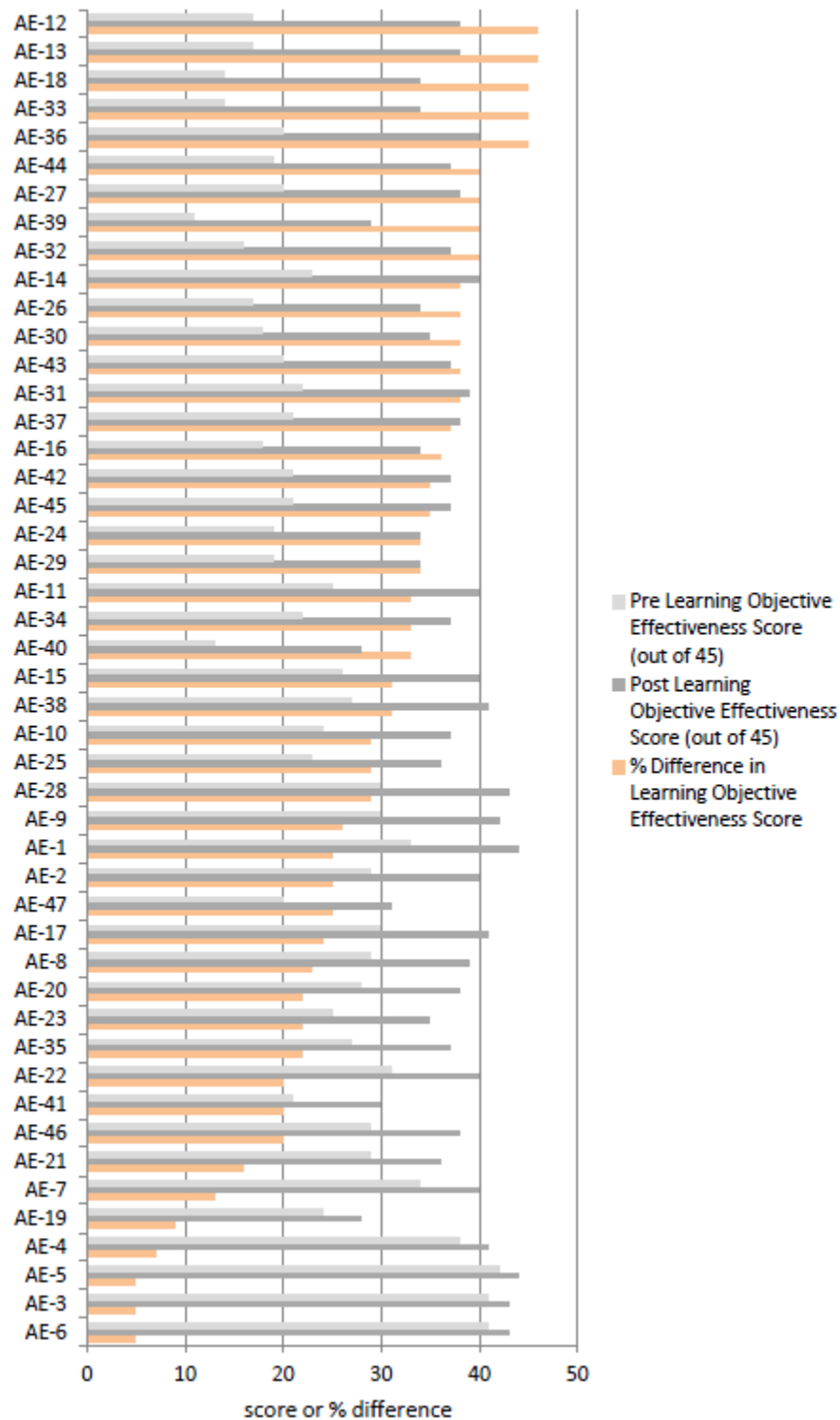
## 5. Results

Each multidisciplinary group produced a comprehensive building and site design that quantified energy consumption and load reduction from over twenty simulated energy efficiency measures. At the end of the course, the students presented their work in a critique format and turned in a final book that extensively documented their simulation analysis throughout all phases of the project. While the final critique and book served as an effective way to document the progress of the students, the pre and post-course surveys were more insightful into the effectiveness of the course in terms of its learning objectives. The quantifiable set of data produced by the surveys provided a clear indication of each student's self-assessment and growth before and after the course.

