Integrated Luminous and Thermal Design:
A Cold Climate Approach to Zero-Energy Carbon-Neutral Design Education

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ABSTRACT: This paper discusses the outcomes of a new design/technology hybrid studio which was developed to integrate the ecological and environmental content of zero-energy and carbon-neutral design processes and methods found in the technology courses into the design studio. This new studio course replaces all required environmental technology courses in the graduate program. The investigation focused on a cold-climate approach to zero-energy carbon-neutral design education, with an emphasis on the roles of daylighting, passive cooling, and natural ventilation. The design studio curriculum content, methods, outcomes, and lessons are discussed, as well as the design tools and assessment and analytical methods.
Key words: design education, carbon-neutral, zero-energy

INTRODUCTION
A perennial challenge for design education in schools of architecture has been the inability to successfully integrate the ecological design processes, strategies, principles, and tools from environmental technology courses into the design studio. Despite the magnitude of current ecological challenges and the urgent need for an integrated zero-energy carbon-neutral design education, many students are provided little or no formal instruction on the topic. Yet, today there is evidence of a growing transformation in design education. In response to global warming, as well as the calls from the *2030 Challenge* and *2010 Imperative* (authored by Ed Mazia et al.), many schools of architecture are reconsidering their curriculum to integrate issues of zero-energy and zero-carbon design [1, 2]. To address the ecological challenges of our time, the School of Architecture at the University of Minnesota recently eliminated all of the required environmental technology courses in the professional graduate architecture program and replaced them with a new studio/technology hybrid course focusing on the integration of luminous and thermal design for zero-energy and carbon-neutral architecture. This is the second in a series of three new integrated studio/technology courses (others focus on structures and materials and methods).

STUDIO DESIGN FOCUS AND OBJECTIVES
The students were asked to consider how architectural design can respond to global warming and climate change and to explore the role of solar design (broadly considered) in shaping the next generation of sustainable architecture. While there are many issues related to zero-energy and carbon-neutral design, the new course focused on how daylighting, thermal, and bioclimatic considerations for cold climate architecture could dramatically reduce or eliminate fossil fuel consumption and greenhouse gas emissions.

As a school of architecture located in a cold climate, there is still a persistent myth held by many local and regional design professionals that the climate is too severe to effectively utilize passive solar strategies, and that a focus on high performance systems is most effective (rather than a passive solar and integrated systems approach). The course set out to challenge this perspective and to explore the integration of passive solar as a primary strategy for energy and carbon reduction for cold climate architecture. An exploration of new approaches to passive solar design and active renewable energy systems integration was central to the curriculum. As architect and professor Manfred Hegger explains, solar design is the primary means to reduce the energy demand in buildings: “In paying attention to a few simple rules, solar architecture is thus the most effective and progressive form of gaining and conserving energy in buildings. Heating demand is reduced, while the heating season and the periods for supplementary heating are considerably shorter. Building thus makes a considerable contribution to environmental protection by reducing CI2 emissions….[3]” As a course for first year graduates, the new curriculum needed to provide tangible zero-energy carbon-neutral design processes, methods, strategies, systems, and evaluative tools while also fostering design confidence in the students.

Studio Design Objectives
The objectives for the course were to: 1) remedy the separation between environmental technology course content and the design studio, 2) introduce ecological processes, methods, and tools for architectural design, and 3) prepare students to integrate zero-energy and

carbon-neutral strategies and assessment methods into their future design education and practice. The vehicle for the course investigation was a local project, which was the design of a new "Zero-Emission/Zero-Energy Design Lab" as a proposed third floor addition to the College of Design at the University of Minnesota (a real project proposed by the Dean of the College). The course challenged the notion that zero-energy and carbon-neutral design was mainly a technological problem. Students were asked to investigate how the building – through its site design, massing, section, envelope, materials, systems integration, and details – could significantly harvest solar and renewable energy to reduce and meet the energy demands while also addressing design excellence and creating meaningful architectural experiences.

