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

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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." The physicist Fritjof Capra defines the two great strands of systems thinking as "process thinking" and "context thinking." 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 systemic context, its environment. Each element must be understood, not just as an objective thing, but also as a 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, that wholeness beyond the parts' sum; 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 Educations's Fund for the Improvement of Postsecondary Education (FIPSE). The goal is to help architecture students to better understand energy concepts and design energy efficient buildings. Each of four "center" schools are developing curricula and providing support to "node" schools in the form of software, training, instructor peer dialogue, evaluation techniques, and eventually, shared publication of results. Node schools use the teaching resources in their own courses, adopting and adapting as necessary.

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 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 Internet at <http://darkwing.uoregon.edu/~esbl/ARCHITECTURE+ENERGY/>.

PREMISES

There are two simple and quite general premises of the perspective on teaching and learning architecture + 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 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 2.

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, students 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 five weeks of time at about 6 hours per week per student, working in teams of two. Figure 3 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.

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.

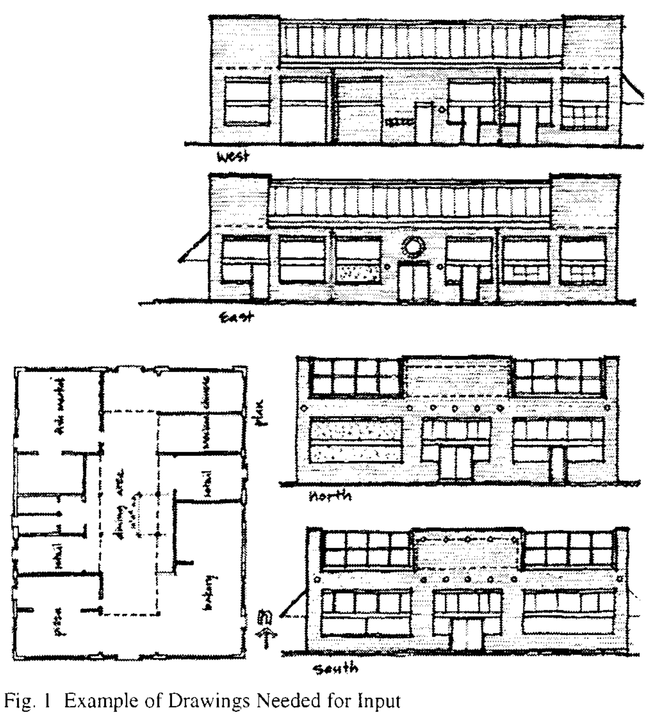


Fig. 1 Example of Drawings Needed for Input

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 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 predicted 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 that are used as the basis for testing ventilation and lighting in Energy Scheming.

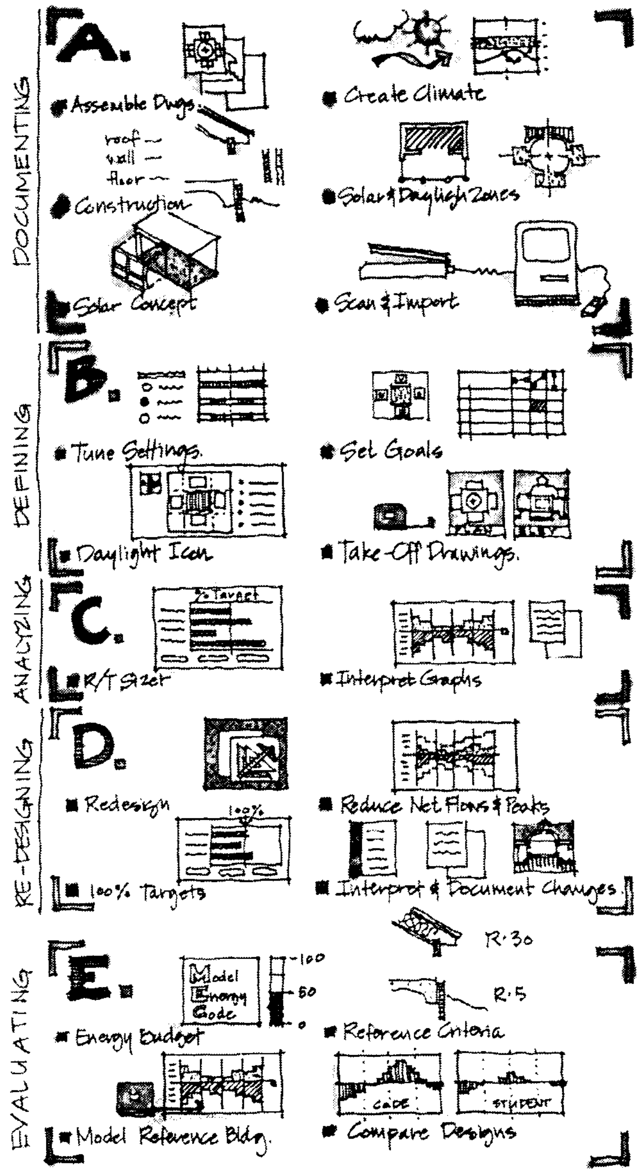


Fig. 2 Outline of the Re-Cycling with Energy Scheming Exercise

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 8 and 9 show an example of window takeoffs done over the elevation drawings and a corresponding window specification. The graphic nature of the process keeps energy conceptually tied to its associated form. Area definitions are calculated by the software from mouse-driven take-offs and element specifications are from a graphic library of options. The intent of this procedure is to give a direct connection between a

