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ABSTRACT

Computer programs capable of describing the thermal behavior of buildings are used to help architectural students understand environmental systems. The Numerical Simulation Laboratory at the Architectural School of the University of Texas at Austin was developed to provide the necessary software capable of simulating the energy transactions affecting the environment of internal spaces of buildings and to make these programs easily accessible to students. Several specialized programs of the Dynamic Energy Response of Buildings (DEROB) system were integrated to describe the energy transactions within a building: Solar generates solar exposure tables; PERSP produces solar perspective views of the structure; GLASS uses dielectric algorithms to describe the dynamic energy responses of solid walls; and DYNWALB describes the energy behavior of opaque walls. Evaluation of the architectural design course using computer-assisted instruction shows an increase in skills and a strong level of student receptivity to the project. (CH)

AN EXPERIMENT IN THE USE OF COMPUTER-BASED EDUCATION TO TEACH ENERGY CONSIDERATIONS IN ARCHITECTURAL DESIGN

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AN EXPERIMENT IN THE USE OF COMPUTER-BASED EDUCATION TO TEACH ENERGY CONSIDERATIONS IN ARCHITECTURAL DESIGN[1]

A B S T R A C T

A growing awareness of the need to improve the training of architecture students in environmental systems led to the investigation of Computer-Based Education as a possible vehicle to facilitate this improvement. An extensive array of algorithms and computer programs have been developed to form the core of a Numerical Simulation Laboratory. One set has been used in a limited enrollment course to evaluate the potential effectiveness of numerically simulated experiments as a teaching tool in an Architecture School. The evaluation results, although preliminary, indicate that this can be a very effective way to achieve a competent curriculum in environmental systems in architecture.

[1] A similar version of this paper is to be published in the Journal of Architectural Research in the near future.

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Introduction

There seems to be a growing concensus that architectural education should help a student in understanding and developing the means for studying environmental systems in a more thorough and systematic way than before. The problems is how to increase this capability, and how to link it with the designing of the built environment, within the given limitations of Architecture Schools.

Computer-based instruction is being tried as a possible solution to this problem. A number of computer programs capable of describing the thermal behavior of buildings are being developed by the Numerical Simulation Laboratory of the School of Architecture and Planning of The University of Texas at Austin.

One of these programs, DYNWALB, which describes the energy behavior of opaque walls has been integrated into a regularly scheduled course on Passive Environmental Controls. The students' progress in this course and their attitude towards the use of computer-based instruction is being monitored and evaluated.

The results of this preliminary evaluation indicate that this approach has a high potential for success. This article describes the rationale that prompted the use of computers in the teaching of environmental systems; the scope of the computer software developed for this purpose; and the results of the evaluation of students attitude and performance.

Rationale

The construction professions, including architecture, are directly and indirectly responsible for 35% of the total energy consumed in the U. S. About 70% of this total is spent in driving the metabolic processes of buildings. These processes include comfort heating and cooling, lighting and air circulation. The energy consumed in these processes is highly dependent on the shape and orientation of buildings, on the choice and distribution of materials, and on the arrangement of internal spaces and masses. In short, it is dependent on architectural design features.

Architectural education should provide the necessary training to students so that as professional practitioners they will be able to reduce as much as possible the level of energy consumption to which they commit their buildings. To the extent that it is possible, the student should be able to determine the quantitative trade-offs of his decisions. To be able to determine such quantitative trade-offs, however, considerable familiarity with the physics and mathematics of thermal transactions is necessary.

It is not reasonable to expect that architecture students will be able to devote the necessary time to master these subjects, and still carry their remaining loads. On the other hand, the traditional courses that would cover these subjects for architecture students fail to provide the necessary depth. Better ways, therefore, must be found to impart the necessary understanding of thermal transactions in buildings.

In attempting to carry out educational innovations one must keep in mind that if the education experience of a student is not to become obsolete soon after he leaves school, he must learn general principles and not just memorize specific solutions to specific problems. General principles are learned best where the student discovers them himself. Thus, any educational strategy should seek to provide the conditions that facilitate discovery.

