CASE STUDY AS A TEACHING TOOL INTEGRATING DESIGN, ENERGY, AND ECONOMIC ANALYSES

by

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Case Study as A Teaching Tool Integrating Design, Energy, and Economic Analysis

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Submitted to the Department of Architecture on May 11, 1984 in partial fulfillment of the requirements for the degree of Master of Science in Architecture Studies.

THESIS ABSTRACT

Architecture educators and students are challenging traditional methods of teaching technical subjects related to buildings, seeking new teaching tools and methods. The case method, developed by business and management educators, holds promise as an approach that can improve the teaching of architectural technology. Through the use of prepared case studies, the student makes decisions at critical points of the building process, using quantitative and qualitative analysis techniques. Following individual work on the problem or issues presented in the case, the teacher helps the students in a classroom discussion, consider the consequences of their decisions to the analytical steps and processes they used. This gives the students an opportunity to verbalize their thinking about a shared problem and compare that experience with that of their colleagues.

This thesis describes the use of the case method use in architectural education to integrate the teaching of design and technical subjects. It documents the promise as experience in preparing testing, and evaluating a case. Design, energy consumption, and economics were the related topics of the case, given as an assignment to a class of architecture graduate students. Their to response the case was documented and evaluated as the basis for modifications.

This study will guide others interested in using the case method. The documentation and discussion of a teaching tool specifically developed for architectural education will incite further discussion and study of the methods of architectural education.

thesis supervisor:

Ranko Bon

Assistant Professor of Economics in Architecture
I would like to express my gratitude to my colleagues who were often my teachers and to my teachers who treated me like a colleague, as well as a student. I also would like to thank the students who participated in this project and the Cabot Fund.
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Before beginning this thesis the reader must be aware of several underlying assumptions made by the author:

**First,** one of the purposes of architectural education is to prepare individuals for professional practice in architecture. As the Architecture Education Study of the East Coast Schools of Architecture states:

"The essential functions of collegiate schools of architecture are to prepare students for architectural careers, broadly defined, and to provide leadership to the profession through the development and dissemination of new knowledge and methods resulting from research and study." (1)

**Second,** design studio teaching provides a successful method of teaching architects. Says architect James Goldstein:

"... of all academic disciplines, the architectural

curriculum consistently and routinely develops integrative and coordinative patterns of thought, ones which can live with uncertainty, resolve space and time conflicts, arrange and display objective and subjective criteria for evaluation, conceive of strategies and tactics for choices and decisions and, in short, manage courses of action to achieve goals. "Design", as the late Louis Kahn said, "is a circumstance of order." The intellectual power of architectural design and coordination of information, is becoming the accepted analog for management techniques in other fields, especially notable in the computer age." (2)

Third, technology has been taught, in most curriculums, differently and separately from studios. In a studio situation, the teachers place responsibility on the student to define the goal and find the solution; the student actively participates in the learning process.

In contrast, most technology teachers convey through lectures and demonstration, specific analytical skills without teaching the application of those skills in the context of architectural practice.

The strict dichotomy, which separates design and lecture classes, has proved ineffective; students don't make the

expected interconnections. The issue is a complex and institutionalized one, (although it is in no way the only issue, or even most important aspect of architecture shared by educators, practicing architects, and students in their concern for appropriate education.)

Technology teachers who want their subjects to become relevant to the design student must address the student's need to acquire a vocabulary developed through experience. For example, until a mathematical formula for calculating heat loss in a building can be incorporated into the student's vocabulary of design tools, it is merely a fact and not utilized fully.

Part of the dilemma facing technology educators is that in most fields, such rapid advances are made that technical procedures become obsolete as they are taught. Most teachers are aware that some teaching will, in hindsight, be merely academic exercises, but given the amount of discussion at ACSA conferences held in recent years on the topic of integrating teaching technology and design, technology educators recognize the need for change and improvement in their teaching methods.