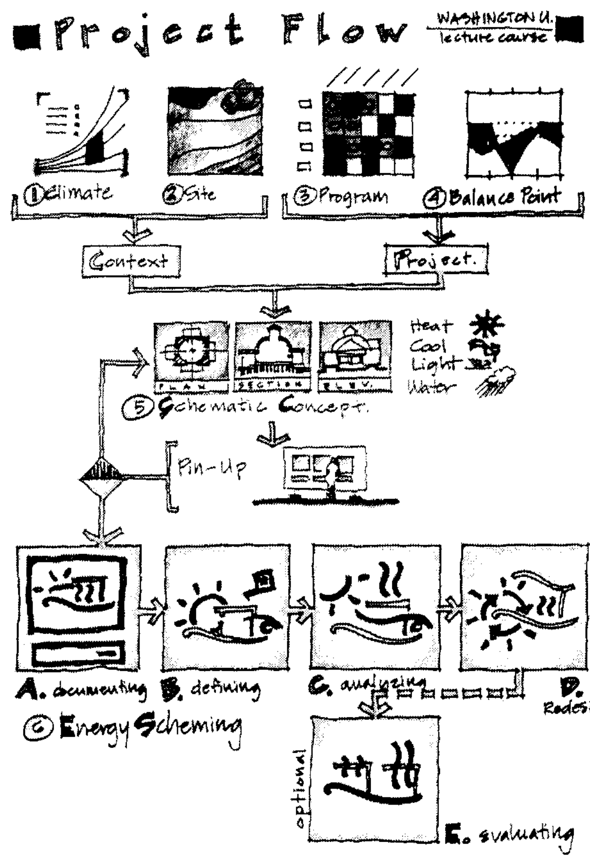


Fig. 3 Integration of the Re-Cycling with Energy Scheming exercise with other assignments in the Climatic Design course.

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 10 and 11 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 by fixing the quantitative target also shifts the focus to the architectural design 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