The design method was to consider a "hybrid-solar approach" to zero-energy carbon-neutral design which integrated both architectural and technological issues. Solar design and renewable energy were at the heart of the problem. As Manfred Heggar explains in his essay *"From Passive Utilization to Smart Solar Architecture,"* hybrid-solar design is the next generation thinking that is transforming the face of architecture: "…this will be the path to sustainable, energy-efficient solar architecture. It begins with passive solar use…which respond appropriately to solar radiation – smart materials. It is controllable through intelligent, self-regulating control technologies – smart control. Finally it combines passive and active solar systems….Keywords in this field are hybrid solar systems, micro-climatic building skins and self-regulating facades. The development of smart solar architecture will give rise to new technologies, and to an eagerly anticipated new architecture [4]." Consideration of solar and renewable energy as both design and technological issues were addressed by concurrently integrating the issues at different scales and levels of design detail. The educational challenge was to design a curriculum that captured the complex design processes, methods, and integrated thinking necessary to promote the next generation of zero-energy and carbon-neutral sustainable design practice.

COURSE STRUCTURE AND CONTENT

The team of instructors needed to carefully consider how the course structure and content could support the primary objectives of the course. While tangible design strategies, processes, methods, and tools were key to the successfully meeting the ecological objectives, a perhaps greater concern was to model an ecological process for design thinking that would inform the students' future education and practice. Dr. David Orr, professor of environmental studies at Oberlin College, argues that humans – not design or technology – are the challenge to implementing a lasting and ecological transformation of design: "The greatest impediment to an ecological design revolution is not, however, technological or scientific, but rather human…A real design revolution will have to transform human intentions and the larger political, economic, and institutional structure that permitted ecological degradation in the first place…[5]" The team of instructors was interested in fostering an ecological mode of design thinking and providing processes and methods which would enable the students to explore the complexity of the ecological design issues and intentions.

In contrast to the typical design studio, this new nine-credit hybrid design/technology studio was scheduled for only 6.5 weeks (in contrast to 15 weeks). The forty-five students worked in teams of three and took only one additional three-credit course during the 6.5 week period. Class met from 10:00 a.m. to 6:00 p.m. on Mondays, Wednesdays, and Fridays. Morning sessions were organized with lectures, while afternoon sessions were typically used to meet with teams in the design studio, to study local buildings, and to teach the computer tutorials for Ecotect and other performance methods and tools. As we find in professional practice, each student team was responsible for integrating all of the course content and methods into the design project; however, individual student were not expected to be responsible for all of the content (e.g. one student might focus on the daylighting modelling while another integrated the daylighting into a thermal assessment). To ensure that all students learned the essential assessment and analytical methods, the completion of computer tutorials were required of each student. The course was taught by a team of design educators in collaboration with visiting practitioners (including three fulltime educators in environmental technology, sustainable design, and computer methods; three visiting design critics who provided additional design studio reviews; and three visiting practitioners who attended the reviews).

The content of the course was organized as a series of iterative projects around six topical modules related to zero-energy carbon-neutral design: 1) bioclimatic response, 2) daylighting inspiration, 3) thermal exploration, 4) ecological envelope, 5) experiencing sustainability, and 6) an integrated whole. While the projects were designed to encourage students to consider multiple issues concurrently, the emphasis of the projects shifted between focused investigation of an individual topic to integration across topics. Students addressed the design of the "whole" and the design of the "parts" by alternately focusing on different issues and scales. The following discussion considers the educational intentions, processes, and outcomes of the modules and how they were integrated throughout the 6.5 week period.

Bioclimatic Response

The first exploration grounded the students in the principles of bioclimatic design. Since the project was an addition to the existing College of Design, the students were generally familiar with the building. Yet surprisingly few students have taken the time to explore the ecological and environmental forces of the site and existing building that they inhabit. The intention of the project was to begin the design process by considering a comprehensive whole in a particular locale, including early explorations into the relationship between bioclimatic design and the three primary passive design strategies of daylighting, natural ventilation, and passive heating.