(3)

(3) For example: Annual DOE sponsored ACSA Summer Institute at MIT, Annual Symposium of Technology educators, Special Workshops at recent ACSA Annual Meetings.
Fourth, one essential aspect of architectural practice is the need to make decisions while dealing with uncertainty. This applies not only to design decisions, but technical ones as well. The studio mode is more successful in teaching this than is the lecture mode, for in the studio, students make decisions without the complete context or complete information. Lecture courses, on the other hand, come with the underlying message that using the formula correctly will produce a correct answer. The interrelationship of these two modes must be made by the student, although the first time the student is required to link the lessons from studio with the lessons of technical course work may be in practice, when complex and contradictory technical information must be managed. Until recently the office structure was able to support this experience. The professional draftsman, the sly fox who knew everything about construction and the practice, was the teacher for new architects. Changes in architectural practice have caused the loss of this a valuable resource, as younger draftsmen go to other places.

Fifth and finally, if we assume that architectural education is to prepare students for practice, and we can no longer assume that the connections between design and technical information will occur in the architectural office, we need to address the issue within academia.

The case study method is one tool which can bridge the gap
between design and technical teaching. First, in technical
courses, it allows the study of technical skills within a
context of uncertainty often found in practice. Second, the
case method allows the student to use design skills in
technology courses, as well as make technical decisions within
the design process. Third, practitioners in any profession are
aware that in any real situation, they never apply textbook
examples; the case method likewise, requires some sort of
judgement to be made by the students, who thus learn the
applications of any given tool. The habit of learning from
experience can be developed. Fourth, in architectural
practice one also rarely works on a project from beginning to
end, and one never works entirely alone. At any given moment,
one wants simultaneously more and less information - more
specific information which can be directly applied and less
conflicting, and erroneous information. The context of the
problem carries as much influence on one's judgement as
technical knowledge; the case study provides that context.
For all of these reasons, the case method offers better
preparation for making technical decisions in practice, than
does the traditional lecture method.
THE CASE METHOD IN ARCHITECTURE EDUCATION

In 1919, a separate faculty within Harvard University was established to teach business administration within the professional curriculum. The apprenticeship method of teaching, common in business education up to that time had, proved to be inadequate to meet the evergrowing and changing needs of the society it served. The faculty for the new program were specialists trained in separate, but related fields, who shared experience and interest in administration and in education. New teaching methods had to be developed that would encourage creativity, or the ability to make a "leap in logic", considered essential for the success of an administrator. (4) The case method emerged as that new mode of teaching business administration. Experiences from the field are researched and documented in written form, similar to legal precedent, presenting the teaching material for situations similar to the architecture studio problem.

Today, architecture faculty are becoming increasingly specialized. They have training in architecture and also in related fields. Their activities in research and in practice

(4) Towel, Andrew R., To Study Administration by Cases, Harvard University, 1969
are in specialized areas such as energy, historic preservation, behavioral science, building performance, economics, etc. Few believe that their specialty presents the only view of architecture, or the only model for architectural practice, but the lack of methods integrating their fields has had the affect of splitting the architecture community, in addition to the evident separation between design and technology. Their shared goals are often obscured in debates stemming from the lack of a shared format for dialogue, critical analysis, and review. New teaching and research methods are required. The striking similarity of the conditions which generated the case method in business administration and those facing architecture today suggests that the case method deserves the attention of architectural educators.

The written case with teaching notes provide opportunity for dialogue between educators in a field where few faculty have formal training in education itself. Feedback from cases used in various teaching settings, incorporated into the teaching notes, can make the use of a case more effective, allowing teachers to systematically learn from each other. (In business schools a few cases have been so widely used and discussed that the teaching notes for a single half page case have been printed as books.)