Figure 3 shows a summary of evaluation results for the change in learning of the combined architecture and engineering student questions. The graph shows the pre and post learning objective effectiveness scores, and organizes questions from highest to lowest change in percent difference between the two. Including the pre and post scores gives a sense if the students already more fully understood the concept before the course and provides some context for a high or low percent change in the scores. While a discussion of the most salient results is included below, a complete set of

charts with question keys can be found on the University of Idaho website<sup>7</sup>.

*Figure 3 Architecture and Engineering Student's Change In Learning Objective Effectiveness Scores<sup>7</sup>*





Over half of the questions show a substantial increase (+30%) in the student's pre and post perceptions. These questions represent statements where the students started with low to medium levels of comprehension and experienced substantial gains in confidence. The two questions (AE #12, AE #13) that showed the most change in learning have to deal with students' familiarity with high performance efficiency goals and what it takes to achieve these targets across multiple building types. The questions that showed the smallest amount of change (AE #3, AE #6) deal with the perceptions of the students own discipline as collaborative and their understanding of the integrated design process. The small percentage difference does not necessarily reflect a low level of comprehension of that particular question, but that it started with a high overall level of understanding.

The questions that showed medium to high levels of change more directly address design issues and performance metrics about daylight and energy. These questions reveal whether or not the students were beginning to understand the complex relationship between design and performance. Figure 4 shows the results from important individual questions that relate to this particular learning objective organized from most change to least change.