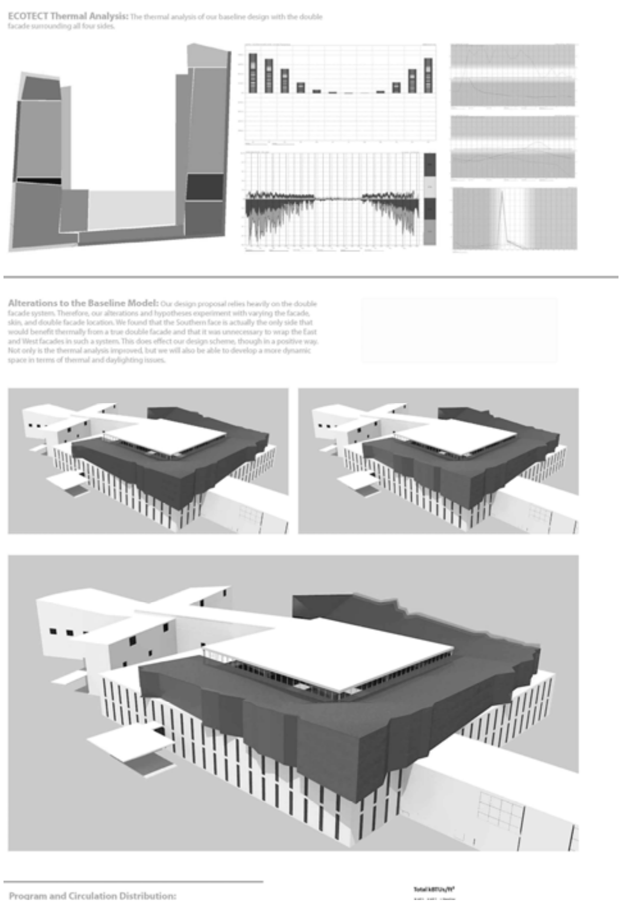

Figure 1: Example of Bioclimatic Charette.

In Project One, students participated in a design charette to evaluate Rapson Hall at the site and building scales and to develop preliminary design proposals that explored the bioclimatic "story" or "narrative" of their site and program for the "Zero-Emission/Zero-Energy Design Lab" at the College of Design. They were asked to develop a graphic and verbal presentation capturing the experiential and physical forces on the site that could shape architectural design from a bioclimatic perspective. Phase One focused on an ecological inventory and Phase Two involved development of three design proposals at the scales of the site and building massing. The evaluative process used a "bioclimatic inventory," which included photography, graphics, and diagrams to investigate the following issues: site and bioclimatic forces and features; luminous and thermal phenomena; indoor environmental quality; the journey through the site/building; construction and enclosure materials and details; and the experiential and poetic opportunities. Conceptual design proposals included physical and computer models at the site and massing scales, time sequence studies of the models, Ecotect solar studies at the site/building massing scale, and a written and graphic critique on critical bioclimatic issues and lessons.

The students were given great freedom in both exploring and representing the findings of their inventory and their design responses. While initially overwhelming, this project was valuable in challenging students to explore the complexity of multiple ecological issues (e.g. heating, lighting, and cooling) and varied scales of design (site, building massing, section, and envelope) from the very earliest phases of design. The project provided a glimpse of a holistic and systemic approach to design in lieu of a linear model.

Daylighting Inspiration

Building on the bioclimatic massing and sectional studies, the students moved into a series of qualitative and quantitative daylighting investigations. This enabled the instructors to elevate the integration of design excellence, spatial quality, and human experience while simultaneously considering quantitative luminous performance. While daylighting was the primary lens used in the second project, the related issues of thermal comfort, heating, and cooling remained present in the investigation.

In Project Two, students worked as a team to evaluate the daylighting design from their bioclimatic design proposals in Project One. They considered how to use the daylighting design to capture and celebrate the bioregional qualities of light in place and to harvest free site energy. The evaluative process included development of a comprehensive daylighting program based on activities (written and photographic qualities of light); physical site and massing models; plans and sections; diurnal and seasonal photographs of the physical models; an Ecotect quantitative analysis on a diurnal and seasonal basis (illuminance studies for 9 a.m., noon, and 3 p.m. for the equinoxes and solstices); and a written and graphic critique on critical daylighting issues and lessons.