The use of the case method is just beginning to be
explored in architectural education. At M.I.T. several projects on the investigation of the case method are in progress. The Lab of Architecture and Planning has prepared a number of cases about the building processes and the design of energy efficient buildings. In the Planning Department, research on regional shopping malls is being utilized as a source of cases. In the Architecture Department, research and writing are part of two courses, one in the academic curriculum and one scheduled for the Summer of 1984 for practitioners. These courses are designed to investigate economic concepts and models through the study of the design and construction of two buildings. The case method is also a central part of a program of the Bartlett School of Architecture and Planning. (5) The success of initial experiences with cases demonstrates that the method can be incorporated into existing teaching practice. Although the definition of the case method is not precise, it results in the teaching of both knowledge and values, integrating the application of qualitative and quantitative analysis. Essentially, the student is required to take an active part in the learning process, to ferret out general principals through experience with the case, rather than to apply given rules from which to draw conclusions.

A number of cases have been written using guidelines established by business and management educators. At MIT, Michael Joroff and Douglas E. Mahone served as Co-Principal Investigators for NEA sponsored project to investigate the case method for its potential to architectural education. The project included seminars to discuss the case method as it is used by other disciplines, as well as researching, writing, and testing of cases dealing with architecture. In a report to NEA (6) four types of cases were identified for development, although this research team produced only the second type.

The first type are building process or business cases. Many excellent examples, available through the Intercollegiate Case Clearing House, have been written about architectural firms.

The second type are about the management of the design process, or process cases. The structure of the first type is used; the reader is brought to a decision point in a real project, which includes information on the individuals involved, as well as the facts of the case. The student then must make some type of judgement on the basis of the information presented. The issues can be drawn from

management, architecture, programming and design, although the first cases were developed around issues related to energy conscious design in buildings.

The third type are design decision cases. The building process is described providing background and technical information and the decision point concerns a design issue, which the reader may be asked to continue the develop. Design decisions, in this case, may be broadly defined as any decision related to the life cycle of a building.

The fourth type are design cases. The design case strictly adheres to the facts of the case study to pose a problem for development by the reader.

Other types of cases are used in architectural education. For example, there are studio cases, which draw select information from typical cases, or the personal "war story" type, drawn from personal experience. These familiar case types have the potential to be extended and developed to provide the basis for case method teaching, which includes the written case and class discussion.

The case presented in this thesis: "Dormitory - Next House - 500 Memorial Drive" (Next House), included in Appendix A is the third type of case outlined above. It was developed in response to the need for more effective modes of teaching. 
technical subjects which are relevant and useful to building designers. One approach is to integrate the teaching of technical and design principles demonstrating their interrelationships. The assignment of a case requires problem formulation as well as solution requiring technical analysis. Specific techniques, such as the analytical tools of a specific discipline, can be taught within the broader context, which exposes their limitations and highlights their potential.

In the classroom, the written case is a device similar to the studio design problem which immerses the reader in a situation at a point of decision. The reader is motivated to "suspend disbelief" and experience the process of identifying the critical issues; to make judgements and analyses with the information at hand; to use discretion in determining a course of action; and to identify the reasoning behind his/her work. The student learns because of a need to know. A text on a technical subject otherwise opaque and unintelligible will become immediately useful. The underlying parameters framing a method of analysis are evident in their application for decision making. In class discussion, students share their experiences with the case, verbalizing their analyses and their opinions about the issues.

Design problems have additional meaning seen in the context of the concerns of the owners, contractors, and the
architects. In practice, few students will begin projects at the beginning and continue to develop them uninterrupted until their completion in a way studio projects can often be organized. The nature of the written case allows the student to be placed in the middle of the design process of a building. From such a vantage point, an in-depth analysis of a single issue exposes the complexity of such parameters as building codes, minimum property standards, energy legislation, interest rates, or office policy.

Through experiences which utilize calculations, rules of thumb, and previous experience to solve problems, the student gains confidence in his/her own reasoning and decision making abilities, allowing internalization of basic principles, and avoiding over reliance on a single method, or on the numbers, or on consultants, or whatever. Through experience with analytical tools acquired in many settings, the student can evaluate and integrate them into a meaningful context; for class discussion offers a setting to introduce experts representing disciplines and points of view relevant to the case.

