Time and Adaptive Comfort Studies: Luminous and Thermal Design for Zero-Energy Architectural Education

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ABSTRACT

It is necessary to have an understanding of time-based, dynamic, and adaptive approaches to luminous and thermal comfort (and the impacts on global climate change related to these approaches) in order to transition towards net-zero, and net-positive energy architectural design. To foster this understanding, architectural students need to explore visualization and assessment processes and use tools to model the ecological forces that shape our sense of comfort and our relationships to the natural and built environments. This paper explores the goals and outcomes of a series of project modules designed to foster the awareness, intuition, and design skills that will support the students’ decision making as they approach low- and net-zero energy design. Using bioclimatic design, daylighting, and thermal comfort as focal topics, students were challenged to consider the relationships between design decisions, human comfort, energy consumption, and ecological impacts. Seasonal and diurnal forces were explored as visual, tactile, and experiential ways to engage student interest and enhance their understanding of the intersections between poetic and performance attributes of energy and architecture.

Key Words: Zero energy, bioclimatic design, energy efficiency, and architectural education.

1. INTRODUCTION

In response to global climate change, 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 investigate emerging issues of carbon neutral and low-, net-zero-, and energy-positive design [1, 2]. To meet the ambitious energy and carbon reduction goals of the 2030 Challenge, it is essential to investigate how dynamic environmental forces and ecological processes can inform design thinking, strategies, and methods in architectural design education and the profession. To address these and related energy and ecological challenges of our time, the School of Architecture at the University of Minnesota eliminated required environmental technology courses in the professional graduate architecture program and replaced them with a required studio focusing on an integrated luminous and thermal design approach to net-zero energy and carbon-neutral architecture. This paper explores the lessons from the past five years of studio instruction, including learning objectives, methods, and tools to foster greater understanding of architecture within a dynamic, responsive, and adaptive ecological context.

2. DESIGN STUDIO FOCUS AND OBJECTIVES

While there are many dimensions of net-zero energy and carbon-neutral architecture, this studio focused on how daylighting, thermal, and bioclimatic considerations for cold climate architecture could dramatically reduce or eliminate fossil fuel consumption and greenhouse gas emissions. The students
were asked to consider how architectural design can respond to global warming and climate change. Central to the question of net-zero energy is the consideration of architecture as part of a living-ecological system, with the need to seasonally and diurnally harvest daylight, solar, thermal, and on-site renewable energy sources and to use these factors to inspire and shape architecture and systems design. Architect Bill Reed suggests that the architectural profession needs to design “relationships” rather than “objects” and that shifting to a living-systems perspective is a necessary transition from “conventional” to “regenerative practice”: “…an object by itself cannot be regenerative – it’s about the relationship between the objects and how they are continually evolving that makes them regenerative. [3]” The studio explored the shift to designing “relationships” and the necessity to employ dynamic processes and tools that model the changing ecological forces that shape our natural and built environments.

The objectives for the studio were to: 1) introduce dynamic ecological processes, methods, and tools to inform architectural design, 2) explore architecture as a living, constantly changing, and adapting set of ecological relationships grounded in a particular place and time, and 3) prepare students to integrate zero-energy and carbon-neutral strategies and assessment methods into their future design education and practice. The program included the design of a new 20,000 square foot “Zero-Energy Design Lab” as a proposed third-floor addition to Rapson Hall, which houses the College of Design at the University of Minnesota, and a reconsideration of the building’s. Interior and exterior spaces, which included laboratories (daylighting, energy, materials, structures, mock-up spaces), meeting rooms, classrooms, offices, and exhibition areas as well as outdoor demonstration labs for research on sustainable landscape design. Students were encouraged to develop flexible and adaptable interpretations of the program brief.

2.1. Cold Climate Challenge and Passive Potential

The University of Minnesota is located in a cold-climate state with extreme diurnal and seasonal climatic variations. There persists a myth, held by many regional design educators and professionals, that the locale is too severe to effectively utilize passive solar strategies and that a more effective energy approach is to optimize high performance systems (in lieu of a combined passive design and integrated systems approach). The studio 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. As architect and professor Manfred Hegger explains in his essay “From Passive Utilization to Smart Solar Architecture,” 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…” [4]” The studio considered a “hybrid-solar approach” to net-zero energy and carbon-neutral design that integrated both architectural and technological strategies as promoted by Manfred Heggar: “…this [hybrid solar] 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].” A fresh exploration of passive solar, bioclimatic design, and active renewable energy systems integration was central to the studio curriculum.

