Learning Design + Energy Through the Whole Building Approach: Using Energy Scheming Simulation in Lecture Courses

Mark DeKay, University of Tennessee, Knoxville
This paper outlines an approach to learning architectural designing with energy in the context of lecture courses on environmental controls and similar topics. The approach investigated helps students to learn about energy while learning to design buildings. Designed for incorporation into existing lecture courses, a set of linked, weekly exercises teach energy simulation within the context of the richness that can only be engaged in the fullness of whole building design. Accessible computer simulation methods are constructed as an access point into beginning perceptions of complexity, as a characteristic of living systems in which form is always linked to process. In the exercises, a schematic design developed in a design studio class, or a case study building, is evaluated for its performance using Energy Scheming. Using feedback about the building’s patterns of energy use, students then re-design the building, alternating between proposing new solutions and testing them, until the design meets performance targets set by the student. A method for comparing the performance of the student’s design to that of a building specified by energy codes is also offered. Designed for instructors that wish to allow students to work with the building and site of their choice, a web database of climate information is available, along with the exercises and a fully worked example project.

THESIS

On one hand, the discreet topical knowledge domains of support courses are rarely incorporated and synthesized well in studios. On the other, it has always seemed difficult to get students to think synthetically about complex interrelated issues in the context of a lecture course. Computer simulation would seem to offer a possibility for increasing students’ ability to deal with greater complexity in a shorter time frame, especially with thermal and lighting issues – if it could be effectively woven into the basic required thermal or climatic design course, one which often has many topics competing for class time and student attention.

Energy patterns are, of course, complex phenomena placed in the context of the further complexity of architectural design. How architects should learn about and master the complexity of their field is an old question asked anew with frequency. But why is complexity important to architects?

Because it is critical to correcting essential misperceptions about the nature of architecture and the role of designers that have led to, among other things, buildings and cities that are literally destroying the environmental processes that sustain our life. The term “complexity” as used in this paper is an aspect of “wholeness” and of “systemic behavior.” Fritjof Capra defines the two great strands of systems thinking as “process thinking” and “context thinking” (Capra, 19XX, pp. x). In order to understand the fundamental nature of architecture and its relationships, we have to not just break it down analytically, but also place it within its larger system context, its environment. Each element must be understood, not just as an objective thing, but also as participant in numerous dynamic processes.

The primary educational lesson is always then to learn how to design an integrated environment which has the qualities of life and wholeness. The beginning of that education requires two things: 1) to learn how elements are configured in patterns to create the emergent characteristics of a holon; and 2) to learn how form guides the flows of dynamic processes, such as energy, water, and occupant use.

Because process always involves time, the conventional static tools of design, drawings and models, can only imply process. Therefore, computer simulation, which models behavior in compressed time, offers a seductive potential. Taking energy issues as a beginning point, the educational hypothesis is that students who learn using whole-building simulation will gain a good understanding of complex, higher order building energy relationships.
CONTEXT of the PROJECT

This curriculum development is part of the Teaching Architecture + Energy Project, a collaborative network of energy technology teachers in architecture schools, being sponsored by the U.S. Department of Education’s Fund for the Advancement of Postsecondary Education (FIPSE). The goal is to help architecture students to better understand energy concepts and design energy efficient buildings.

Currently, there are four diverse approaches being pursued at different schools, each using Energy Scheming. The University of Oregon is developing a Web-based "instructorless seminar;" the University of Minnesota is working with studio applications; Virginia Tech and Washington University are both tackling lecture courses from different perspectives. All of the curricula developed are centered around Energy Scheming, a very graphical, user-friendly Macintosh-based energy simulation tool with minimal numerical inputs that helps the student think about energy as an integral part of building design. Contacts and Details of each project can be found on the Web at: http://darkwing.uoregon.edu/~esbl/ARCHITECTURE+ENERGY/

PREMISES

There are two simple and quite general premises of the perspective on teaching and learning design + energy that form the basis of the resources being developed at Washington University:

1) That to make energy issues relevant to the work of designers, the issues should be engaged on the terms of the designer. That means that, in some way, energy has to be thought of as part of the cyclic process of design

2) That to understand energy patterns is to engage a complex system in which the interaction of parts and their agglomeration in to systems is an essential, rather than secondary or advanced concept. Therefore, at some point in the learning process – beginning, middle, or end – the interaction of architecture and energy must be considered in a whole building.