**Figure 4 Combined Architecture and Engineering Student Design and Performance Questions<sup>7</sup>**

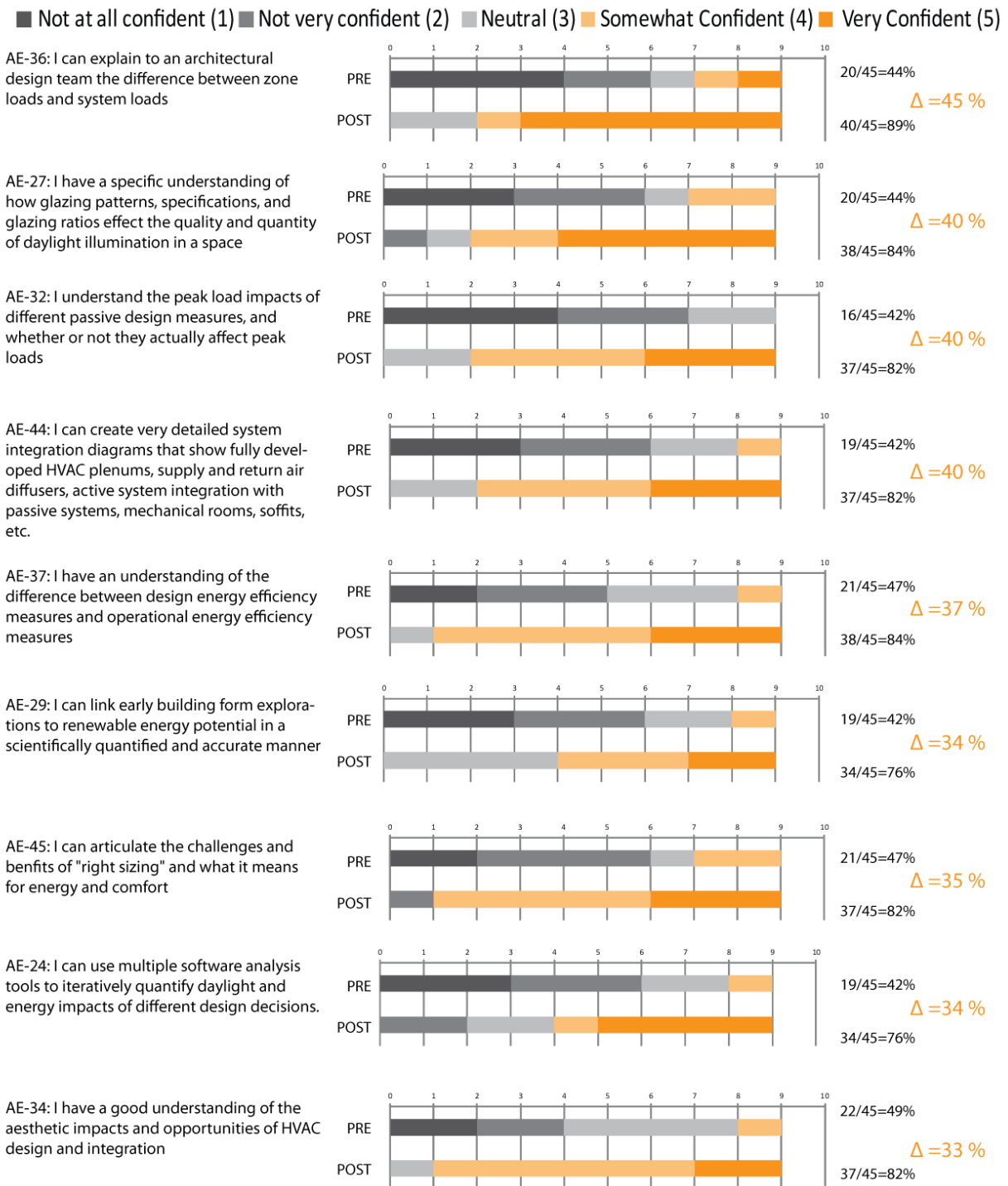


Figure 5 shows some of the key results from the individual architecture and engineering student-specific questions (A-53, 51, 53; E-65, 61, 55, 62, 56), organized from most to least change.

*Figure 5 Architecture and Engineering Student -Specific Discipline Questions<sup>7</sup>*

■ Not at all confident (1) ■ Not very confident (2) ■ Neutral (3) ■ Somewhat Confident (4) ■ Very Confident (5)



In

summary, the combined architecture and engineering questions showed the following key results:

- Students gained a working knowledge of building and system loads and whether or not design decisions affected them.
- Through numerous simulations of multiple glazing strategies, students reinforced their basic understanding of daylighting fundamentals and increased their intuitive knowledge of how design decisions affect daylight performance.
- Students started to feel more comfortable with communicating schematic HVAC design intent through diagrams and integration with their architectural concepts.
- Students expanded their definition of design versus operational energy efficiency measures.
- Students experienced how passive design measures affect annual energy consumption and loads.
- Across the board, students felt more confident with their ability to optimize the daylight and energy performance of their designs through the entire design process.

The discipline-specific questions showed the following key results:

- After the course, the engineering students were substantially more confident about their exposure to an open-ended design process.
- The engineering students felt like their discipline has a key role to play at the onset of a building design project.
- Both student disciplines felt more confident in their ability to work with the other discipline post-course.
- While the engineering students felt more comfortable with their understanding of how engineering decisions impact aesthetics, architecture students had a marginal increase in their confidence concerning how architectural decisions impact early schematic HVAC design.

## 6. Discussion and conclusions

### 6.1 Workflow insights

Multiple insights were made into the simulation workflow between architects and engineers throughout the course's integrated design process. As mentioned in the literature review, simulation workflow models in the profession are still typically siloed in the engineering discipline. The course aimed to further define how exactly architects can get involved in using energy modeling to provide value to their designs and to help coordinate with the engineering discipline. However, this is still out of reach when the engineering firm or third party energy analyst, is solely responsible for the energy model and coordinates with the architect on its development. This model is still wrought with

coordination issues, opportunities for miscommunication, and infrequent feedback loops that are not conducive to effective high performance design. Since architecture firms typically do not get involved in the energy modeling process, the impact of energy modeling on design decisions is several steps removed from the act of designing. In some cases, design firms use architecturally-focused energy modeling programs like Autodesk's Project Vasari or Ecotect for thermal and solar analysis. However, the tools are not accurate enough for engineering load calculations, and currently the lack of interoperability of file types disallows a smooth transition to more engineering-based simulation programs<sup>5</sup>. These simulation workflow factors add up to significant obstacles when trying to facilitate a true integrated design process.

To address these workflow issues, both student disciplines worked simultaneously on the same energy model from conceptual development to advanced HVAC modeling.

This is an atypical workflow in the profession, but proved to be critical in helping the architecture students understand the impacts of their design decisions on building loads and comfort. It was also critical for the engineering students to begin to understand the link between building form, heating and cooling loads, and HVAC design opportunities.