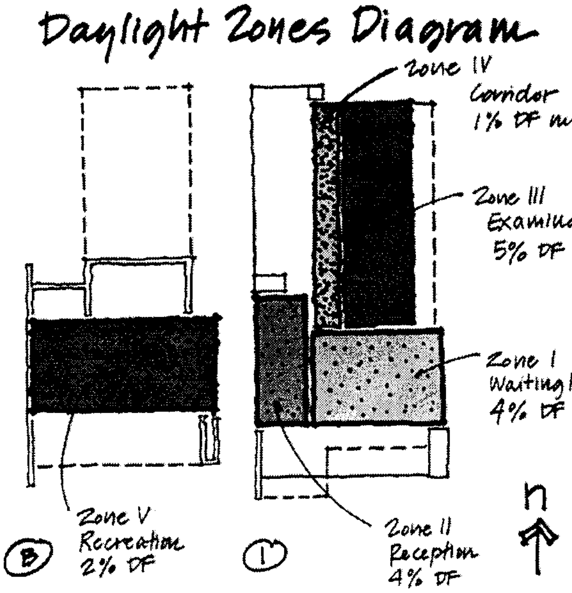


Fig 4 Example of Diagrams for Daylight Zoning

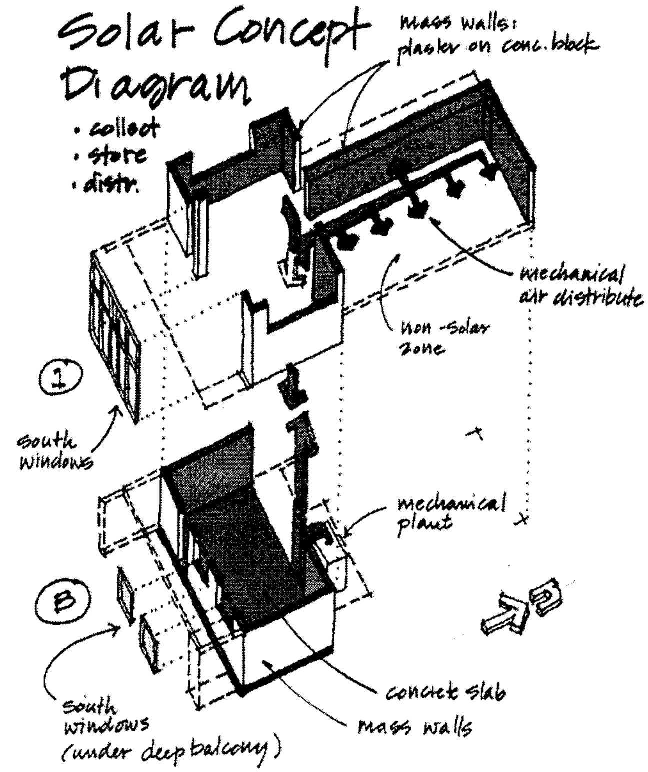


Fig 5 Example of Diagrams for Building's Solar Concept

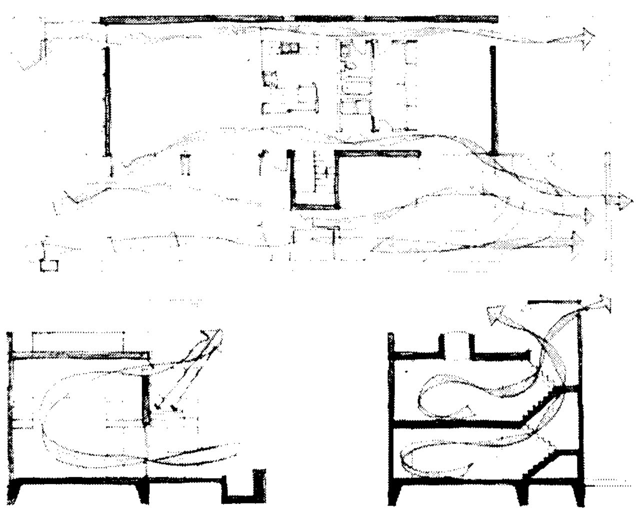


Fig. 6 Example of Concept Studies for Natural Ventilation

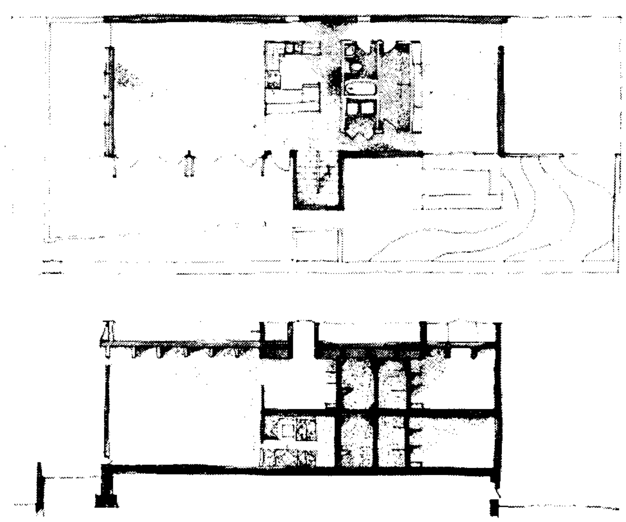


Fig 7 Example of Concept Studies for Daylighting

the 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 changes to improve it.

Figure 12 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 patterns 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

