

# The “engineer” on the magic mountain: Integrating building performance with design

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**ABSTRACT:** There is a widespread misperception in architectural schools that anyone, student or teacher, interested in evaluating building performance likely lacks well-developed design skills; that perhaps the two mindsets are fundamentally incompatible. However, this paper presents the argument that the design process that leads to compelling spaces can, and optimally will be, the same process that leads to valid, versus smoke-and-mirrors, building analyses. The linking of technical prowess with design skills is a constant and worthwhile endeavor for architectural faculty and their students, particularly in this renaissance of age of sustainability when the effects of the built environment on the ecosystem can no longer reasonably be ignored.

This paper gives pedagogical examples of means by which students in an environmental building systems course taught by the author are encouraged to understand buildings' behavior at an elemental level by engaging simple calculation methods, rules of thumb, and quick modeling techniques in their current or recent design projects. In these classes, analysis is brought out of the realm of the purely scientific, where it is often perceived by students as both unapproachable and unassailable, and brought back to the drawing board. Both failures and successes resulting from student engagement with these exercises are shared and examined, student perceptions of this approach are cited, and recommendations for refinement of these strategies are made.

**KEYWORDS:** Architectural design, building performance, sustainability, pedagogy

## INTRODUCTION

Architecture faculty who teach courses related to the environmental performance of buildings often feel a bit like Hans Castorp, the hero of Thomas Mann's novel *The Magic Mountain*. Hans Castorp leaves his bourgeois life as an engineer to visit a sick cousin for a few weeks and winds up, thanks to a suspicious spot in his lung, persisting in the rarefied environment of a Swiss sanatorium for seven years. Because of the topics they engage, building science educators are often regarded as “engineers” with just a little “moist spot” of consideration for the sublime and mysterious in architecture. But usually the reverse is the case; many are first and foremost architects who happen to have a particular penchant for building physics and passion for acknowledging its importance in the built environment.

In defining the educational aspects of the discipline of architecture, a strong dichotomy has often been drawn between a belief that architecture is implicit and learned by emulating a process of design, and a belief that it is, or should be, explicit and rationally described using a scientific model. A discussion of this theme can be found in the now-classic collection of essays entitled *The Discipline of Architecture* (Piotrowski and Robinson 2001). In “Disciplining Knowledge: Architecture between Cube and Frame”, Michael Stanton paints a picture of professional degree programs in architecture where formalistic design processes are taught with little regard to rigorous intellectual inquiry. This practice “paradoxically advances an intuitive paradigm that is in fact a form of antiknowledge” (2001, 17). Stanton states that design is approached as a game, a series of self-referential riddles to be solved using one's own internal creative capacity without resorting to the crutch of reference to other works, disciplines, or ideas. This approach, born with the modern movement, is characterized by an anti-intellectualism that Stanton feels is outmoded in today's world. Sharon Egretta Sutton, in

"Reinventing Professional Privilege as Inclusivity: A Proposal for an Enriched Mission of Architecture", cites James S. Polshek's view of architectural pedagogy:

Architectural principles...have been transmitted from one generation of architects to another for thousands of years....Despite the logic inherent in these ordering systems, the manner of their transmission...has been more akin to folk art than to the studied and systematic teaching of science (2001, 191).

Julia Williams Robinson, in her essay "The Form and Structure of Architectural Knowledge: From Practice to Discipline", echoes this dichotomous view of architectural knowledge which she defines as:

(1) the intellectual, or explicit knowledge disseminated primarily in academia, and (2) the knowing embedded in the process of making architecture that is essential to design, what Polanyi calls tacit knowledge that is learned by doing and that cannot be critical" (2001, 66).

This break, which Robinson says traditionally separated the scientific disciplines in the first case from the guild-like profession of architecture in the second, has since the 1960s been manifested within the discipline of architecture itself. The result is that architects as form-givers are viewed as central to the discipline, while researchers who delve into the sociopolitical, cultural and scientific impacts of architectural forms are considered marginal or external to the discipline. Robinson calls for a new view of architectural education in a paradigm that integrates the subdisciplines, thereby framing "architecture as a cultural medium, deriving from the design question 'what ought architecture to be'"(2001, 78)?