Results from the pre and post-surveys showed substantial increases in the students' confidence when linking their design decisions to daylight and energy performance.

Additionally, the concept of an architect providing an energy model to an engineering firm, or even to an internal engineer at a multi-disciplinary firm, for analysis is rare in the industry. However, the studio experiment revealed that both disciplines could work on the energy model up until the definition of advanced HVAC systems. At this point, the architecture students played more of a supportive role for the energy analysis, and instead focused on architectural integration strategies of the HVAC system equipment defined by the engineering students. A logical break point between the disciplines still existed, however, the transition was much more seamless given that the flexibility of the software allowed for both advanced architectural and engineering analysis on the same model. Since the engineers had been actively involved in the model from its inception, loss of information between design intent and mechanical systems design was minimal.

Thus, architectural design intent and load assumptions had a better chance of influencing the HVAC design and analysis. This type of process proved that simultaneity, consistency across the entire design process, and software selection are critical for effective workflow and communication.

## 6.2 The need for curriculum immersion/integration

The major challenge of the studio proved to be the steep learning curve in learning some of the most accurate and comprehensive energy and daylight simulation tools

available today. The original plan involved conducting a series of four two-class period workshops (eight hours total) at the beginning of each major phase of design. However, this proved to be insufficient and a much more distributed workshop approach was taken for teaching the software. In the end, the first hour of studio was dedicated to learning simulation skills for about 60% of the class periods. The dedication of this much time to tool learning, versus tool application, was the root cause of many challenges encountered by the course. Students showed difficulty with both graphically displaying performance data and articulating its impact on their design decisions. A successful high performance design process requires the need to understand advanced spatial metrics of daylight analysis, complex interactions between energy loads and consumption, and the balance between these two realms of building science. It is critical to get both clients and designers to look at these graphics as a tool for improving the design rather than just another form of documentation. This lack of proficiency allowed students to end up with spaces flooded with too much daylight because they were unable to use the energy analysis to tune their daylight solution and vice versa.

Additionally, the compression of time due to excessive tool learning limited the iterative design exploration of projects. This led to the use of the tool to mostly document initial design decisions, instead of performing iterative analysis to learn about the energy impacts of multiple design approaches. More time would allow students to simulate and explore, for instance, multiple glazing patterns and ratios to optimize their schematic designs for both lighting and load reduction. A balance must be struck, however, between the amount of iterations, design complexity, and the depth of analysis.

These issues can be mitigated by the natural refinement of the course beyond its first execution, but the challenges illuminated the need to situate the studio within a curriculum that has more focus on high performance design and simulation as prerequisites to the studio. The concentration of resources that made this type of course possible was mostly due to the integration of a research lab<sup>21</sup> into the curriculum. The consulting and technical assistance interface of the lab developed the institutional knowledge required to deliver such a technical course between the architecture and mechanical engineering student disciplines. However, not every school has access to this type of resource. Thus, the replicability of the educational model may need to focus on more of a curriculum-based approach.

Despite the need, there is currently little guidance on how to integrate a more evaluative, measurement-based, and high performance approach to design throughout the spectrum of an undergraduate or graduate architecture degree. A wide range of simulation tools exist, as indicated by the extensive inventory conducted by the NREL, each with their own level of difficulty and depth of analysis. These tools range from

simple spreadsheet calculators, to website applications integrated with TMY weather data, to software programs capable to fully account for time dependent variables using hourly time-step simulation. A lack of guidance on requirements set forth by the National Architectural Accreditation board (NAAB) is indicative of this issue on how to integrate different levels of simulation into different levels of architecture courses.

Currently, SBSE has identified this problem and are working with NAAB on drafting guidelines for the full curriculum integration of performance-based design. Additionally, the variability of content and length of Environmental Control Systems courses also point to the need for consistent guidelines and additional courses dedicated to building systems and science. The studio proved that an introductory rule of thumb-based approach does not give students an adequate understanding of high performance design. More focus is needed on developing these types of skills in architecture students that emphasize a performance-based design process that allows them to work across disciplines.