2.2. Passive Design and Adaptive Comfort

Students were also asked to investigate the intersection of “passive solar and renewable energy design” with “adaptive comfort”. The “adaptive comfort model” in ASHRAE Standard 55-2010
considers an expanded comfort zone for occupant-controlled naturally-conditioned spaces (with no mechanical systems). The expanded comfort zone accounts for occupants’ ability to adapt to seasonal temperatures in contrast to the “static comfort model” of providing all occupants with the same indoor temperature across seasons (see Figure 1). Findings from the Center for the Built Environment at the University of California Berkeley underscore the potential benefits of the adaptive comfort model: “In the design and operation of buildings and mechanical systems, an advanced understanding of human comfort presents opportunities to save energy while still keeping occupants comfortable. The standard convention of attempting to maintain a narrow temperature band can be an energy-intensive practice. Instead, using CBE’s comfort prediction tools with ASHRAE Standard-55 as a guide, building designers may find that a wider temperature band will provide adequate comfort, saving a significant amount of energy.”

Students were asked to consider how the experience of comfort can vary greatly for occupants and to explore potential climatic, cultural, typological, seasonal, sensory, physiological, psychological, and behavioural dimensions. As Fergus Nicol and Fionn Stevenson emphasize in their research on “Adaptive Comfort in an Unpredictable World,” “…studies of climate change adaptation will need to draw on the knowledge generated by the thermal comfort discourse…No longer is it seen as a function just of the physical and physiological state of the human body; it is also a function of the ways buildings are heated and ventilated, the opportunities the building affords for its inhabitants to control it, the form(s) of energy inhabitants use to fit the building to their needs. This provides designers with major opportunities to design out energy inefficiency through the use of more enlightened thermal comfort strategies.” Students considered both “passive and adaptive perspectives” in developing the program and the design strategies across the site, building, room, envelope, and detail scales.

Figure 1: Comfort zone as defined by the Static Comfort Model (left) and Adaptive Comfort Model with expanded comfort zone in pale blue (right); Thermal Comfort Tool for ASHRAE 55-2010, Center for Building Energy, University of California Berkeley [5].

3. COURSE STRUCTURE AND CONTENT

A cohort of faculty worked together to develop, pilot, and refine the studio over a five-year period. The course was taught by a team of design educators in collaboration with practitioners (including three fulltime educators with expertise in environmental technology, sustainable design, and computer methods as well as studio critics who provided additional design reviews). In contrast to the typical design studio, this six-credit hybrid design/technology studio was scheduled for only 6.5 weeks
The cohort of first-year graduate students (typically 48 students) worked in teams of 3-4 students 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 desk crits, pin-ups, and reviews, while afternoon sessions were used to introduce topical content, to teach the computer tutorials and other performance and assessment methods and tools, and to study local buildings. Each team was responsible for integrating all of the course content and methods into the design project. To ensure that all students learned the essential assessment and analytical methods, the completion of computer tutorials were required of each student. (The selection of analytical tools has varied over the five years; during the past two years students used Integrated Environmental Solutions Virtual Environment – IES VE and they previously used Ecotect, among other tools [7, 8]. (For the next studio, we are exploring the capabilities of Diva and Safaira Concept for energy and thermal analyses.)

The course was organized as a series of iterative project modules around six topics related to the design of a net-zero energy and carbon-neutral building addition and landscape renovation for Rapson Hall (see Figure 2 for site context. Module topics included: 1) bioclimatic response, 2) daylighting inspiration, 3) thermal exploration, 4) ecological envelope, 5) experiencing sustainability and 6) an integrated whole. While students were asked to consider multiple issues and scales concurrently, the emphasis of the projects shifted between investigations of a focused topic (e.g. bioclimatic design, daylight, thermal, envelope, systems, etc.) 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 across seasons and time (see Figure 2). The following discussion considers the educational intentions, processes, and outcomes of the project modules and how the concepts of place and time were integrated into a luminous and thermal approach to net-zero design education.

Figure 2: Site and building context (left) and 6.5 week studio content schedule (right).