To exclude from the discipline of architecture that which is not considered purely "architectural" rejects the richness of scientific inquiry, the complexity of cultural and environmental repercussions, and alternative methods of knowledge transmission. This leads to a deeper question of the role of the discipline of architecture in society. In "Environment and Architecture", Donald Watson states that architecture has a capacity as an ethical apparatus, capable not only of improving the global environment in our own time, but also of addressing the needs of the earth's future inhabitants through dedicated environmental stewardship (2001, 172). The challenge, then, for teachers of both the design lab and the "support" courses, who may be and often are the same people, is to find ways of integrating questions of building performance into the rhythm of the design project.

A host of architects and engineers have begun to both explicitly engage this question in the profession and explain their rationale. In the realm of structural engineering, Jennifer Kabat in a *Metropolis* article explains that Cecil Balmond is attempting to introduce structural questions at the outset of design rather than as a refining process. Considering Balmond's work, she writes:

Form for its own sake isn't good enough for him—nor is creating a new shape without rethinking the underlying structure. His solutions inevitably have an enormous impact on buildings, but it's not as if he wants them to look like "feats of engineering." Instead they appear so integral to each project that you can't tell the engineering from the architecture (2007, 101).

In the realm of environmental building systems, a growing number of renowned architects including Renzo Piano, Nicholas Grimshaw, Thom Mayne and Glenn Murcutt refer explicitly to the centrality of questions of solar geometry and wind forces in the design of their buildings. In a quote from his essay "On the Teaching of Architecture", Murcutt relates his strategy for teaching students the criticality of response to climate in architecture:

I'd take the students into various sorts of spaces and leave them to understand why a room feels a bit too cold, or a bit too humid—and why they'd like to open a window to get a bit of air in....When you know what you want, you can find a way of achieving it. When I want the sun to come in during wintertime, but not in

the summertime, or if I want to catch the north-east breeze and pass it through the building, there are many ways of achieving it—ways that respond in a beautiful way to the climatic variations (2008, 17-18).

## **1.0 BACKGROUND**

### **1.1. The structure of the Environmental Building Systems II course**

The Environmental Building Systems II course (EBS II) taught by the author is the second in a two-semester series of required survey courses exploring concepts of architectural form, climate, and human response, ordinarily taken in the third year of a five-year Bachelor of Architecture sequence alongside a required six-credit design laboratory. Through a series of lectures, readings, assignments and exercises, students are exposed to strategies for minimizing the environmental impact of buildings through informed planning and design of passive and active building systems. The enrollment is typically between 90 and 100 students. Half of the assessment is through multiple-choice tests, and the other half is through the completion of pass-fail in-class exercises and, more prominently, three assignments of longer duration. The first of these is weighted less heavily and involves the preparation of a small graphical board presenting a building material or system that contributes to the thermal performance of a built project of the students' choice. This is considered a warm-up exercise to prepare students for the two thermal comfort exercises that follow, which are discussed in this paper.

In the in-class exercises, students are asked to differentiate between appropriate architectural responses to hot-arid and hot-humid climates, to navigate the psychrometric chart, to calculate thermal resistance of the building enclosure and heat loss and heat gain for a small model building, to design a passive solar direct gain space, to size a photovoltaic array, and to consider the advantages of different means of heat distribution. These exercises are designed to be completed in one class period so that they can be related directly to architectural examples in the course.

The course previously included an assignment engaging energy modeling software, but difficulty with partitioning hard drives and other technical problems associated with running the software quickly consumed disproportionate amounts of time for both students and faculty and compromised any learning resulting from the tool. Even the simplest of these programs assumes a base level of building science and systems knowledge that the majority of the students do not yet possess, so the result is that the software becomes a black box with many unfounded assumptions made to generate the necessary input values. This is a common issue; at the 2013 Association of Collegiate Schools of Architecture (ACSA) Fall Conference, Brad Deal (2013) reflected on similar initial challenges in teaching an elective seminar on building energy modeling at Louisiana Tech University.

Improving architecture students' facility with energy modeling is a laudable and arguably necessary goal in the architectural profession if architects are to claim control over building performance. However, the most recent EBS II course focused instead on the fundamentals of climate and thermal comfort, and how these interact with building enclosures. This said, the students, of their own accord, overwhelmingly chose to use basic, self-taught design tools such as Climate Consultant to analyze their sites for the assignments explained below.