### 6.3 Balance

Despite the compression of the studio schedule due to learning the simulation tools, the students still achieved a well-developed architectural design with a deep level of rich energy analysis. At this point, students had engaged in design exercises only during the charrette and had spent the rest of the time wrestling with their first round of daylight and energy simulations. Analysis was conducted on three of the conceptual designs developed during the charrette before a final design was chosen to carry forward through development. For two out of three of the student groups, this choice was made for design reasons that sometimes conflicted with energy efficiency fundamentals. This forced the students to develop their designs in ways that mitigated the energy penalties associated with their original design moves. It served as an important lesson on optimizing early design decisions and what it takes to overcome the conflicts that arise between aesthetics and performance. For instance, one student group designed a series of cascading rectangular volumes with southwest-facing glass ends, see Figure 5 below. Much of the students' design refinement had to then focus on minimizing the peak-cooling load associated with the sub-optimal orientation. The simulation results revealed the extent of the design move's impact on the zone's BTUH per square foot cooling load in comparison with the other zones in the building and amongst the other projects. The students could then use building simulation to explore multiple types of shading devices and glass properties to optimize daylight and mitigate the energy impacts of the design's early massing strategy.

*Figure 5 Final Student Design Visualization<sup>23</sup>*



In some cases, architectural studios over emphasize design and aesthetics and neglect performance and occupant comfort. This course sought to bring a balance to the two, but emphasized analysis over design during the first half of the semester. The course had assumed that the charrette would provide enough design substance to carry through the first half of the course, but feedback from the mid-project critiques requested more traditional design exploration. Consequently, adjustments were made post mid critiques to ensure students had proper time to develop iterations based on both design ideas and simulation results, with hopefully a strong relationship between the two. For example, while the engineering students worked on modeling advanced HVAC systems like a geothermal zonal heat pump system with dedicated outside air and heat recovery, architecture students focused on creating spatial diagrams depicting location of the equipment within their design. The architecture students had to work closely with the engineering students and the energy model to make sure that all of the plant, zone, and distribution equipment was accounted for in their drawings. This allowed the architecture students to explore architectural attitudes toward integrating HVAC equipment into their aesthetic and spatial concepts.

#### 6.4 The future



Incorporating building simulation into the studio opens up further opportunities to promote a multi-disciplinary studio experience. This course was successful in showing how it can provide a link between the architecture and engineering discipline, but it can go much farther in future applications. Once energy savings are simulated, cost savings can also be estimated and fed into economic analysis. Business and finance students can be brought into the studio to conduct economic analysis of simple payback, return on investment, and net present value. Students could also analyze life cycle cost and investment grade pro-forma analysis. This type of financial analysis needs detailed construction costs, which would facilitate further integration with civil engineering students. Additionally, the landscape students participated in the studio in a traditional manner, but could embrace simulation and a measurement-based approach to their coursework as well. Simulating and quantifying rainfall catchment, water consumption, stormwater impacts, and wastewater flows through a building are all within the scope of an integrated studio that focuses on high performance buildings. The enhanced integration of additional disciplines into the studio would only serve to further ground the design process in the constructability, economic considerations, and other realities important for architecture.

Future experimentations in this type of studio will need to address the logistical issues of cross listing courses, scheduling within or across colleges, and integrating classes into studio that do not require the same amount of time commitment. As mentioned earlier, the current version of the studio used parallel landscape and architecture studios, but incorporated the engineering students via an independent study. This limited the involvement and work that the engineering students could contribute to the studio. The ideal and alternative model would involve integrating the first semester of the engineering student's capstone year into the architecture studio. This would allow the engineering students to participate more fully alongside the architecture students, while informing the second semester of an HVAC or building-oriented capstone project.

Additionally, the course's main goal and target criteria involved reducing energy consumption to 25 kBtu/sf-year. This number was chosen after the initial benchmarking workshop and represented a number that was low enough to potentially achieve net-zero design. While this criteria was helpful in guiding the students' design process, future versions of the course could explore different approaches to reduction targets.

For instance, students would approach their designs differently if the course emphasized load reduction as a means to achieve alternative HVAC strategies such as radiant systems. The current version of the course attempted this idea to some degree through trying to forgo mechanical cooling in the gym space by using aggressive passive design. This goal focused the student's simulation work and analysis beyond just reducing energy to a certain EUI goal. Additionally, a net-zero focused studio goal

has a large impact on early conceptual design exploration. Load reduction, energy consumption reduction, and renewable generation capacity constantly inform and balance one another as students travel through the design process. Finally, comfort modeling and metrics provide great opportunity to further increase students understanding of how design decisions affect occupants, rather than just energy.