The daylighting studies elevated the intersection between poetic and pragmatic ecological design considerations and captured the students' imaginations by revealing the potential design and experiential opportunities of daylighting as well as the energy and performance considerations. The early daylighting studies were carried forward into the next project to evaluate the effectiveness of the proposed thermal and passive design strategies.

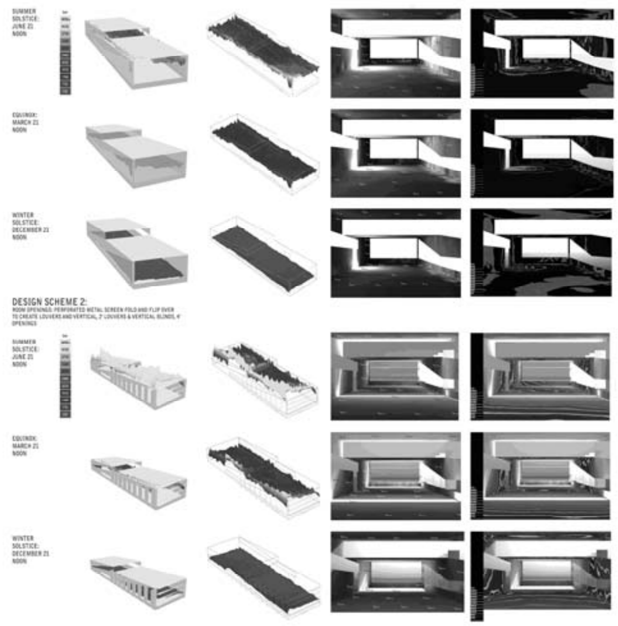

Figure 2: Example daylighting investigations.

Thermal Explorations

In Project Three students established energy and thermal performance goals and sought to achieve thermal design optimization through the application of an iterative analysis method. This involved the development of several hypotheses that could be tested through parameter isolation, iterative simulation, and comparative evaluation. Thus students continued to improve upon their earlier design proposal though incremental refinements and testing toward the goal of thermal design optimization for a passive design approach. Teams explored the process of design evaluation and incremental improvement through hypothesis testing. Teams then optimized thermal design parameters using parametric studies.

The evaluative process for Project Three focused on the use of Ecotect computer modelling to test their hypotheses and examine the resulting impacts on building heating and cooling loads as well as other performance metrics such as internal temperature, passive gains, and thermal discomfort. Each team was asked to prepare a presentation illustrating their research data, hypotheses, methods, findings, and conclusions. A written and graphic critique was required on critical thermal lessons and intersections with earlier studies on bioclimatic and daylighting design.

Ecological Envelopes

In Project Four, students revised their initial design proposal to explore the integration of ecological concepts and passive and active approaches to lighting, heating, and ventilation at the scale of the building envelope. The challenge was to consider the opportunities of the building skin as an ecologically responsive envelope. They were asked to consider the concept of “fivefold functionality” by exploring how the envelope might address multiple issues such as the integration of passive and active systems for heating and cooling as well as additional ecological concerns such as harvesting water, generating electrical energy, creating habitat, responding to health and well-being, creating beauty, connecting to place, etc.