3.1. Project One: Bioclimatic Response – Context in Time

Project One: Bioclimatic Response asked students to observe, experience, and document site and contextual forces and to consider potential bioclimatic design opportunities and constraints related to daylighting, natural ventilation, and passive heating. The first phase of the exploration was framed as a hands-on “bioclimatic inventory”. Since the project was a third-floor addition to the existing Rapson Hall at the College of Design, the students were familiar with the existing building; yet few students had explored how the site and building were (or were not) responsive to ecological and environmental forces. Site and building conditions were assessed through time-lapse photography,
diagrams, documentation of the material attributes and luminous and thermal qualities, and interpretation of diurnal and seasonal weather, climatic, and contextual forces. Students developed “seasonal metabolic profiles” to understand how the site changed over time and to consider potential adaptive design responses for seasonal conditions related to comfort, experience, and opportunities to harvest on-site sun, wind, and light for heating, cooling, and ventilation (see Figures 3 and 4).

Figure 3: Example bioclimatic inventories (Left: Butitta, Gardner, Merlis, Tremal; Right: Bell, Fleishaker, Kang, Wingate).

Figure 4: Examples of preliminary seasonal programming (Left: Frandrup, Roys, Schmitz, McCormick; Right: Berger, Breton Gulyanska, Hulmer).
Teams used the “bioclimatic inventory” as a point-of-departure for a weekend design charrette to investigate “time” and “seasonal adaptation and change” as inspiration for development of three bioclimatic design proposals at the site and massing scales. Conceptual design proposals included physical and computer models at the site and massing scales, time sequence studies of the models, solar studies at the site/building massing scale, and a written and graphic critique on critical bioclimatic issues and lessons across time and seasons. (see Figure 5).

3.2. Project Two: Daylight Inspiration – Luminous Qualities and Quantities of Time

Building on the bioclimatic massing and sectional studies, the students moved into a series of qualitative and quantitative daylighting investigations. Project Two: Daylight Inspiration brought the occupants, program, and seasonal and diurnal qualities, opportunities, and challenges of natural light to the forefront of design thinking. Daylighting studies explored the integration of design intentions, programmatic needs, spatial characteristics, human comfort and experience, and thermal considerations. While daylighting was the primary lens used in the second project, the integrative issues of energy consumption, comfort, heating, cooling, and ventilation remained present in the investigations. Students evaluated the design opportunities and limitations of the initial daylighting design proposals from Project One: Bioclimate Response, and were asked to develop a graphic “daylighting program” to use as design criteria for iterative daylighting explorations at the building scale. Students explored how to use the daylighting strategies to capture and celebrate the bioregional qualities of light in place, to harvest renewable sources of seasonal energy at the site, and to integrate emerging program considerations.

The evaluative daylighting processes included development of a graphic seasonal and diurnal daylighting program based on activities and human needs (desired qualities and quantities of light, precedents, potential material, physical, and experiential attributes); physical daylighting massing models; diurnal and seasonal photographs of the physical massing models; seasonal plans and sections; illuminance studies (9 a.m., noon, and 3 p.m. for the equinoxes and solstices); daylight autonomy studies; and a written and graphic critique on critical daylighting issues and lessons.
Quantitative seasonal and diurnal illuminance studies were conducted with either IES VE, Ecotect, Radiance, or DAYSIM. Students compared “diurnal and seasonal illuminance studies” to an “annual daylight autonomy simulation” using DAYSIM to assess the “Useful Daylight Illuminance” (UDI) and when electric lighting was not needed [9, 10]. The studies explored poetic and pragmatic design considerations through daylighting as well as potential seasonal energy, comfort, and experiential issues. These early iterative studies encouraged students to consider simple adaptive strategies through programming, massing, spatial planning, section, and envelope (see Figures 6, 7, and 8).

**Daylight and Thermal Issues:**

- Light contrast / Use of light as a role in time and a destination.
- Using light as a tool for orientation in space.
- Personal control to adapt daylight experience to suit individual preference.
- Allowing some used to enter the building / cross ventilation.
- Minimize the amount of direct sunlight during the winter.
- Control the amount of direct sunlight in the summer.
- Diffuse daylight in workspaces, leave the opportunity for play with texture, contrast and color in more public space.

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**Figure 6:** Example luminous and thermal programming (Brown, Determan, Olsen, Velez).

**Figure 7:** Example daylight illuminance and wind studies (Bell et al.).

The exploratory daylighting studies were carried forward into Project Three: Thermal Explorations to evaluate the daylighting effectiveness in relation to seasonal thermal, energy, and passive design performance and comfort criteria. Students refined the energy and thermal performance program goals and used iterative parametric energy analyses to optimize design strategies. Teams developed “thermal comfort and energy hypotheses” that could be tested through parametric isolation, iterative simulation, and comparative evaluation on a diurnal and seasonal basis. Teams continued to improve upon earlier bioclimatic and daylighting design proposals through incremental refinements and testing toward the goal of thermal optimization.