In the case of energy transactions in building this requires an architectural energy laboratory, where controlled experiments can be carried out. However, full size simulation chambers are prohibitively expensive, while scaled down models can not reproduce full size effects since thermal phenomenon are size dependent. With digital computers, however, selected classes of thermal problems can be solved numerically. These can be programmed to simulate architectural thermal experiments. Therefore, computer-based education and computer-assisted instruction are being investigated as possible vehicles to improve the training of architectural students in the field of energy considerations in architecture.

Intended Scope of Project

To this end, the Numerical Simulation Laboratory (NSL) was initiated. The Laboratory was funded by the Computer-Based Education Project (PROJECT C-BE) with a grant from the National Science Foundation, with supplementary funding from the University Research Institute.

The plan for the implementation of the Laboratory was broken down into three general phases: the development of the algorithms and computer programs; the utilization of these programs into the design methodology of studio courses. Each of these phases is, of course, open ended. As the software is developed and tested, it is gradually introduced into the lecture courses. As the techniques become more refined the programs are introduced into the design courses.

The general intent of the laboratory is to provide the necessary computer software capable of simulating the energy transactions that affect the environment of the internal spaces of a building; and to make these programs easily accessible to architecture students. The computer is being used, however, not to teach material that can be taught as effectively without the computer. Rather it is being used to try to teach material to a depth that may not be possible to achieve using standard methods.

The comprehensive set of algorithms and programs that describe the energy transactions within a building is called Dynamic Energy Response of Buildings (DEROB). The various components of DEROB are assembled separately into a number of specialized programs. The solar algorithms, when used alone, generate solar exposure tables (Solar). These tables are in turn used to carry out preliminary solar control analysis. The solar algorithms together with the non-interactive sector of the geometric algorithms are integrated with a hidden line discriminator to produce solar perspective views of the structure (PERSP). This program is to be used as fine tuning to the solar control analysis. The solar algorithm and the boundary conditions are integrated DYNWALB to describe the dynamic energy response of solid walls. This program is to be used both in design and lecture courses. The GLASS program is similar to DYNWALB, except that instead of using the heat conduction algorithms, it uses the dielectric algorithms. GLASS is also to be used in design and lecture courses. The fully integrated program (DEROB) is used primarily as a research tool.

Classroom Experience

DYNWALB is the only program that has been used so far under classroom conditions ("DYNWALB Instruction Manual," IM-16/8/14/74). It is used in a one semester lecture course on Passive Environmental Control

Systems. The main intent of the course is to teach architecture students the extent to which they can control the thermal environment of buildings through appropriate manipulation of shape, orientation and choice of materials.

DYNWALB is programmed to simulate controlled experiments of the energy transactions across a solid wall. The user, in this case the student, has to specify the values of twenty different parameters (Appendix 1) that identify uniquely the conditions of the experimental run. For each run, the program outputs a table of "measured" data.

In a controlled experiment the student will hold all of the input parameters constant while changing the values of the parameter subject to the experimental test. A separate run is made for each parametric value. He must then analyze the data and report his findings in a written report.

The reports must be written in three sections. The first section should include a concise statement of the purpose of the experiment, and any assumptions the students may have as to the possible outcome of the experiment. The second section includes the strategy he proposes to follow in order to answer the question posed in the first section. The strategy includes a complete set of the input data as well as the strategy for analysis. The third section includes the analysis of the data. The analysis must include the appropriate graphs and their interpretation, and a comparison of the results with the assumptions made in the first section. This section should also include suggestions for further experiments to help clarify ambiguous results or to help answer questions that may have arisen in the course of the analysis.

A different experiment is carried out every week. For the first half of the semester, the experimental topics are preassigned and integrated with the lecture material. By the time the second half of the semester starts the students have gained sufficient confidence in the use of the program to start designing their own experiments. They are free to choose their topics. Most of them either choose to pursue questions that lingered from previous experiments or try to answer questions that arise in their design studios.

Evaluation

The course is being evaluated for its teaching effectiveness by administering a test before and after each time the course is offered. This test measures the minimal skills needed to analyze energy transfer phenomena. The results of these tests show an increase from 5% to 85% in these skills. Similar results could probably be expected from other courses that cover the same material using standard methods.