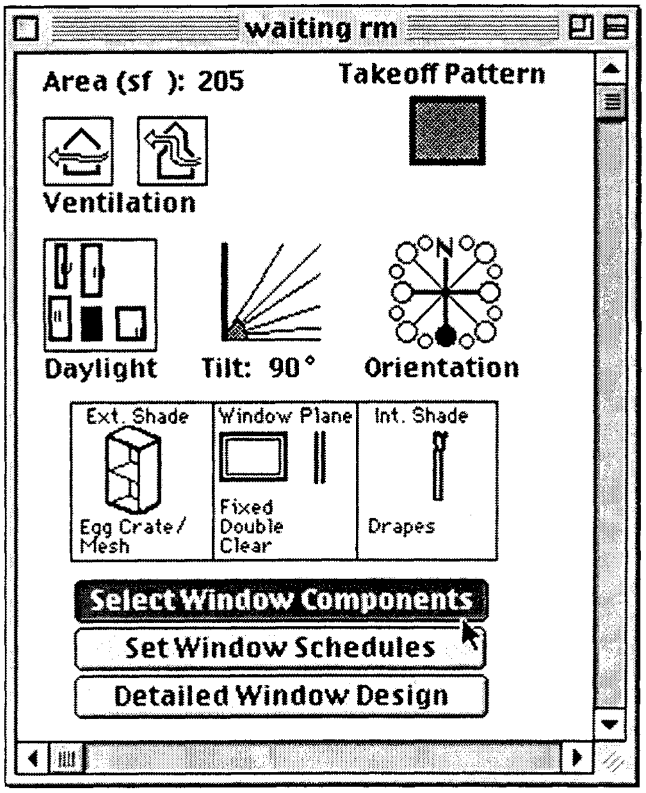


Fig. 8 Example of Specification for Windows

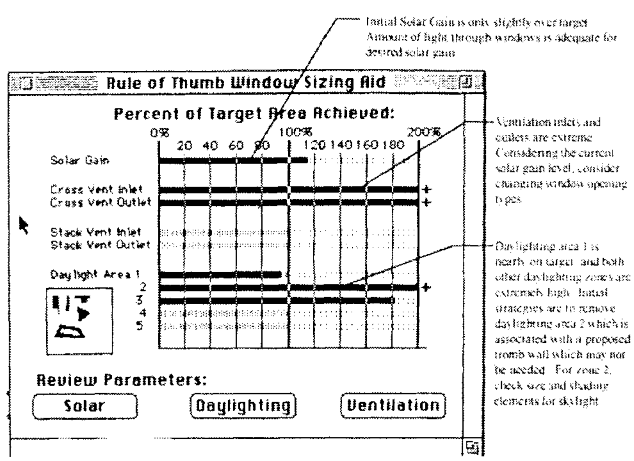


Fig. 10 Student Analysis of Window Sizing Before Redesign

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 13 shows a student's method of annotating a final element group report for a typical cloudy winter day. Figure 14 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 was recently used in the Spring 1999 lecture class. It provides a method to

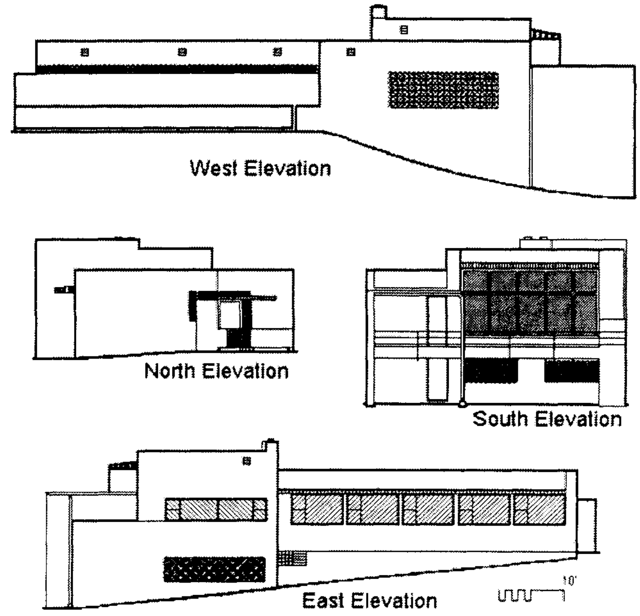


Fig. 9 Example of Graphic Takeoffs for Windows

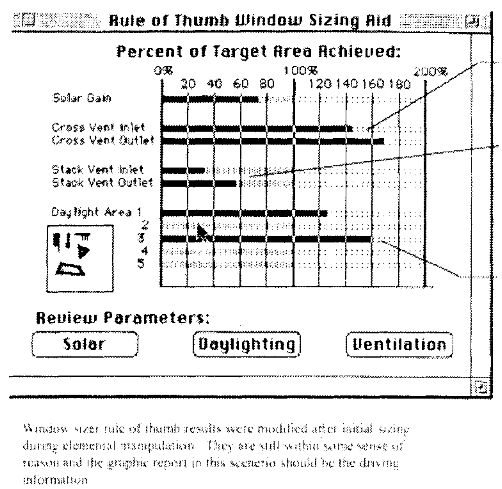


Fig. 11 Student Analysis of Window Sizing After Redesign

compare a building's energy use with that of a code minimum building.

EDUCATIONAL EVALUATION

Educational Objectives

The Energy Scheming simulation exercises used in the lecture course are 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.