## 6.5 Future software development

It has already been established that integrated design and building simulation play a critical role in high performance design. Rob Gugliemetti, from the National Renewable Energy Laboratory, further describes this relationship in the following manner:

*“High-performance buildings require an integrated design approach for all systems to work together optimally; systems integration needs to be incorporated in the earliest stages of design for efforts to be cost and energy-use effective. Building designers need a full-featured software framework to support rigorous, multidisciplinary building simulation<sup>11</sup>.”*

He argues that simulation, like integrated design, must be fully integrated to fully provide the functionality needed to embark on a high performance design process and accurately predict energy use. This integration is a necessity given that most energy analysis engines do not model daylight accurately and vice versa. The course had hoped to capitalize on a new workflow developed by NREL, which utilized OpenStudio as a front end for both Radiance and EnergyPlus--two research-grade simulation tools. The new workflow would also automate the input of annual results from Radiance into the EnergyPlus simulation engine. However, the new workflow did not debut in time and the studio handled daylight and energy simulation in two separate models and workflows; even the geometry existed in two different modeling programs. This duality proved to be unwieldy and prohibited an iterative, interactive, and simultaneous analysis of energy and daylight.

Even without the new integrated workflow, OpenStudio proved to be critical in executing the course. The use of all non-proprietary software programs also helped with content creation and delivery. Most importantly, the recent development of the OpenStudio front end for EnergyPlus provided an approachable platform for architecture students to engage in energy modeling. Significant progress has been made to develop OpenStudio to handle more and more of the energy modeling process within an intuitive interface directly within Google Sketchup. The students handled everything from the definition of thermal zoning, constructions, internal loads, and now even baseline HVAC systems via a drag and drop interface via OpenStudio. The software continues to

develop at a rapid rate and since the execution of the course, two additional major releases have been launched that have completely restructured the interface and workflow of OpenStudio. The software is continually evolving and with every release it becomes easier and easier to use for both architects and engineers. This future development and integration of the OpenStudio modeling software has the potential to alleviate some of the challenges that the course encountered due to a compressed schedule. An accurate, integrated software platform would require less time to learn and open up more time to use the tool to explore the connection between daylight and energy. Significant progress has been made in terms of software development, but great potential still exists on where these tools can take the integrated design process.

## 7. Acknowledgements

The authors would like to thank Professor John Gardner, PH.D., for helping to coordinate the cross-collegiate nature of the course and integrated his Boise State University mechanical engineering students into the course. This aspect of the course was perhaps the most critical in helping to teach and facilitate a true integrated design experience for the students involved. Don Belts and Steven Drown helped to facilitate the integration of University of Idaho landscape architecture students and deserve much thanks. Additionally, special thanks go to University of Idaho Professors Bruce Haglund and Randy Teal, who helped to develop the course, facilitate the professional charrette, and review projects. Finally, the participation of all professionals involved in the charrette and final reviews was much appreciated and extends out to: Tim Johnson at CTA Architects, Nick Hubof at CTA Architects, Steve Benner at CSHQA, Dwaine Carver at CTY Studio, Katie Leichter from Musgrove Engineering, and both Scott Henson and Scott Wendell from LCA Architects.

## 8. References

1. American Institute of Architects. (2007). *Integrated project delivery: A guide*. Retrieved from <http://www.aia.org/aiaucmp/groups/aia/documents/document/aiab085539.pdf>
2. American Institute of Architects, "AIA/COTE Top Ten Green Projects." Last modified 2013. Accessed January 6, 2013. <http://www2.aiaopten.org/hpb/>
3. Architecture 2030, "The 2030 Challenge." Last modified 2013. Accessed January 6, 2013. <http://architecture2030.org/>.
4. Brown, G.Z. & Cole, J., 2006. *Rethinking the design process*, Portland, OR: Energy Studies in Buildings Laboratory, University of Oregon and Konstrukt.
5. Bruning, S. (2011, April). Bim test at ashrae hq. *ASHRAE Journal*, 42(4), Retrieved from [http://www.nxtbook.com/nxtbooks/ashrae/ashraejournal\\_201104/](http://www.nxtbook.com/nxtbooks/ashrae/ashraejournal_201104/)
6. Department of Energy (2011). *Building Energy Software Tools Directory*. [http://apps1.eere.energy.gov/buildings/tools\\_directory/alpha\\_list.cfm](http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm)