It is difficult to measure directly the effectiveness of this approach. However, through the use of attitude questionnaires the student's receptivity can be gauaged, and thus one can infer about the effectiveness of the approach. The Measurement ano Evaluation Center of The University of Texas at Austin, administers a set of Pre- and Post-evaluation tests for C-BE funded projects. Preliminary results of these tests indicate a very strong level of student receptivity to this project. The statistical reliability of the results, however, have not yet been established because the course has only been offered twice and each time the enrollment was limited to 30 students. The questions and the average student responses that directly pertain to this course and to its use of computers are listed in Appendix 2.

The following general conclusions could be drawn from these responses. The majority of the students enrolled in this class had not had previous computer experience; however, they had only minor problems in mastering the use of the programs used in this course. Students felt that the computer was of considerable help in understanding passive thermal control systems in building. While the students entered the course without well defined expectations from the computer-based instruction, they came out of the course feeling the the PROJECT C-BE technique was a definite asset in their learning experience. In the pre-course evaluation the use of the computer was ranked fifth and last in terms of importance in the overall learning experience in a course of this type. In the post-evaluation it was ranked a very strong second. Both in the pre- and post-evaluation, lectures were considered the most important aspect of the course.

The overall average evaluation of the course and its computer-based instruction rose to an approval level of 3.5 from a pre-course expectation of 2.5 (see Appendix 2 for evaluation scale).

CONCLUSION

These evaluation results, although preliminary, offer very strong encouragement to continue and to expand the use of Computer-Based Education in attempts to improve further the training in environmental systems.

Additional training is desirable because a one semester course on Passive Environmental Controls does not provide the comprehensive background that may guarantee the student's mastery of the subject.

The use of Computer-Based Education in these curriculum additions is justified because the use of numerically simulated experiments can be a very effective tool in the teaching of Passive Environmental Controls.

Future implementation of PROJECT C-BE methods into environmental systems training will have to be carried out within the context of an architecture curriculum. This context requires that principles learned in lecture courses should be translated into action in the design studios.

The problems associated with the incorporation of numerically simulated experiments into architectural design courses have not been fully identified, much less resolved. As these problems are identified, and hopefully resolved, we hope to establish the foundation of a strong and effective curriculum to teach environmental systems in a School of Architecture.

APPENDIX 1

DYNWALB

DYNWALB is a program that describes the dynamic energy transactions at the boundary layers as well as within the interior of solid opaque wall. It is programmed to be used as a numerically simulated laboratory.

INPUT PARAMETERS (with sample values)

A. External Environment

Month (June = 6)	Outside Air Velocity (20 mph)
Day (1)	Maximum Outside Air Temp. (95°F)
Latitude (31° North)	Minimum Outside Air Temp. (68°F)
Internal Air Circulation (3 mph)	Constant Inside Air Temp. (77°F)

B. External Wall Characteristics

Southern Azymuthal Angle (105°)	Outside Roughness (4)
Zenith Angle (10°)	Inside Roughness (2)
External Solar Absorbtivity (.99)	
External Infrared Emmisivity (.96)	
Internal Infrared Emmisivity (.91)	

C. Internal Wall Properties

Number of Layers (3)

Layer Number	Thickness	Conductivity	Capacity	Density
1	.333	.580	.200	144.
2	.250	.022	.200	1.5
3	.166	.400	.200	105.

OUTPUT DATA (with sample values)

External Surface Temperature (104.88^{o}F)

Internal Surface Temperature (77.62^{o}F)

Heat flow across Inside Surface (2.32 BTU/hr/ft^{2})

Outside Air Temperature (95°F)

Inside Air Temperature (77°F)

Time of Day (4:03 pm)

Time Since the Start of Experiment (40.1 hrs.)

Temperature Distribution Within the Wall Section Exclusive of Surface Values

(x = 0 coincides with external surface)

x	Temperature
.058	105.90
.115	106.40
.173	106.5
.230	106.4
.288	106.3
.346	105.8
.403	99.1
.461	92.4
.519	85.7
.576	79.0
.634	78.3
.691	78.0

APPENDIX 2
EVALUATION RESULTS

The results of two classes with 30 students each were combined (N = 60). The students average response is quoted next to the question. The answers are expressed according to the following scale.