Teams were asked to weigh strategic benefits and potential energy, comfort, and economic costs of design decisions and to consider potential design trade-offs and consequences necessary to reach low- or net-zero goals (as well as other performance metrics such as internal temperature, passive gains, and thermal comfort). Students presented their comparative research hypotheses, methods, findings, basecase energy performance and alternative design proposal performance data, and comparative integrated thermal and luminous lessons (see Figures 9 and 10). This series of energy and thermal parametric studies enabled the students to compare and contrast design decisions at different scales across seasons and to consider adaptive design strategies to optimize comfort and energy performance (e.g. luminous and thermal zoning, seasonal flexibility, migration inside and outside, adaptable room configuration, sectional depth and height, fixed versus adjustable solar control and shading, and the roles of material properties and envelope detailing).
Figure 9: Example envelope parametric energy and comfort studies (Karlberg, Volhouse, Young).

Figure 10: Example building energy performance on a seasonal basis (Duenas, Marti, Bralow, Shrimpton).
3.4. Project Four: Ecological Envelopes – Response to Time

In Project Four: Ecological Envelopes, students revised their design proposal to explore the integration of ecological concepts, passive, and active strategies at the scale of the building envelope. The challenge was to consider the opportunities of the building skin as an ecologically responsive and adaptive membrane. Teams were asked to consider the concept of “multi-functionality” and to explore how the envelope might address synergistic issues such as the integration of passive and active systems for heating and cooling among other ecological concerns such as harvesting water, generating electrical energy, creating habitat, responding to health and well-being, creating beauty, connecting to place, etc. The evaluative process included development of large scale physical models and building details to explore the intersection of program, comfort, and performance concepts with building materials and detailing (see examples in Figure 11). Great strides were made in the students’ understanding of the integration of construction systems, materials, and detailing with thermal and luminous opportunities and challenges. The large scale physical models enabled students to clarify and test strategies for seasonal response and adaptation for comfort and energy performance (e.g. light, heat, air, view, and connection between inside and outside spaces).

Figure 11: Example envelope studies (Top: Berger, Quilinskya, Hulmer, Breton; Bottom Left: Anton, Busey, Ennen, Greene, Tanaka; Bottom Right: Duch, Fischer, Paoli).
3.5. Project Five: Experiencing Sustainability – Poetics of Time

Prior to moving into whole building systems integration, students were asked to step back and look at the experiential quality and detailing of one room within the proposed building addition. This enabled the students to more deeply explore materials, construction, detailing, and systems integration. In Project Five: Experiencing Sustainability students selected either a “typical” or an “important” room within their project. They developed and tested both poetic and pragmatic design intentions through qualitative and quantitative studies using large scale physical and computer models. These detailed room studies enabled students to gain a deeper sense of the experiential dimensions of design decisions while further exploring adaptive seasonal strategies and detail development of the preceding envelope studies. The shift between studies of the envelope and room enabled students to further integrate the details, quality of the room, and related performance criteria for daylighting and thermal design. At this point in the semester, students had gained sufficient experience with the qualitative and quantitative methods of testing and analysis to quickly evaluate and modify design proposals. The evaluative process included photo-documentation of the quality of light and sun penetration for the room studies; illuminance and glare studies on a diurnal and seasonal basis; and thermal studies to evaluate hourly temperatures, passive gains, and comfort. The room models from Project Five: Experiencing Sustainability were invaluable in enabling the students to experience the character of the space in time and to integrate design quality and design performance (see Figures 12 and 13).

Figure 12: Physical daylight model studies and solar data (Left: Brown et al; Right: Anton, Bussey, Ennen, Green).

Figure 13: Daylight illuminance studies using Radiance (Anton et al.).
3.6. Project Six: An Integrated Whole – Dwelling in Time

Project Six: An Integrated Whole, focused on the integration of passive and active design strategies for lighting, thermal, HVAC systems, and renewable energy systems. Emphasis was on the conceptual resolution of a meaningful whole that supported human experience, comfort, ecological performance, and design excellence throughout the seasons. In the Project Six, teams presented a “conceptual systems” proposal for the whole, and a “detail development” for a select area of the building. Teams presented the evolution of design concepts, proposals, strategies, and trade-offs over the 6.5 week period. The teams analysed the “final proposal” 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 (see examples in Figures 14, 15, and 16). The evaluative process for Project Six: An Integrated Whole included updated physical models and time-sequence photographs (including the massing model, select envelope details, and final room model); integrated whole building sections or axons; wall sections; experiential images, daylighting and thermal performance evaluation for energy, comfort, and system integration; and written findings and conclusions.