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

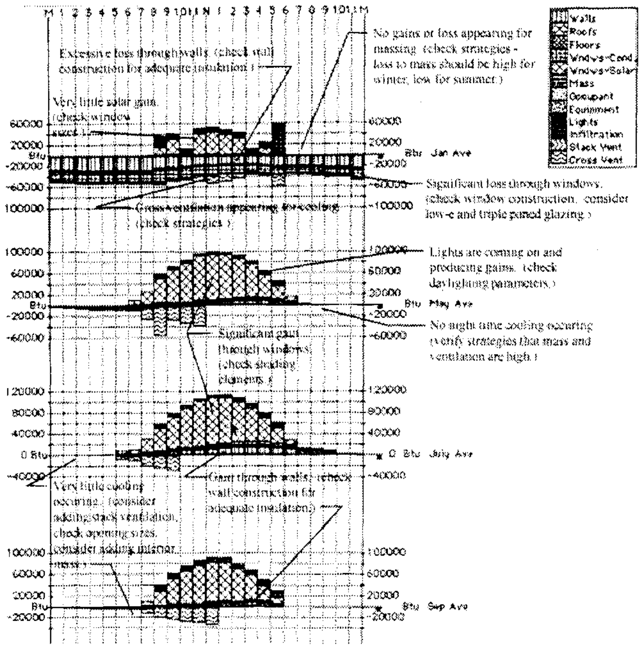


Fig. 12 Student Analysis of Graphic Reports Before Redesign

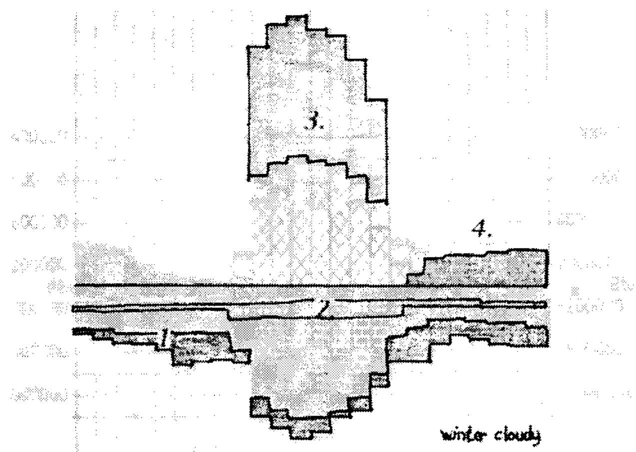


Fig. 13 Student Analysis of Winter Element Group Graphic Report After Redesign

	Heating	Cooling	Lighting	HVAC	Multiple Topics	Total	E.S. questions
Concepts & Principles	3	6		7	4	20	1
Sizing Procedures	5	4	1		1	11	
Design Strategies	1	1	1	2	5	10	3
Thermal Integration					9	9	7
Total	9	11	2	9	19	50	

TABLE 1 Objectives of Final Exam Questions

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, 1996, and 1997, respectively.

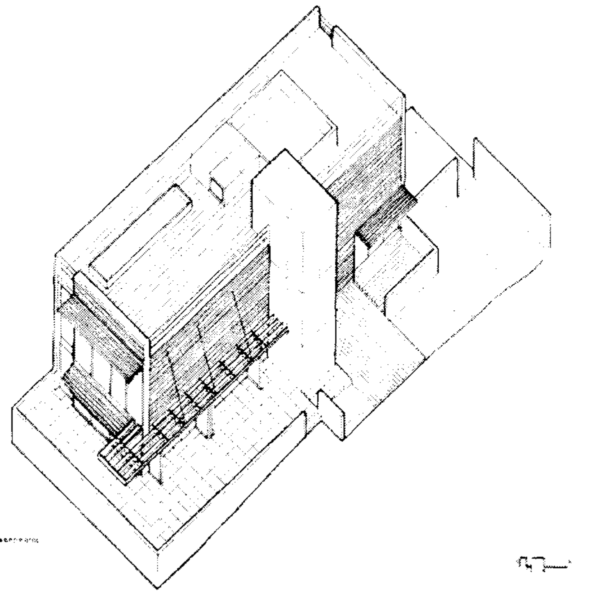
Changes in course format and delivery

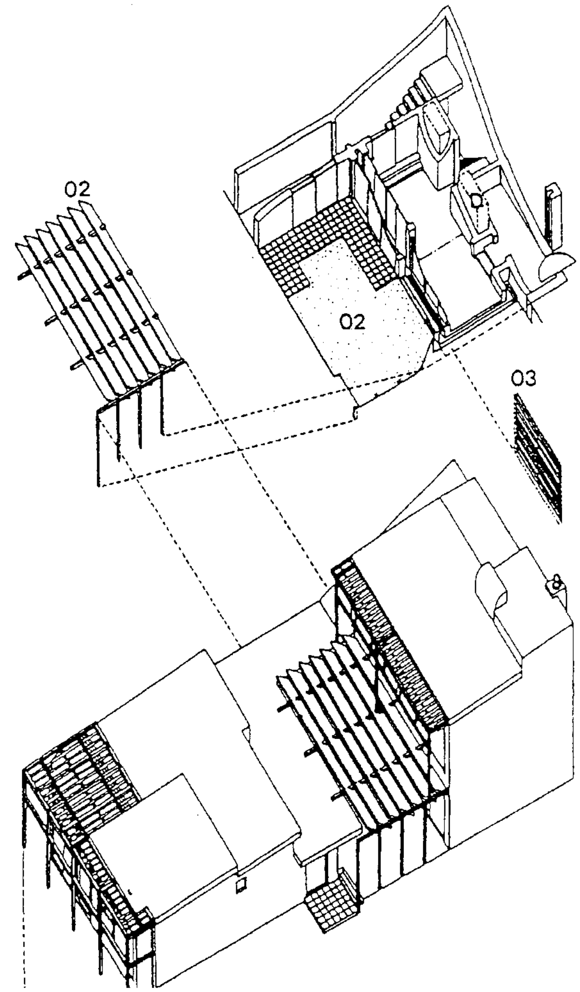
Energy simulation in the basic climatic design lecture course has been used at Washington University for the past four years. For the last three years, the content of the exercise has been basically the same with slight variations and improvements. What has changed significantly is the means of delivery 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 with Energy Scheming" exercise. In 1997, the web site was substantially expanded and the Re-cycling exercise was conducted entirely via the web, with expanded instructions 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.