THE EXERCISE: "RE-CYCLING with ENERGY SCHEMING"

Overview

In the exercise presented here, a schematic design developed in a design studio class, or a case study building is evaluated for its performance using the computer software, "Energy Scheming." Using feedback about a building’s patterns of energy use, students then re-design the building, alternating between proposing new solutions and testing them, until the design meets the performance targets that the students have set. In the last part, students can also compare the performance of their designs to that of a building specified by energy codes.

Objectives:

The learning objectives of the exercise are:

- To gain experience with a design tool that can help architects to verify the quantitative thermal implications of non-thermal design decisions, and to explore the non-thermal design potentials latent in passive design.
- To understand the complex relationships between architectural form and its energy and lighting performance.
- To experience a process of cyclic architectural design that incorporates issues of energy and lighting, and to begin to develop this process on an individual basis.

Outline and Organization

The exercise is organized into five parts: Documenting, Defining, Analyzing, Re-Designing, and Evaluating, as summarized in Figure 1.

A. DOCUMENTING: input your building

In Part A, students assemble schematic plans and elevations of their design, identify the building’s construction types, diagram the solar concept and daylighting zones, decide on a strategy for what part of the building to model, and import design drawings into Energy Scheming.

B. DEFINING: take-offs and specifications

In Part B, student establish performance goals, evaluate their first schematic design and understand its strengths and weaknesses, in terms of energy and daylighting. They take-off all of the "architectural elements" of the project while leaving some settings at their default.
C. ANALYZING: understanding energy patterns
In the analyzing phase, students use Energy Scheming’s Rule-of-Thumb Window Sizer to understand how the design is performing at a coarse level for daylighting, solar heating, and ventilation. They also look at Energy Scheming’s graphic feedback in several formats. From this, they interpret and assess the building’s performance and recommend design changes to improve performance.

D. RE-DESIGNING: generate and test cycles
In Part D, students creatively re-design their schematic design and evaluate it using Energy Scheming until it meets performance goals, attempting to reduce net flows and peak loads. ‘Before’ and ‘After’ performance is documented, and students make changes to schematic design drawings that show changes made as a result of energy analysis.

E. EVALUATING: comparing with energy codes
How Low is Low Energy Use? When working with Energy Scheming, the question often arises from students, "How do I know when I have reduced my energy use enough?" This section is designed to allow comparison with a code minimum building. Students set an energy budget as a percentage goal reduction from the Model Energy Code, or their state energy code, then establish prescriptive criteria that would meet the code and, simulate the code building, using their previous Energy Scheming file as a starting point. With both runs, it is then easy to compare their design to the code building.

SETTING in the COURSE
The Re-cycling exercise as designed is appropriate for a term project requiring at least four weeks of time. Figure 2 shows how the Energy Scheming exercise has been incorporated into the Climate and Light course at Washington University. This course follows a combination of ‘design process’ and ‘architectural elements’ organization, while assignments are clearly biased towards design process, beginning with a series of short exercises on climatic analysis, site design, programming for energy and light, and a balance point analysis. The key project in the sequence is the schematic design exercise, in which students design or re-design (more often the case) a building for heating, cooling, and lighting. This gives them all the basic drawings they need for input to Energy Scheming, along with some hypotheses and concepts that they can test. While this approach seems valuable, one might also simply hand out a building to analyze or assign particular case study buildings.

EXAMPLES OF THE PROCESS

A. DOCUMENTING
In nature, form and process are always two aspects of one whole. Keeping the study of processes, such as energy flows, tied to the architectural forms that give rise to them requires adapting and merging the methods of quantitative modelling with the representations designers use to create and modify ideas. Figure 1 shows an example of a computer scanned, hand drawn input file for Energy Scheming. Drawings may also be done in a CAD software and imported. Drawings may be even more diagrammatic than those shown and will still yield important design feedback in the process of re-scheming using Energy Scheming.

In the process of the exercises, students are asked to develop three distinct concepts: one for heating, one for cooling, and one for daylighting. The idea is to build intuition about the relationship between form and performance by hypothesizing the size and behavior of the building’s elements and how they fit together in a process. While Energy Scheming can test the quantitative performance, its use requires assumptions based on a conceptual study of the patterns of process behavior, such as how direct
Fig. 2  Outline of the Re-Cycling with Energy Scheming Exercise
and diffuse light behave in a complex room. Dialogue with an experienced instructor is also required to identify fundamental conceptual errors, such as whether the predicated movement of air within the building is a reasonable assumption or whether the strategy for storing and distributing solar heat is workable.