It is necessary in architectural practice to understand and to utilize knowledge from many specialized disciplines. Tools of analysis developed in various fields are simplified models constructed with underlying assumptions, shared by the specialists within it, but often not accessible to those
outside the field. Specialists rarely return to basic principles because their shared experiences and accepted conventions act as a sort of shorthand. Thus, while it is not difficult to understand how to use a type of analysis, in an abstract exercise, its application in a real, complicated situation requires awareness of the assumptions for it to be useful. Exercises that make these explicit and that match the models to the situations they are intended to depict afford both a greater understanding of the models and how to use them, and valuable insight into the field that developed them originally.

A difficulty that must be faced with the use of the case method in architectural education is that many buildings lack extensive documentation. Often it is prepared by specialists in related fields, with specific purposes. The documents are useful in learning about selected aspects of building design, but as is often the situation even in building research, an integrated approach is rarely applied. Economic data is especially difficult to obtain. Rigorous, systematic documentation of our experience in building design is especially important today considering such fields as energy conservation. Experimentation with various single-strategy building solutions have given us a new awareness of our environment, and of new applications of old materials, but the collective lessons from these buildings need be shared and integrated with the best design solutions the architectural
professionals can produce.

The case method is a way to motivate students to perform analytical exercises. The basic idea of utilizing a concrete experience as a context to present data and concepts in a manner that facilitates testing ideas and scrutiny by students, teachers, researchers, and practitioners of diverse disciplines is a simple one. However, it holds the potential for far-reaching consequences. The collection of documented cases would provide a centralized body of knowledge to be drawn from over a long period of time, one that would allow comparisons not possible.

The use of the case method in architecture is proposed as an additional teaching strategy, one which can integrate the teaching lessons of the classroom into the studio and vice versa. It is not suggested as a panacea for all students, or all faculty, at all times, nor as a replacement of methods which have been successful. The written case should be used in courses in addition to lectures, assigned and recommended readings, field trips research projects, etc. The adaptation of the case method for use in architecture will not be without critics. Experience at Harvard showed that most criticism of the case method was actually disagreement about the purposes of the educational program - what should be taught in school and what to leave for the field. Similar issues about architectural education are unresolved. Is the benefit of
"real experience" in the academic environment worth the costs? Should all academic resources be utilized to benefit development of formal design skills, for example? The most beneficial aspect of the discussion of the case method may be as a forum for dialogue between the professional, and academic communities about what, where, how, and when to teach.
PREPARING CASE STUDIES

The following steps in preparing cases are included to give the reader a better understanding of the process and are not intended as instructions. The method is flexible enough to allow adaptations by an individual teacher to his or her teaching goals and manner of teaching. Typical steps in using the case method:

Identify the case to be studied. The criteria for the selection of a case may include availability of data, willingness of the participants to contribute to the case, the teaching goals of the course for which it is intended.

Research the story of the case. Who was involved? What did they do? When did they do it? What were the issues addressed and not addressed? Talk with the people who may be able to give insight into the case issues and provide a human perspective for your case writing.

"A case study is like a piece of detective work. At each step of your investigation, be it interviewing or researching documents or sifting through data you've accumulated, you must ask yourself two questions. First,
what is the lesson to be learned from this information?
Second, how can the information be communicated? (7)

Select the written case topic. From the many possible cases yielded from the research of a single case study, a selection must be made to present only a manageable number of interesting issues. The selection may be based on the teaching goals of the author or the anticipated use of the case within a specific course. It is very difficult to write a case without clear goals.