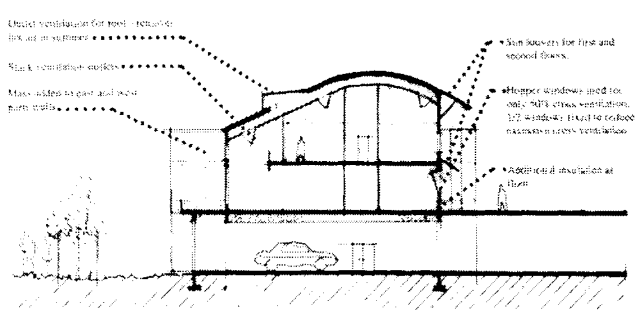
Trends for Final Exam Scores

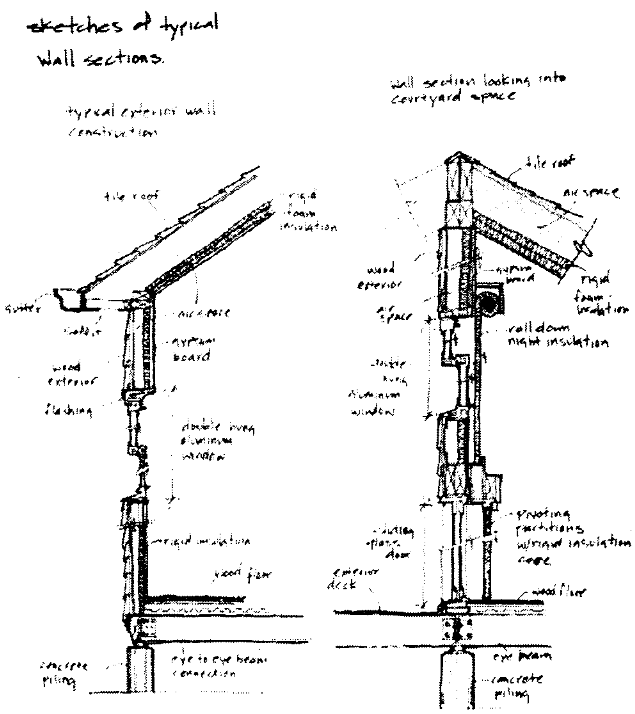
Average test scores for the final exam in each of three years are given in Table 2, along with the standard deviation. Average scores jumped from 71 percent in 1995 to 80 percent in 1996, returning to 71 percent in 1997. Data for the spring 1999 class is not yet available at this writing. The high scores for 1996 may be due to what was considered an exceptional group of students.

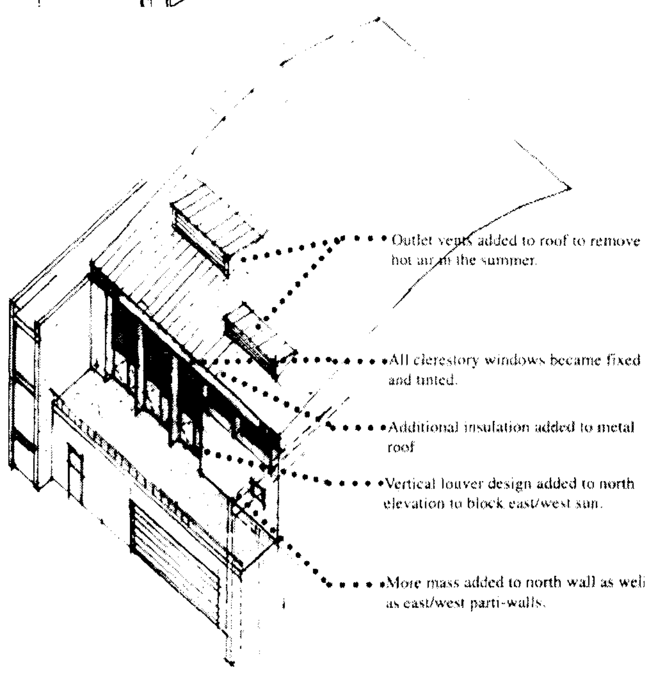
The standard deviations however are the most interesting finding and, when compared with the distribution curves for each class, reveal a notable pattern. The standard deviation decreased by about 30 percent each year, indicating a narrower range of scores in the











Figures 14a, b, c, d, e, f: Examples of Various Student Drawings Documenting Their Projects After Redesign