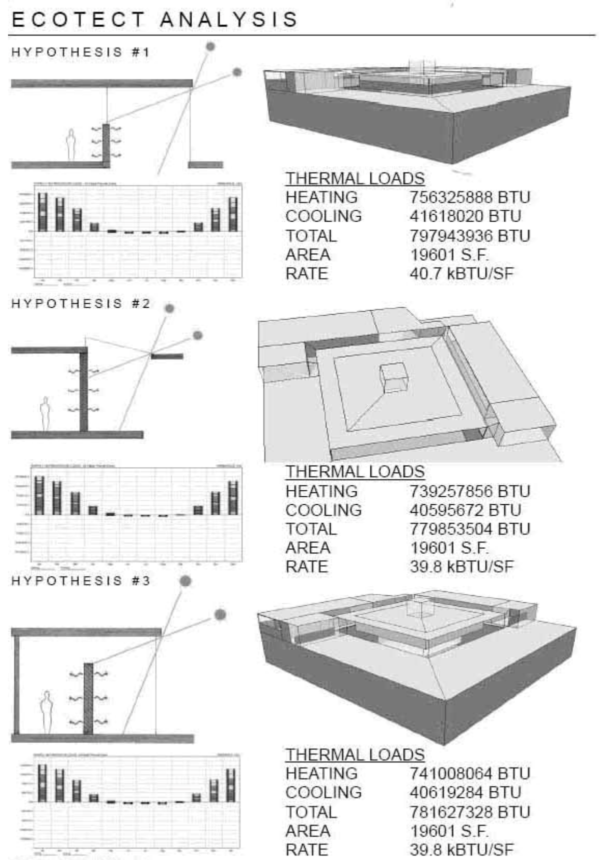

Figure 3: Example thermal analyses.

The evaluative process included development of large scale physical models and building sections to explore the integration of ecological concepts with building materials and detailing. Great strides were made in the students’ understanding of the intersection of construction and thermal and luminous issues due to the material and detail focus of physical models. The large scale physical models encouraged students to integrate ecological issues seasonally and diurnally and to gain an understanding of construction methods and details.

Experiencing Sustainability

Prior to moving directly into the whole building systems integration, the instructors chose to ask the students to step back and look at the quality and detailing of one significant space within the proposed building addition. This enabled the students to more deeply explore materials, construction, and systems integration at the scale of a room. In Project Five students were asked to select either a "typical" or an "important" room within their project. They developed and tested both poetic and pragmatic design intentions through parametric studies

Figure 4: Example envelope analyses.

using large scale physical and computer models. These studies enabled them to gain a better sense of the experience of sustainability in their project while also further exploring the material and detail opportunities of their design proposals. The evaluative process included photo-documentation of the quality of space and sun penetration studies; Ecotect illuminance studies on a diurnal and seasonal basis; and Ecotect thermal studies to evaluate hourly temperatures and passive gains. While time consuming, this project resulted in great insight into the quality of the space and further resolution of daylighting and thermal considerations. At this point in the semester, students had gained sufficient experience with the qualitative and quantitative methods of testing and analysis to successfully evaluate and modify their design proposals. The qualitative daylighting studies of the large-scale physical models were invaluable in enabling the students to experience the character of the space in time and to successfully assess both design excellence and design performance. In the final project, students were asked to use this study to inform systems integration at the scale of the whole.

An Integrated Whole

The final project focused on the integration of the architectural design with lighting, thermal, and renewable energy systems. Emphasis was on the creation of a meaningful whole that supported human experience, comfort, ecological performance, and design excellence. In the Project Six, teams presented a final iteration of the evolution and evaluation of their project. They developed an integrated design solution for the proposed addition and compared the performance to a "baseline case," which was their initial concept presented in Project One and analyzed in Project Two. Teams were required to meet the daylighting, thermal, ventilation, energy, greenhouse gas emissions, and other relevant design and ecological goals set by the team. They analyzed the final design and compared the results to the original "baseline case" showing the estimated improvements in energy use, carbon dioxide emissions, thermal comfort, daylighting performance, life-cycle cost and other ecological metrics of student's choice.

Figure 5: Example study of one room.

The evaluative process for Project Six included envelope models; annotated wall sections; daylighting studies (qualitative time sequence photographs and Ecotect quantitative analysis on diurnal and seasonal basis); Ecotect Studies for the thermal performance for passive solar and system integration; physical models; graphical systems integration studies; and written findings and conclusions on systems integration.