Write the case and keep teaching notes to serve as guidance in the selection of material for the case and as an aid in its future use. The written case is a specific literary form which uses a number of structures interwoven to present the issues in an interesting way and honest way. The skills of the journalist can be a great asset because good writing is essential. In the best cases, the reader is drawn into the case, "suspects disbelief" and participates in the story. The evidence of the human voice in the writing, which is one aspect that can be gained in the research phase, can aid this. Following are several basic rules for writing cases:

a. The case has to be an clear description of the events people and data.

b. It must be set in time and use time sequence appropriate to the story.

c. It should be a mystery, a "who done it" with all clues to the answer or to many appropriate answers in the case and exhibits.

d. Every word should hold clues for the reader. A student will read a case many times to glean every piece of information it holds. Therefore, the writer must be aware of the readers path. Both red herrings and real clues must be part of a structure. One can expect readers to find purposes unintended by the case writer.

e. Select reading material to be used with the case. If the case is a very technical one, the researchers may select from reading that helped them in understanding the issues.

f. Cases often include exhibits, which add a sense of connection to the real story. The actual document or a "cleaned up" version may be used. Exhibits should be appealing and neat. Too many things makes reading unnecessarily difficult and there must be strict
correlation between the text and exhibits. When exhibits are modified for any reason, there is increased potential for error and added difficulty in maintaining clarity. A single misplaced word or a typographical error in figures can unpredictably change meaning. Case preparation can demonstrate various roles of the architect within the building industry through the selection of cases and the structure of the research team. For example, in research of a project in which the architect is one of many specialists on a building team, each member of the research team could focus on a specialized aspect.

Test the case by having others read it or by giving it as an assignment for discussion in a group. Feedback from people who are not knowledgeable about the issues can aid in evaluating the case with respect to the writer's intent. Preliminary use of the case may include reading the case and having a group discussion of the issues, solving the problems or resolving the conflicts presented in the case. Group discussion can compare individual work and approaches to the issues.

Rewrite the case. Prepare formal teaching notes for your own use and to aid others who may want to use the case. The teaching notes may include the following: promise as intent in writing the case, an outline of the case concepts, lists of study questions, teaching questions, case facts where, when,
what), useful calculations, estimates of the degree of
difficulty, areas and degree of difficulty, the intended use
of the cases, and what the student should gain form it.

Use the case in various teaching situations. It is a
flexible tool for teaching and can be adapted in various ways
to meet specific needs.

Maintain the teaching notes from feedback gained through
experience and using the case. Record the successes and the
things to change. The teaching notes can serve as guidelines
as well as a form for sharing teaching experiences with
colleagues who are using the same material. The case may be
adjusted over time and its use may become increasingly
sophisticated as teachers gain experience in using them.
Experience in using the case method has shown that one can
expect similar results each time the same case is used.

These steps show the development of a case from beginning
to end. Many of the uses of case in architectural education
today stop at the first step - identifying a problem - but
they could be extended. That is, teaching/learning
experiences can be planned around any part of the process;
one can easily stop at any point. Students can benefit by
developing cases with direction from an instructor. For
example, the research phase offers a specific type of learning
experience, which is appropriate for some students. Case
researchers have the opportunity for a firsthand view of the building process. They meet with the professionals and are introduced to the various points of view of architecture through the people in each case, giving a longer exposure to a single case, during a semester, than students who participate in many prepared cases in the same time period.

Since the cases are documents and require the cooperation of the participants, they also require legal releases in order to be published. These may be difficult to obtain. The inability to obtain a release may limit the use of a case in which a great deal of time and effort has been spent. An excellent article on the topic of writing cases "McNair on Cases", available through the Intercollegiate Case Clearing House. McNair describes case writing and states that a "good case is a definite literary accomplishment," (8) a statement that will have additional meaning for the case writer after the first case is finished.

"Next House and New House, view from Boston," by Marc Maxwell

THE CASE

"Dormitory - Next House - 500 Memorial Drive" is one of several cases written as part of a long term research project in building economics initiated by Ranko Bon, Assistant Professor in Building Technology. Professor Bon is the Principal Investigator of two dormitory buildings, New House and 500 Memorial Drive, on the MIT campus. During the Fall of 1983, his seminar class in life cycle costing for buildings researched and drafted cases on the two buildings in addition to study in economics. Each student identified an area of interest, struggled through the documentation on each building, sought interviews with the people responsible for the construction of the dorms, and drafted cases. The long
term goal of the project is to develop a set of comparative cases, describing the life cycle phases of the two buildings.