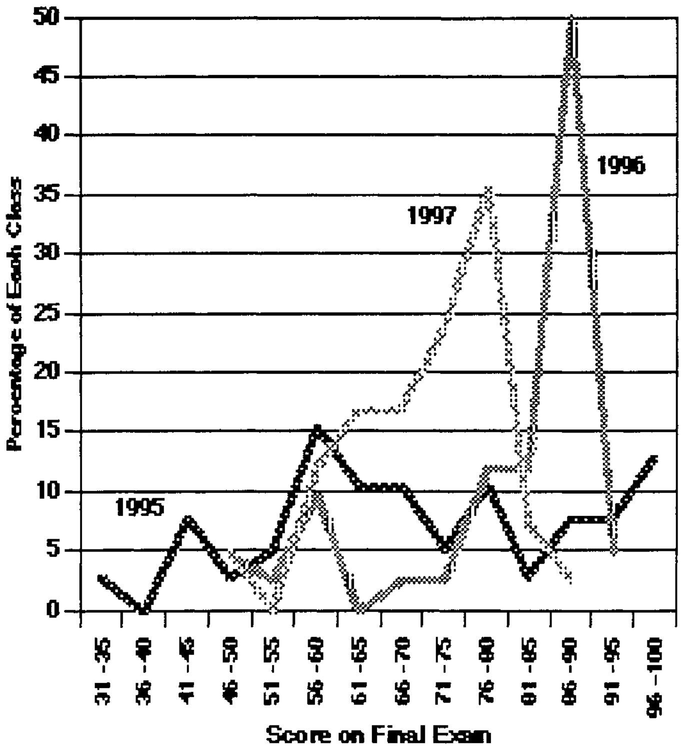


TABLE 2 Final Exams Scores for Three Years of Climatic Design Course

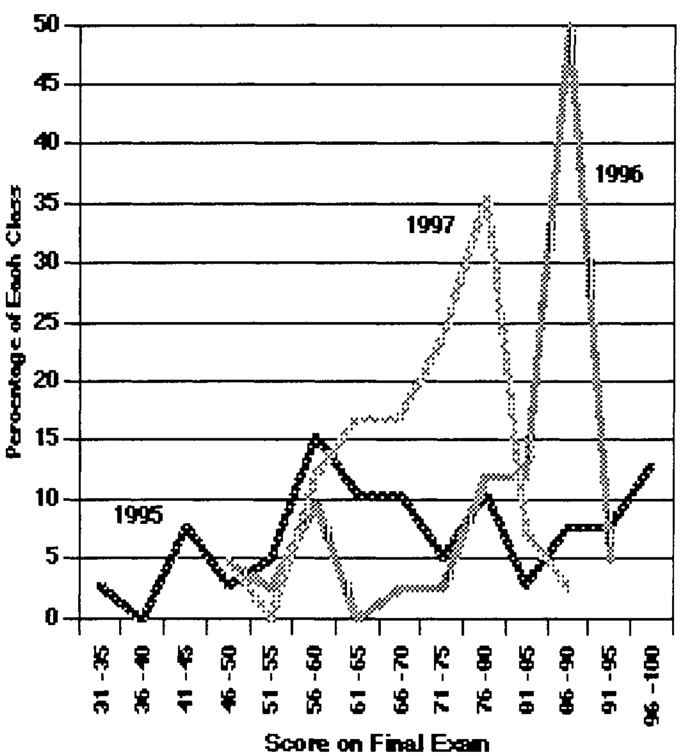


Fig 15 Distribution of Final Exam Scores for Three Years of Climatic Design Course

class. Figure 15 shows that in 1995, 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 percent. 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.

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. Results for each question will be analyzed to differentiate student performance by different knowledge types. A pre-test at the beginning of the class and an identical post-test at the end of the class will be administered to both assess student progress.

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 arrangements 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 16.

Climate Resources

The climate database has data for a city representing each of 17 standard continental US climate zones (see map in Figure 17), plus a few others. Each city has a climate page with graphic and tabular data in the form of normals, wind, sky, and radiation 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 corresponding section in the worked example. The problem is generic enough to be used in a variety of ways, but gives specific instructions to guide students who need detail.

Example Resources.

A fully worked example is given, using the Shanley Dentist Offices in Clayton, MO, a 1936 minimalist 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

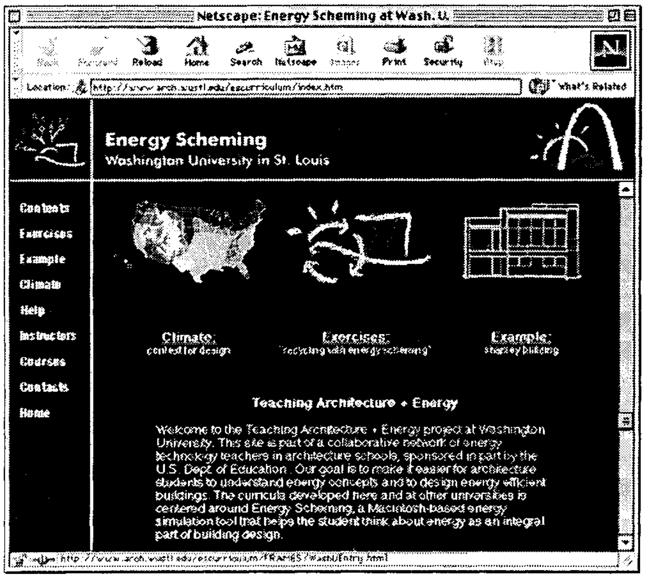


Fig. 16: Homepage for the Teaching Architecture + Energy Project at Washington University <http://www.arch.wustl.edu/escurriculum/index.htm>.