Figures 4 and 5 show examples of diagrams used to study concepts of how the building behaves thermally, collecting, storing, and distributing heat, and the needs of different uses and areas for light. *Energy Scheming* is then used to test the thermal concepts and to size windows for light. Figures 6 and 7 show student studies in plan and section used as the basis for testing ventilation and lighting in *Energy Scheming*.

**B. DEFINING**

In addition to defining a series of performance targets, student use *Energy Scheming* to define the size and characteristics of the building’s elements, occupants, and use. Figures 7 and 8 show an example of a window takeoffs done over the elevation drawings and a corresponding window specification.

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*Fig. 3*  Integration of the Re-Cycling with *Energy Scheming* exercise with other assignments at Washington University.
Fig 4  Example of Diagrams for Daylight Zoning

Fig 5  Example of Diagrams for Building’s Solar Concept

Fig 6  Example of Concept Studies for Natural Ventilation

Fig 7  Example of Concept Studies for Daylighting
The graphic nature of the process keeps energy conceptually tied to its associated form. Area definitions are calculated by the software from mouse-driven takeoffs and element specifications are from a graphic library of options. The intent of this procedure is to give a direct connection between a building as drawn and its corresponding thermal behavior by linking in the mind of the student architectural elements, their configuration, and their characteristics relevant to energy.

C. ANALYZING

In the analyzing phase, students use Energy Scheming’s Rule-of-Thumb Window Sizer to understand how the design is performing at a coarse level for daylighting, solar heating, and ventilation. Figures 9 and 10 show students’ annotated reports of the window sizer results before and after redesign. In the window sizer graphs, the 100% mark of the bar graphs is set by the student as a design performance target. Their re-design task is to work with the design of the building’s elevations, attempting to both solve the architectural pattern acceptably and to achieve a balanced and acceptable performance for the many process roles of windows. This is a fundamentally different process than the sequential calculation and analysis of separate daylighting, solar heating, and ventilation factors. Seen simultaneously, students can begin to grasp the interrelationships of multiple variables, even for a single element such as a window. Beginning with fixing the quantitative target also shifts the focus to the architectural de-
sign as the important variable.

Students also look at Energy Scheming’s graphic feedback in several formats. The graphic reports allow one to understand heat gains and losses on a 24 hour cycle for typical days in each season. They can be viewed in numerous formats. One of the most revealing is the element group report, which shows the relative magnitude of each element that contributes to heat gain or loss and each internal heat source. It is then possible to understand the major and minor factors affecting the building’s energy balance and to begin to track the thermal behavior of the building through time, integrating all of its complexity. From a design perspective, this allows one to know which design decisions have more impact on energy. Students then interpret and assess the building’s performance and recommend design change to improve it.

Figure 11 shows a student’s interpretation of a graphic report for four seasons and represents the patterns of energy flow before the building was redesigned. What emerges out of this process is a perception of pattern. The patterns found in the graphic feedback are one way of seeing the interdependent pattern of form and process. Patterns consist of configurations of relationships; the relationships students identify are both particular and general. They are particular to the specific configuration of their design and its fit with the climate. At the same time general patterns emerge over time, such that patterns like “internal load dominated building with cooling in the winter,” “solar heating with mass transfer,” “night flushing,” “unshaded western view” and “too hot to ventilate,” become familiar themes. Seeing the complexity of the particular within the context of these general patterns is the essence of the recognition of the complex interdependence between structure and function, form and flow.

D. RE-DESIGNING

Based on their own analysis, students work iteratively between re-designing their building and evaluating its energy performance until it meets the performance goals they have set. All of this is done, not with fully developed design ideas, but with the schematic level designs typical of design studio classes. At the end, the schematic drawings are updated with changes made to improve the energy performance and evolve the building’s design concepts.

Figure 12 shows a student’s method of annotating a final element group report for a typical cloudy winter day. Figures 13 shows a few images of the kind of final documentation students use to show their buildings after the re-design.

E. EVALUATING

This part of the exercise has been pilot tested in a studio class during the Spring of 1998 in student projects for the Leading Edge Competition. Since then it has been further refined and will be used in the classroom in the Spring 1999 lecture class. It provides a method to compare a building’s energy use with that of a code minimum building. However, rather than simply documenting compliance, it encourages students to see energy use in buildings as
Fig 14 Examples of Various Student Drawings Documenting Their Projects After Redesign
both a measure of the design’s quality and as a value position. By setting an energy budget in relation to the Model Energy Code, or their state energy code, they must grapple with the paradox of relatively precise quantitative feedback and quite flexible, imprecise criteria.