Ranko Bon defined a research agenda in which the vast resources of MIT could be tapped. In searching for case examples, he enlisted the support and cooperation of the several departments responsible for the functioning of MIT, among them Physical Plant Department, Housing and Food Services, and the Planning Office. Building types representative of those in typical architectural practice were sought. Bill Dickson, Senior Vice President of Operations, was instrumental in the selection of the two buildings, as well as the subject of this case. Both buildings are considered successful by MIT. They were designed and built by the same architect and contractor, constructed with a three year between the end of the first and the beginning of the second. During this time, the Oil Crisis, significant changes in the concept of dormitory living, in the building industry, and in the physical climate had occurred. These forces acted to modify the second dorm, originally planned as a "redesign" of the first. In planning the New House, MIT experimented with the use of a design/build type contract. Emphasis was placed on "absolute thoroughness in the preliminary design phase to avoid change and increased expense later." The parallel stories therefore make investigation of each more interesting. The Physical Plant Department gave the class access to records from the construction both buildings.

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Jim Herold, principal of the architectural firm Sert Jackson and Associates (SJA), worked on both projects. He became a central figure in several of the cases and a central part of the research. He made himself available for interviews, contributed insight into the firm's part in the building processes, and gave the human dimension essential to any endeavor. He answered questions, provided his thoughts, and read many of the cases. For both projects, SJA's partner was the Turner Construction Company (TCC), who also provided much input. The successful drafting of several interesting cases is due to the participation of individuals representing the three firms - MIT, SJA and TCC.

The class used cases from the Laboratory of Architecture and Planning, resources on the subject of case writing, and individual experiences from classes that were taught using the case method as a basis for case writing. The experiences several students had in using cases as assignments from classes in building finance provided a good basis for understanding what a case should be like; as there are no tried-and-true, step-by-step procedures to follow. At the end of the semester the case writers tested each other's cases and made comments for further development. Several cases were selected teaching material in future classes. As additional cases are developed over time, the goal is to make the collection of cases available for others interested in using
them.

Next House was the building selected for the case presented in this thesis. The subject of the first draft was an investigation of the change in the thickness of the roof insulation, which Jim Herold had made as part of an energy conscious study. Three decision points regarding the roof were selected to take advantage of the opportunity to become more knowledgeable about a building system which is technical, potentially troublesome, capable of being isolated for investigation, and of interest to MIT. The next step was to extend the original case to include the design of the roofscape and the selection of the roof membrane.

The roof is a system. Its characteristics can affect many aspects of a building's performance. Insulation, at the time of construction of Next House, 1979-1981, was a standard component in a roof assembly; building designers added it, after the Oil Crisis, to save fuel for reducing heat loss. This apparently minor change in the system resulted in sufficient change in the system's characteristics to cause premature roof failure.

MIT, is an institutional building owner for whom an investment in physical plant is anticipated for the entire life cycle of the building. Longevity of the roof is a critical concern. Routine maintenance is anticipated,
although major repair and replacement are should be minimized.

Heat is supplied to MIT buildings from a central facility, which generates and distributes steam. Fuel expenditure is a cost which can be minimized to benefit the annual budget. Saving energy is a primary concern to MIT both from an economic standpoint and from the aspect of their image as a leader in technological development. During the planning of both dorms, MIT carefully considered their decisions regarding energy technology with both in mind.

Next House was targeted as a candidate for the application of solar energy technology early in the design. Both active and passive strategies were considered. An active domestic water heating system was designed with solar collectors planned for the roof. The designers utilized the solar technology to provide an animated roofscape, (Sert's "fifth elevation"), when the building was seen from a distance. Once the decision was made by MIT to eliminate the active system, there remained an important design project for the architects - redesign of the roofscape. (The passive solar strategies had been approved and incorporated into the design.)