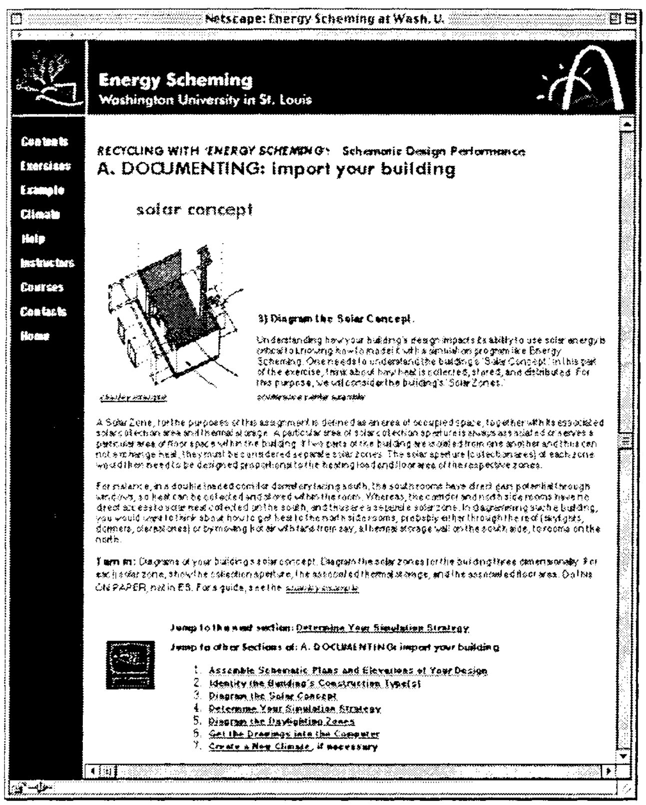


Fig. 18: Example of One of the Exercise Web Pages

uses many good climatic design strategies, such as movable shading and minimum western 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.

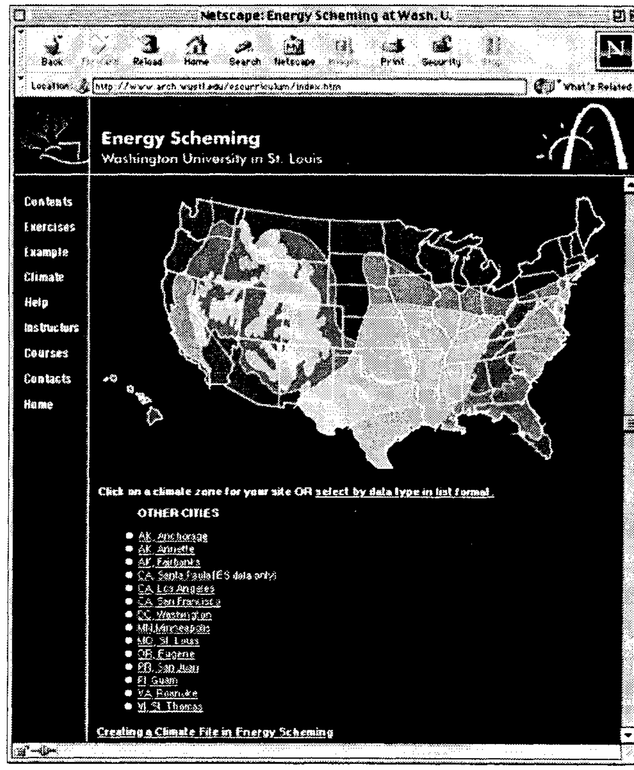


Fig. 17: Web Page for Climate Resources

CONCLUSION

This paper began with a hypothesis that students who learn using whole-building simulation will gain a good understanding of complex, higher order building to energy relationships. The preliminary indications point to significantly improved learning by the poorest students correlated with an increasing emphasis on simulation and active learning in the classroom. Since the exams used in part assess an understanding of 1) complex relationships between energy issues; and 2) the relationships between energy 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 is 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 in the rate of testing design ideas from that of conventional drawing and modelling methods. It is akin to the same jump in design process between craft-based tradition of building, where each revision, success or failure, was built and inhabited, and that of the professional architect, where successive drawings could evolve an idea and test it without having to first build it.

The web site which supports this curriculum has been dramatically increased in scope and resources since the 1997 class, and was recently used in its more developed state to teach the Spring 1999 lecture course. The Teaching Architecture + Energy Network is currently providing material to support lectures, seminars and studios at participating schools. Opportunities exist for peer support and joint educational research and publication. Instructors interested in participating in the 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.