EDUCATIONAL EVALUATION

Educational Objectives

There are a several educational outcomes in lecture courses addressing design + energy that might be considered. In general, faculty are interested in student learning from various perspectives, requiring different evidence of what counts for success. Some examples for lecture courses include the awareness of, understanding of, or ability to engage the following range of issues (among others):

- Fundamental principles of physical phenomenon.
- Basic principles of climate and light as applied to architecture.
- Appropriate climatic and lighting design strategies.
- The interrelationships and integration of various climatic and lighting issues with each other.
- Simple sizing and estimation procedures, including rules-of-thumb.

The Climate and Light course at Washington University attempts to cover all of these areas to some degree, excepting principles of physics, which are assumed to have been learned in other courses. Additionally, depending on the nature of the course, educators may be interested in learning objectives addressing:

- Generation of architectural form based on climate and light.
- Application of climatic and lighting concepts in service to a range of nontechnical intentions.

The Energy Scheming simulation exercises used in the lecture course is intended as a synthesis of more discreet and topical issues as engaged in the earlier part of the course. Students are evaluated in the course based on both a series of exercise projects and a final exam. The final exam is intended to assess student learning and performance for the lecture course objectives given above. As with all such support courses, the implication is that the student will use knowledge gained in the course in future applied situations. There is no known current means of assessing this learning objective.

Evaluation 1995-1997

A final exam was given to each class during the last three years. Each exam consisted of 50 multiple choice questions. The 1995 exam was given in the 1.25 hour class, while the 1996 and 1997 exams were given as a take-home exam. The 1996 and 1997 exams were identical, while the 1995 exam was of similar content with different questions.

The 1996 and 1997 exam consisted of questions designed to test a range of topical areas and skills as illustrated in Table 1. Class size for the three years was 38, 42, and 49 for the years 1995, ’96, and ’97, respectively.

Changes in course format and delivery

Energy simulation in the basic climatic design lecture course has been used at Washington University for the past four years. For the last three years, the content of the exercise has been basically the same with slight variations and improvements. What has changed significantly is the means of delivery and access to information, along with the course format leading up to the simulation exercise. In 1996, a web site was started for the course with basic, mostly text-based information, including the Re-cycling exercise. In 1997, the web site was substantially expanded and the Re-cycling exercise was conducted entirely via the web, with expanded in-

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| Sizing Procedures     |         |         |          |      |                |       |               |
|                       | 5       | 4       | 1        |      | 1              | 11    |               |

| Design Strategies      |         |         |          |      |                |       |               |
|                       | 1       | 1       | 1        |      | 2              | 5     | 10            |

| Thermal Integration    |         |         |          |      |                |       |               |
|                       | 9       | 9       |          |      | 9              | 9     | 7             |

| Total                 | 9       | 11      | 2        | 9    | 19             | 50    |               |

Table 1 Objectives of Final Exam Questions
strucructions and support details available. Another significant change in the class was the reduction of lectures from twice a week to once a week, in favor of more hands-on active learning methods during approximately one-half of the sessions. All classes used a one hour lab for computer support.

**Trends for Final Exam Scores**

Average test scores for the final exam in each of three years are given in Table 2, along with the standard deviation. Average scores jumped from 71% in 1995 to 80% in 1996, returning to 71% in 1997. Data for the Spring 1998 class is not yet available at this writing. The high scores for 1996 may be due to what was considered an exceptional group of students; they also scored higher in general on projects in the course.

The standard deviations however are the most interesting finding and when compared with the distribution curves for each class reveal a notable pattern. The standard deviation decreased by about 30% each year, indicating a narrower range of scores in the class. Figure 14 shows that in 1999, the distribution curve was fairly flat, with a few students scoring in every bin. 1996 scores were higher, with a narrower range, and the bottom of the class had moved toward the center, with no scores below 40%. The 1997 class showed continued and increasing gains in scores by students in the bottom of the class, with a similar narrowing at the upper end to a more expected pattern of the majority of the class scoring in the mid range. Again, an anomalous class of exceptional students may explain the peak of high scores.