The purpose of the design case was to present a design problem in a typical office situation. In this case, the building design and contract documents were almost completed when a major design feature was cut out of the project.
Redesign was feasible only for the roofscape. A budget amount had been set aside to cover this aspect of the building, and it was firm. The first dorm, New House, which had been used throughout the building process as precedent, also had an animated roofline as seen from across the river. Clerestory structures and one stairway, extending above the roof for access, were the major architectural elements used for the redesign of Next House. There was no consideration given to allowing the parapet edge to end the top of the building, which would have been the most expedient, least costly solution. A well designed roofscape was an important part of the building from all perspectives.

Enough quantitative and qualitative information on energy was given to allow the students to make design decisions informed by an analysis of both the base case and any changes made by the student's design. The economic considerations in the case were in redesigning the roofscape within a building design and within the allocated cost of the previous design with solar collectors.

The case is reproduced in Appendix A.
A CHRONOLOGY FROM TESTING THE CASE

Cases are tested in the classroom and are judged by their effectiveness in teaching by both the students and teacher. Until this point the case can only be gauged by the interest it holds for those preparing it. If the story is intriguing to them, it will very likely also be interesting to the students. Typically cases are given to students with some study questions and/or additional reading to prepare for a class discussion on the issues in the case. The teacher guides discussion and plays the role of timekeeper and arbiter of student input.

The test of "Next House" (Appendix A) was in a graduate course of building economics, a required core course in the Master of Science Program in Architecture at MIT. This chapter documents the observations of the author as a teacher assisting in the class for this assignment. During the three week period there were three separate phases: student preparation of the case (April 11-22), class discussion (April 23), and finally a presentation (May 2) by the author to the students after grading their written work. The case was given to the students with the understanding that they should contact the case author for questions about the case and the
professor for general questions. They had a week and a half to work on it.

The following is a chronology of events that occurred in the presentation of this case:

Wednesday, April 11

The Professor handed out a copy of the case to each student, at the end of the class period. He introduced me and explained that my role would be to answer specific questions about the case and his role would be to answer general questions arising from the case and that. The following instructions were given:

"The case looks at several decision points in the design of the roof and roofscape of an MIT dormitory. It gets into technical aspects of the design and economic decisions from the points of view of the architect client and contractor. The case is written in four parts, the introduction and three subcases. Your assignment deals with the first two subcases. First, you should read the case, and then select the roof system or the roof component subcase to work on. Then formulate the problem and use the analytical tools you've been learning so far in this class, as well as your judgement to make a decision. Prepare papers to present the ways you've looked at the issues, the methods of analysis you've used
and the assumptions you've made. Draw conclusions from your work and make a recommendation. There is no one right answer or one correct way to approach the case. Turn in your papers on April 23rd, and we will discuss your work in class. You will have an opportunity to share your approach to the assignment with the group.

There are several books mentioned in the text of the case; they are on reserve or are reference books in the library specifically, Manual for Built-Up Roofs by C. W. Griffin and the ASHRAE Fundamentals Handbook. In addition, your text book Life Cycle Costing by Dell'Isola and Kirk may be useful."

The students were asked to chose between the first two subcases, the roof system and the roof component. The third subcase requires a design solution, best done in a studio setting and was not part of this assignment.

Thursday, April 12

The students began to work on the case. One student found errors in the exhibits and was quite angry; there should have been no errors, but there were and they had to be dealt with. I put copies of the exhibits up by my door noting the incorrect figures and the suggestion that numbers that were used in an analysis should be checked.
Friday, April 13

The first questions asked were about using the case method itself. The students were apprehensive and seemed uncomfortable about the unstructured process of solving the case. I explained to each student that part of the assignment was for them to formulate the problem that they would solve. Then they must select a method to solve it, complete the analysis, and make a decision. They were to put themselves in the position of one of the actors in the case and make a decision using the material available. I emphasized the importance of defining the objectives for themselves and suggested that their further reading be on a specific topic they selected. I assured them that they were not being asked to match the decision that MIT had made. One student had read the case carefully and wanted more information about professional practice. He also asked specific questions which indicated that he had done some outside reading on roofing. This example shows how the case method can encourage further study in areas of particular interest to a student.