## **2.0 METHODOLOGY**

### **2.1. Thermal comfort assignments**

Students in EBS II were given two assignments requiring them to consider thermal comfort in the context of their design work. The first of these assignments asked the students to describe how issues of thermal comfort were addressed in a current or past studio project through the following: a graphic depiction of the climate and microclimate at the site; a graphic representation of the project in the form of architectural drawings, renderings, and photographs with a particular focus on describing the thermal envelope; a diagrammatic representation of

the thermal comfort strategies or systems being developed in the project; and a brief abstract to establish what they proposed, why they proposed it, and how they planned to develop and defend it. Students were reminded, as is emphasized liberally in Norbert Lechner's *Heating, Cooling, Lighting: Sustainable Design Methods for Architects* (2009), the core text for the course, that basic building design should be considered before passive and active systems are developed. All of these elements were summarized and presented on an 11-by-17-inch board. The second such assignment built on the first, and asked for corrections to and development of the previous proposal. It encouraged the use of texts, in-class exercises, reference to precedents and other resources to determine the size and geometry of designed systems or elements. In both of these assignments, students were expected to explain in some detail how thermal performance influenced the building design rather than to give a list of generic strategies. The diagrams and the writing in particular quickly revealed the degree to which students actually understood the building science behind the strategies discussed in class, and individual comments were given to each student to help remedy any misunderstandings. Most importantly, the thermal comfort assignments gave students the agency to explore those elements of thermal comfort that interested them most.

## **2.2. Questionnaire**

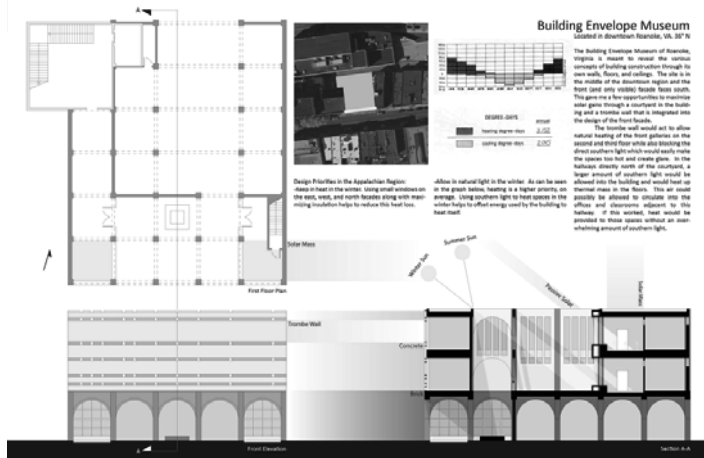
The survey instrument discussed here consisted of questions designed to collect data for the larger goal of improving the author's EBS II course. The specific questions presented in this paper were intended to probe the students' perceptions of the relationship between the EBS II course, with an enrollment of 90, and a concurrent Architecture III course co-taught by the author, with an enrollment of 13, in the 2013 spring semester. The intersection of students enrolled in these two classes was a cohort of ten students, representing a range of performance levels in both courses. Targeting this population allowed for discovery of linkages between the two courses and excluded the possible confounding variable of the different approaches taken by other third-faculty teaching architecture laboratory to students within the EBS II course. With such a small sample size, this study may be viewed as a pilot which will require repetition in subsequent years to strengthen its findings.

A questionnaire was developed and approved by Virginia Tech's Institutional Review board, and delivered to the students via an anonymous web-based survey instrument on June 27, 2013. Six of the ten students responded between June 27 and July 20, 2013. The students took the survey after their obligations to the course and the instructor had ended; however, there is some possibility that the more engaged students in the group responded to the survey due to their inherently stronger sense of duty or loyalty to the instructor.