7. Dunn, J. (2012). *Arch 553 Course Evaluation Results*. Retrieved from [http://www.idlboise.com/pdf/Arch\\_553\\_Pre\\_and\\_Post\\_Evaluations.pdf](http://www.idlboise.com/pdf/Arch_553_Pre_and_Post_Evaluations.pdf)
8. Dunn, J. (2012, May). *Arch 553 Course Structure*. [http://prezi.com/urodhx\\_p06yg/copy-of-idl\\_sbse\\_integrated\\_studio\\_presentation/](http://prezi.com/urodhx_p06yg/copy-of-idl_sbse_integrated_studio_presentation/)
9. Energy Information Administration. (n.d.). *Commercial building energy consumption survey*. Retrieved from <http://www.eia.gov/consumption/commercial/>
10. EnergyStar. (n.d.). *Target finder*. Retrieved from [http://www.energystar.gov/index.cfm?c=new\\_bldg\\_design.bus\\_target\\_finder](http://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder)
11. Gugliemetti, R. (2011, November). *Openstudio: An open source integrated analysis platform*. Conference proceedings Building simulation conference in Sydney, Australia.
12. Lovins, et al. *Natural Capitalism: Creating the Next Industrial Revolution*. Denver: Little, Brown and Co, 1999.
13. MacNamara, S. (2011, June). *Ac 2011-1802: Transdisciplinary design teaching for civil engineers and architects lessons learned and future plans*. Conference proceedings 2011 annual asee conference.
14. Passe, U. (2012, June). *Changing the relationship of form and performance: The conceptual integration of quantitative performance evaluations into design pedagogy*. Conference proceedings International ASEE conference in Barcelona, Spain.
15. Prepared by Busby Perkins+Will and Stantec Consulting (2007). *Roadmap for the Integrated Design Process*. For the BC Green Building Roundtable in Vancouver, BC.
16. Prepared by Betterbricks (2011). *Integrating Energy Engineering & Performance Modeling into the Design Process*. < [http://www.betterbricks.com/graphics/assets/documents/Performance\\_Modeling\\_FINAL-WEB.pdf](http://www.betterbricks.com/graphics/assets/documents/Performance_Modeling_FINAL-WEB.pdf)>
17. Rashed-Ali, H. (2012). *Carbon neutral teaching: Curriculum materials development*. Retrieved from [http://www.architecture.uwaterloo.ca/faculty\\_projects/terri/carbon-aia/teaching/rashed/rashed.html](http://www.architecture.uwaterloo.ca/faculty_projects/terri/carbon-aia/teaching/rashed/rashed.html)
18. Society of Building Science Educators. (2012). *The carbon neutral studio project*. Retrieved from [http://www.architecture.uwaterloo.ca/faculty\\_projects/terri/carbon-aia/teaching.html](http://www.architecture.uwaterloo.ca/faculty_projects/terri/carbon-aia/teaching.html)
19. The AIA Energy Modeling Working Group (2012). *An Architects Guide to Integrating Energy Modeling in the Design Process*. August, 2012. <http://www.aia.org/practicing/AIAB094452>
20. Torcelinni, P. (2011). Zero and net-zero energy buildings homes. *Building Design Construction* , 61(5), Retrieved from
21. University of Integrated Design Lab (n.d.) retrieved from [idlboise.com](http://idlboise.com)
22. Dunn, J et al. (2011). *Using Building Performance Modeling as a Vehicle for Re-Integration*, American Society of Engineering Education 2011 Annual Conference Proceedings, June 26-29, 2011, Vancouver, British Columbia, Canada.
23. Student Group Work. Nick Olreich, Colin Hill. University of Idaho, Idaho Urban Research and Design Center. Arch 553, Fall 2012.
24. Dunn, J. *Using Building Performance as a Vehicle for Re-Integration*. Presentation to the Sustainable Building Science Educators Annual Retreat. June 2012. [http://prezi.com/tlweyuvkkz8u/aia\\_2013\\_nat\\_convention\\_presentation/](http://prezi.com/tlweyuvkkz8u/aia_2013_nat_convention_presentation/)