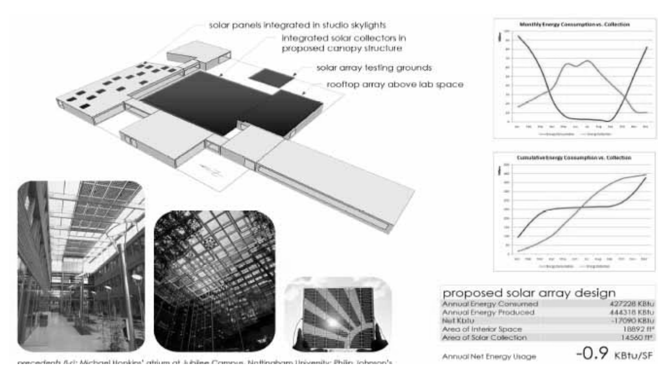

Figure 6: Example of design integration.

Much of the final work involved design refinements and analyses which built on the previous project investigations. Over the 6.5 week period, there was remarkable growth in the students' ability to successfully engage ecological processes, methods, and tools to inform design thinking. Students also verified the significant ecological opportunities of passive solar and renewable energy systems integration for cold climates.

LESSONS FOR DESIGN EDUCATION

This model of integrated ecological design education succeeded in helping students to meaningfully integrate zero-energy and carbon-neutral design thinking into their personal design and decision-making processes. The instructors witnessed a profound change over the course of the 6.5 weeks in the students' abilities, confidence, and skill in framing design questions and then investigating and weighing both poetic and pragmatic ecological design considerations. The instructors hope that this studio has laid a solid foundation that will positively support the students' ability to address ecological design in their future education and practice. The experimental course will continue to evolve and change as we test and develop the new curriculum over the coming years. Lessons for design educators include:

1. Dissolve the Boundaries between Technology and Design: This hybrid design/technology studio is but one way to bridge the gap between the technical courses and the design studio. Other innovative models are being explored in design programs throughout the world. Even if it is not possible to make significant curricular changes, find creative ways to integrate the design and technology courses.
2. Promote Integrated and Iterative Design Thinking: The greatest benefit from the design/technology hybrid course was the growth and change that was evident in the students' ability to frame critical design questions and to address these questions with a high degree of skill and confidence. The studio also provided the depth to meaningfully apply qualitative and quantitative assessment methods. Iterative and integrative processes were essential in moving design thinking to a deeper level.
3. Prioritize Passive Design: Cold climate passive strategies for daylighting, passive heating, and natural ventilation were the foundation of the course. Passive design was considered a primary means to meet energy demand for lighting, heating, and cooling. Innovative approaches to building materials, envelope, and renewable energy systems must be integrated with passive design strategies.
4. Explore Qualitative and Quantitative Assessment Methods: The course emphasized the importance of both qualitative and quantitative design tools as means to develop and assess the architectural quality and performance. This included varied scales of physical models (e.g. massing models, ½" envelope details, and ½" daylighting and section models). Other methods of assessment included sketching, diagramming, Ecotect studies for daylighting and thermal performance, and carbon calculations. Ecotect was a valuable tool for early design studies (even in the first week of class), as it is fairly easy to learn and quickly enables students to compare and contrast the luminous and thermal implications of decisions related to massing, section, form, and window design. Qualitative daylighting models and sketching were used both early in the design process and toward the end of the investigation as a complement to the Ecotect studies.
5. Promote Meaningful Collaboration: Collaborative teaching and learning was essential, for no faculty or student can be an expert in all aspects of ecological design. A team of instructors, visiting critics, and professionals was essential in providing the necessary expertise. Students gained valuable experience collaborating and sharing responsibilities.
6. Acknowledge the Heightened Intensity: Although successfully condensing the content into half of a typical semester (6.5 weeks) seemed highly challenging, it successfully focused the students' attention. With only one additional class, students were less distracted by competing interests and seemed to work more effectively and purposefully toward a successful end result. The disadvantage of the condensed schedule was the limited time to process and synthesize the design methods and evaluative tools. Despite this limitation, the intensity of the course fostered a spirit of collaboration and exploration that will serve the students well as they move forward with their future ecological design education and practice.

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