## **3.0 RESULTS**

### **3.1. Thermal comfort assignments**

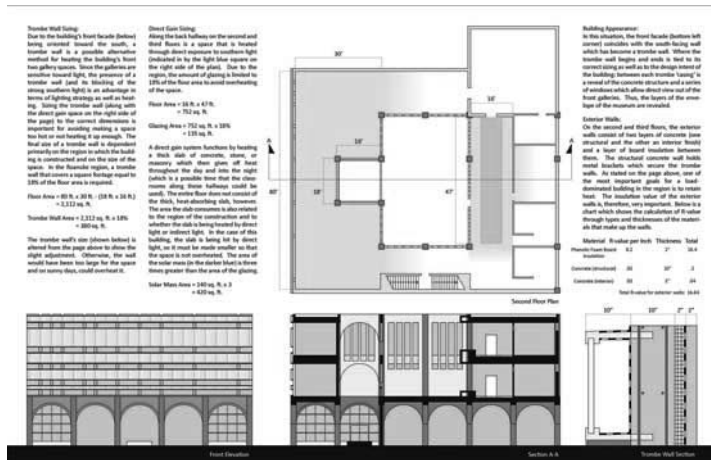
Figures 1 and 2 show an example of one student's submission for the first and second thermal comfort assignments, respectively, as described in Section 2.1. Comments given to the student on the first submission included a suggestion to think about how the glazing needed for the Trombe wall would change the appearance of the facade, and to actually size the area of glass and mass needed. It was also suggested that the student do the same for the direct gain space to check assumptions about its appropriateness. Finally, details about the thermal resistance of the opaque walls were requested.



**Figure 1:** A student's submission for the first thermal comfort assignment in EBS II

The student followed up on these suggestions, likely referring back to an in-class exercise embedded in a lecture regarding passive solar design. The exercise in question was drawn from Norbert Lechner's *Heating Cooling Lighting, Sustainable Design Methods for Architects* (2009). Students were asked to quickly apply the method shown for the design of a direct gain space to their own projects.

The student's resulting final board, shown in Figure 2, includes simple calculations showing the student's use of the rules of thumb presented in class. While addressing insulation, though insufficiently, in the exterior walls, the student failed to realize that the Trombe wall section should not be insulated, because this insulation would limit the desired flow of stored heat energy inward to the conditioned space. The student also viewed the required thermal mass area as a maximum rather than a minimum in his direct gain space. Despite these errors, the student did alter the façade and more specifically consider the materiality of floors and walls as a result of this exercise.



**Figure 2:** A student's submission for the second thermal comfort assignment in EBS II

### 3.2. Questionnaire

In an anonymous web-based survey administered as described in Section 2.2, students were asked to respond to the following statement (#1), "I used a methodology presented in the lectures or in-class exercises to design or evaluate my own building or an element of my building as follows (describe briefly)".

The following responses were garnered from the five students who responded to this statement (see Table 1).

**Table 1:** Responses to statement #1 "I used a methodology presented in the lectures...to design or evaluate my own building..."

#	Response
1	For the second and third class assignments, I took a studio project which I had completed in the fall semester and improved it from a "green design" perspective. I used what I had learned in class to size a Trombe wall for part of the building and also sized a space for heating through sunlight and thermal mass in the floor. Both systems worked well for my building's site and worked well with my existing design.
2	To me, it was very useful to draw information from EBS II and apply it to the studio projects I was working on. It helps to have a better understanding of the realities of construction and the building/design process as a whole.
3	Would it be appropriate for the climate and did it make use of the resources of that climate (wind, solar, etc.)?
5	I integrated my final studio project with the third exercise, in order to add a geothermal heat sink that effectively took over half the cooling load of the project.
6	The information I learned in EBS II was important to my design process. The first step I take is to examine the climate. Where the building will be sited and how it will respond is of the utmost importance.

The next item asked students to respond to the following statement (#2), "I applied the methodology discussed in the last question to my own design" with one of the following responses: "As part of one of the assignments for EBS II"; "As part of my design process in Architecture III, but not for an EBS II assignment"; "For both of these purposes simultaneously" or "Other". All five of the five students responding to this question chose the option "For both of these purposes simultaneously".

Following this was statement #3, "I was able to integrate information learned in EBS II with my design process in Architecture III". Students selected from the following responses: "5 Strongly Agree"; "4 Agree"; "3 Neutral or Undecided"; "2 Disagree"; or "1 Strongly Disagree". Two of the students responded with "Strongly Agree" and four responded with "Agree".

The final statement (#4) of the questionnaire asked students to complete the sentence, "The interrelation of EBS II and Architecture III could be improved by:" to which two students responded as shown in Table 2.

**Table 2:** Responses to statement (#4) "The interrelation of EBS II and Architecture III could be improved by:"

#	Response
5	Having an architectural studio project when the EBS II assignment require[s] integration with a studio project.
6	Making EBS requirements expected in all studio work.