0 = Disagree Strongly
1 = Disagree Moderately
2 = No Opinion
3 = Agree Moderately
4 = Agree Strongly

1. "The subject matter of this course is interesting to me"
   Pre = 3.3
   Post = 3.7

2. "Computer-based instruction makes learning more interesting"
   Pre = 2.1
   Post = 3.2

3. "I am not in favor of computer-based instruction because it is another step in the depersonalization of education"
   Pre = 1.3
   Post = .8

4. "Considering the effort I applied to this, the computer provided me with valuable learning experience"
   Post = 3.6

5. "The use of the computer in the course stimulated me to seek more information about the subject matter"
   Post = 3.1

6. "If I had to do it over again I would prefer to take this course in a conventional section (without computer-based instruction) rather than a computer-based section"
   Post = 0.5

7. "Considering its value in aiding me to master the course material, the time I spent using the computer during this course was definitely worthwhile"
Post = 3.4

8. "The computer did so much of the work in the lessons that I didn't learn as much as if I had done all the computation myself"
Post = 0.4

9. "The use of the computer made it possible for me to concentrate most of my attention on the concepts involved in the lessons without getting bogged down with details"
Post = 3.2

10. "The use of computers allowed me to understand how parameters and constraints interact to determine the performance of the systems we were studying"
Post = 3.5

11. "My knowledge of how to use the computer was adequate to perform the computer operations required in the course"
Post = 3.1

12. "I felt frustrated by the computer-based instruction situation"
Post = 1.1

13. In this course I feel that the computer will:	(Percent) Pre Freq.	Post Freq.
A. Be a valuable tool which will aid me to grasp the course material more readily than would be possible with traditional instruction alone.	36	82
B. Be of some aid to me in understanding course material.	36	18
C. Make little difference to me in my efforts to learn.	21	
D. Be a possible source of hindrance to my mastery of the material.	7	

		Post Frequency (Percent)
14.	Which of the following statements do you consider to be the most accurate in regard to the time requirements imposed by this course as compared to similar courses without computers?	
	A. The computer greatly increased the time that I had to spend on this course	35
	B. The computer slightly increased the time I had to spend on this course.	35
	C. The computer made no difference in the time I had to spend on the course.	12
	D. The computer slightly decreased the amount of time I spend on the course.	12
	E. The computer greatly decreased the amount of time that I was obliged to devote to this course.	6
15.	Which of the following possible sources of difficulty caused you the most trouble during the computer-based segment of the course?	
	A. Logging in.	18
	B. Computer not available.	24
	C. Terminal not available.	12
	D. Error in Program.	29
	E. Equipment malfunction.	6

Pre-test: x

Post-test: /

I feel that the Course Subject Matter is:

16.	clear	0	/	1	x	2	3	4	obscure
17.	useful	0	/	x	1	2	3	4	useless
18.	interesting	0	/	x	1	2	3	4	uninteresting
19.	important	0	/	x	1	2	3	4	unimportant
20.	helpful to me	0	/	x	1	2	3	4	hindering

I feel that, in general, the Computer as an Aid to Mastering Subject Matter, is:

21.	useful	0	/	1	x	2	3	4	useless
22.	speeds learning	0	/	1	x	2	3	4	slows learning
23.	pleasurable to use	0		1		2	3	4	painful to use
24.	congenial	0		1	/	x	2	3	4	quarrelsome
25.	helpful to me	0	/	1	x	2	3	4	hindering to me
26.	skillful	0		1	/	x	2	3	4	bungling
27.	successful	0	/	1	x	2	3	4	unsuccessful

28. I feel that the Computer, as a Research Tool, is:

useful	0	/	x	1	2	3	4	useless

29. I feel that the Computer, as a Tool for Individual Study, is:

useful	0	/	1	x	2	3	4	useless

30. I feel that the Computer, as a Tool for Classroom Learning, is:

useful	0	/	1	x	2	3	4	useless

31. I feel that the Computer, as a Problem Solving Tool, is:

useful	0	/	x	1	2	3	4	useless

32. I feel that the Computer, as a Computational Tool, is:

useful	0	/	x	1	2	3	4	useless

33. I feel that the Computer, as an Information Gathering Tool, is:

useful	0	/	1	x	2	3	4	useless

34. I feel that the Computer, as a Process Simulation Tool, is:

useful	0	/	1	x	2	3	4	useless

35. I feel that the Computer, as an Aid to Me in Mastering My Major Field, is:

useful	0	/	1	x	2	3	4	useless