Figure 14: Example of design and systems integration (Hickcox, Jablonske, Kelly, Shalow).

Figure 15: Example of daylighting and thermal integration (Hickcox, et al.).
Figure 16: Example thermal and energy summary through time (Aversa, Kim, Liang, Brierley).
4. CONCLUSIONS: LESSONS FOR ZERO-ENERGY DESIGN EDUCATION

Over the 6.5 week period, there was remarkable growth in the students’ ability to successfully engage dynamic environmental forces and ecological process to inform design and decision-making processes across topics and scales. Qualitative and quantitative methods and tools were essential to investigate the potential ecological, energy, and experiential opportunities of cold-climate passive solar and renewable energy systems integration for architectural design. Students gained a deep understanding of the roles, principles, strategies, and assessment methods for a bioclimatic luminous and thermal approach to net-zero energy design. Time, seasons, and diurnal forces provided compelling visual, tactile, experiential, and performance parameters to engage the students’ imaginations and interest in net-zero design. Significant growth was found in the students’ ability, confidence, and skill to frame design questions and then investigate and weigh both poetic and pragmatic considerations. The studio laid a solid foundation that will support the students’ design processes. In Fall 2013, this studio course will be pilot-tested as a new 9-credit, 15-week studio that will integrate the luminous and thermal studio with the comprehensive design studio (e.g. integrating luminous and thermal design with structures, materials and methods, and detailing). The theme for the new curriculum is “architecture for the 22nd century city.” Give the monumental social, ecological, and technological transformations facing humanity, the importance of time, adaptation, and flexibility will remain central to the development of the new “comprehensive/comprehensive” pilot studio to holistically consider all levels of technological and design integration. The following conclusions from the net-zero luminous and thermal design studio will be used to inform the development and on-going evolution of the new comprehensive studio curriculum:

1. Dissolve the Boundaries between the Design Studio and Technology Courses: 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 curricula.

2. Prioritize Seasonal Approaches to Passive Design: Climate-appropriate strategies for daylighting, passive heating, passive cooling, and natural ventilation were the foundation of the studio. 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.

3. Explore Diurnal and Seasonal Qualitative and Quantitative Assessment Methods: The studio 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” - 1” daylighting and section models). Other methods of assessment included sketching, diagramming, and computer analyses for daylighting and thermal performance, comfort, and carbon calculations. Simpler and less time demanding “design tools” are needed to help students easily compare and contrast the luminous and thermal implications of seasonal and adaptive design decisions related to massing, section, form, envelope, and window detailing.

4. Engage the Body and Human Experience: Awaken students to embodied experiences of luminous and thermal design through field-studies and direct observation to enhance their awareness and understanding of luminous and thermal comfort and performance in real spaces. Studying and documenting real spaces can complement and inform design thinking graphic visualization, physical modelling, and computer simulations. Constructing and photo-documenting large-scale physical room models and envelope details across seasons and time is valuable in deepening understanding of luminous and thermal design decisions.

5. Promote Integrated and Iterative Design Thinking: Parametric and serial studies were essential in exploring dynamic and adaptive seasonal responses to luminous and thermal comfort and energy
performance. Integrating time and seasons at the earliest design phase is essential in awakening an understanding of a living-systems design perspective.

6. **Promote Meaningful Team Collaboration:** Collaborative teaching and learning were essential to enhancing and balancing individual design strengths and skills for both the instructors and the students. Using a team of instructors, visiting critics, and professionals was very helpful in providing the necessary expertise to integrate issues across topics and scales. Students gained valuable experience collaborating and sharing responsibilities. The Center for Teaching and Learning at the University of Minnesota provided useful insights and resources to support student collaboration and evaluation within teams.

7. **Acknowledge the Heightened Intensity of Integrated Design:** Although condensing the content into half of a semester (6.5 weeks) and integrating environmental technology within a studio context was highly challenging, the increased intensity focused the students’ (and instructors’) attention. The disadvantage of the condensed schedule was the limited time available to process and synthesize the lessons of the class. 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 ecological design education and practice.

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