### 3.0. DISCUSSION

The thermal comfort assignments were successful to the degree to which each student followed through on explaining strategies used to achieve thermal comfort. In many cases, they were required to become much more explicit about the nature of the building enclosure, and more realistic about the amount of glazing appropriate for passive solar strategies. Similar refinements and realizations were made in the arena of natural ventilation when students

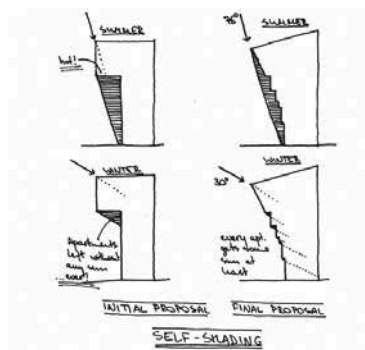
accepted its limitations and the need for intelligent placement and sizing of inlets and outlets to achieve the desired effect. Future investigation might include evaluation of students' design work before and after the EBS II course, to determine the course's impact on their design processes.

In the questionnaire, Respondent #5's response to statement #4 points to an unfortunate scheduling issue that arose during the beginning of the spring semester whereby students worked on several smaller competitions before beginning their main studio assignment of the term. This timing meant that many of the students retroactively applied ideas learned in EBS II to past, rather than current, studio projects for the first thermal comfort assignment. This particular student, respondent #5, subsequently did relate a concept learned in EBS II to his or her current studio project as seen in the response to statement #1.

## CONCLUSION

Both the outcome of student exercises and students' observations regarding the relationship between the two courses suggest the limitations of and the possibilities for the integration of EBS II with the design laboratory. Because there are typically six third-year undergraduate design laboratories taught by faculty with differing approaches and project schedules, perfect coordination of the design exercises in EBS II with design exercises in the laboratories is unrealistic. Often students do not feel ready to introduce newly learned concepts into current design processes even when scheduling allows, and this time-lag effect between the laboratory and the work appearing in EBS II has been evidenced in the assignments submitted for the EBS II class over the past several years.

This situation is not always a negative one, as the rethinking of past work can be instructive when students take more time to analyze certain aspects of their projects. However, the ideal situation would be that they would be enabled by this process to internalize these lessons and incorporate them during the initial stages of design in the future. Figure 3 shows an example of the work of a graduate student enrolled in the EBS II course in 2011, who used the simple idea of winter and summer sun angles to modify the south-facing façade of his proposal during the design process, rather than after the fact.



**Figure 3:** A student incorporates concepts taught in the EBS II course to modify a building façade.

This adaptation calls to mind Glenn Murcutt's simultaneously poetic and precise description of his design of the roof-windows at the Marie Short house, which was introduced in an EBS II lecture:

I opened up the interior to the sky, through roof-windows which face the northern sun, but I realised that the important thing is to control the heat entering the house through the glass. So, I covered the roof-windows with external louvers that are fixed at the mid-winter sun angle and overlapped at the equinox angle of 55 degrees. The sunlight that comes through tells you what time in the

year it is. The thinner the shadow of the louvers at mid-day, the closer you are to mid-winter. As the shadow gets thicker and thicker you get closer to the summer equinox. It's a diary (2008, 18-19).

As this snapshot of Murcutt's thinking demonstrates, the architect remains chiefly responsible for the performance of the building. The increasing fragmentation and specialization of the complex process of building design should not give architects license to disregard, or delegate, decisions about siting, thermal envelope, energy balance, and other concerns generally grouped under the umbrella of sustainability to consulting engineers or other practitioners. Sophisticated performance analysis cannot and should not replace the judgment of the architect, who needs to internalize these basic concepts at the earliest stages of design, when they make the most difference. Simple analytical exercises reinforce the veracity of certain assumptions and help the designer make choices between alternatives. They check the naive suppositions of the inexperienced architect (and some experienced ones as well) and should be viewed as information to be filtered through the design process, like any other. At their best, they offer a range of possible scenarios that give designers a fluid feel for the consequences of their judgments regarding orientation, geometry, solid and void, materiality, and proportion. Educators in the realms of design and building science have an obligation to teach their students to employ these strategies within the context of the design project.

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