The general tentative conclusion would seem to be that more active learning, combined with web-based delivery can improve student learning about climatic and lighting issues in a lecture/workshop format course. Since there were two major curricular changes during this time is difficult to speculate on which is more influential. This must also be tempered by the possibility that, given more time to complete an exam, poorer students or those who work more slowly, may improve their scores on a take-home exam, relative to a timed exam. However, since similar improvements occurred in the low range scores between 1996 and 1997, this improvement can not be attributed to the test format alone.

**Expanded Evaluation for 1998 and 1999**

This analysis has been conducted retrospectively. In the next two years, the evaluation will be expanded and refined by collecting profiles of the student population and writing additional specific questions related to assessing learning about more complex issues. Results for each question will be analyzed to differentiate student performance by different knowledge types. In addition to the longer take-home exam, a short pre-test at the beginning of the class and an identical post-test at the end of the class will in a timed format to both assess student progress and to shed more light on the question of the significance of test format.

**INSTRUCTOR and STUDENT RESOURCES**

A web site with resources for instructors and students has been developed and is operated from Washington University. Instructors may use the resources directly, download them, or arrangement can be made to set up the materials on one’s home web server. Participants may choose to use the material as is or modify it to suit their particular teaching needs.

The site currently consists of four main parts: a climate database, pages outlining the whole building
simulation exercise, a fully worked example problem
using a small commercial building, and examples of
student work. The home page is illustrated in Figure
XX.

**Climate Resources**

The climate database has data for a city repres-
enting each of the standard continental US climate
zones used by DOE and others (see map in Figure
17). Additionally, a random selection of cities are in-
cluded, based on past student projects and sites for
Alaska, Hawaii and US possessions and territories.
Each city has a climate page with graphic and tabu-
lar data in the form of normals, wind, sky, and radia-
tion data. There is also a page for each city with
data in the precise format required by Energy
Scheming for climate files.

**Exercise Resources**

The exercise itself is outlined in a series of
linked pages with two levels of depth, outline and
detailed. The detailed level includes specific tutorial
style instructions on how to use Energy Scheming for
the problem, including lots of screen captures from
the software. Each section is also linked to the cor-
responding section in the worked example. The
problem is generic enough to be used in a variety of
ways, but gives specific instructions to guide stu-
dents who need detail.

**Example Resources.**

A fully worked example is given, using the Shan-
ley Dentist Offices in Clayton, MO, a 1936 minimal-
ist modern building by Harris Armstrong. The
building is small (less than 3000 square feet) and is
sited on a small urban lot with a short south side.
The building uses many good climatic design strate-
gies, such as movable shading and minimum west-
ern exposure, but because it has no insulation in the
masonry walls and poor ventilation, it still performs
poorly as a passive design. It offers a good example
of how many strategies must work together for the
design to effectively work in terms of energy. And
students think it is a piece of good architecture.

**CONCLUSION**

This paper began with a hypothesis that stu-
dents who learn using whole-building simulation
will gain a good understanding of complex, higher
order building energy relationships. The preliminary
indications point to significantly improved learning
by the poorest students correlated with an increas-
ing emphasis on simulation and active learning in the classroom. Since the exams used in part assess an understanding of 1) more complex relationships between energy issues and form, we can reasonably assume that increased test scores are at least an indicator of enhanced learning in these knowledge areas. However, the comparison with conventional techniques, such as a lecture dominated class with hand-calculation exercises, remains to be made and will be included in the next year’s evaluation.

Working with whole building simulation of energy is one small step towards building a consciousness of complexity, which is in turn one step towards being able to create ecologically sustainable architecture with the integrity of nature. Sustainable architecture must emulate living systems, and therefore its form must arise from an understanding of its many processes. The configuration of elements in pattern characteristic of the designing act. To embody in those patterns enough intelligence to shape the process flows (such as energy) that move in and are shaped by these patterns is the beginning of an architecture of life-support. To go further and reveal, manifest, express, and give meaning to these defining processes requires an even deeper understanding and mastery of the dynamics of complexity. Simulating with models of complex systems allows us to make a quantum increase the rate of trial and error testing of design ideas from conventional drawing and modelling methods. It is akin to the same jump in design process made from the craft-based tradition of building, where each revision, success or failure, was built and inhabited, to that of the professional architect, where successive drawings could evolve an idea and test it without having to first
The web site which supports this curriculum has been dramatically increased in scope and resources since the 1997 class, but has not yet been used in teaching in its more developed state. Instructors interested in participating in the Teaching Architecture + Energy Network or specifically in using any of the materials developed for this project are encouraged to contact the author via contacts given in the web sites mentioned in the beginning of the paper.