Sunday, April 15

Four students were working together, each had approached the problem a bit differently. One of the students in this group was familiar with the case method and wanted to assure
himself that this case was to be approached like a business case. At this time he proposed a solution to the first subcase: to compare the $11,000 savings of the roof with the overall cost of the building of $8 million and to realize that there was no reason, for so small a sum, to take anything but the best (most expensive) roofing material and the one MIT wanted. I responded that this sounded like a good solution, but the group felt that this would be too simple for this course. They were looking at the insulation case and felt they needed to study the energy used in the building as a whole. Although each of the four students held fairly strong attitudes about handling the case, they were willing to give up an individual stance to a degree to work in a group. (The ability to work in teams has recently been identified as an important skill for architects; one not easily fostered in studio.)

The students asked many questions and wanted more resources. A balance between giving too much and too little information was important from my point of view. Some students were going way outside the boundaries of the case, some had difficulty starting because a key part of the assignment was in its definition. I was unwilling to prevent them from exercising their judgement in handling the case, since defining the limits of problems is important in making similar decisions in practice.

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Tuesday, April 17

It was clear by this time that the errors in the exhibits were causing a stumbling block, which in addition to unfamiliarity the case method, was difficult for some students to overcome. Students needed convincing that they could do the assignment. Much of the uncertainty could be traced to the case. There was uncertainty on the part of those who were making decisions, which in practice is commonplace and does not cause notice. The errors in an academic setting were unsettling. This is a positive aspect to the case method and should be used in a specific way as part of the learning process.

Wednesday, April 18

In addition to complaints about numbers, there was positive feedback from the first students. Working in groups was not encouraged nor discouraged, but the question of group papers was raised. One student asked if their group could turn in a single paper; they were working together and, it seemed that one paper should suffice. I responded that I expected individual papers. Each student should define the problem individually and, although they might use the same or similar analyses, they should have individual attitudes and conclusions. A single group effort to define the problem may be even more difficult than agreeing on a single one. [ This

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The students who had gotten started in solving the case had begun asking specific questions about the exhibits, roofing. Those who hadn't begun were asking what the assignment was all about. One student said that price was not a problem, that the case was too easy. She looked very practically at it. She made a similar case to the earlier one: the value of $11,000 savings in an $8 million dollar building wasn't worth spending time on an economic analysis on. This observation was correct. Although there are a great many methods of analysis, business decisions are generally made quite roughly, without the benefit of detailed analysis. [She went on to do research on many energy aspects and found that every lead she followed required more and more following. She didn't know how to come to a conclusion. She was excited about the problem, though. She was approaching the case like a design problem, which was good. I suggested that she should identify what she really did know now and asked if she could define and solve a problem from that set of information.]

Friday, April 20

By this time, most students had begun to work on a
specific approach. I was trying to identify each and give them something that they could use to take the next step, even for those who were trying to solve the problems outside of the framework of the case. I noted that they were trying to find additional information rather than identifying what they did know, make assumptions, and solve the problem.

The group of students who wanted to turn in one paper worked on the component case and found that the numbers they got from an energy calculation that contradicted their knowledge about energy consumption. They wanted to know why. One student in this group became quite angry; he did not want to merely perform an "academic exercise". I responded that the case allowed him to define the assignment in any way he wanted. It could be an academic exercise if he chose to make it one. Why they were having trouble in their figures was not immediately obvious, but I was convinced that their general approach was right, so encouraged them to continue. One explanation may be their inability to clarify the issues, another was their method of working. One person working with a calculator, while others called out numbers. A student who left the group found that they had not used low enough values for insulation to see a pattern on the use of energy.

At this point it was evident that the case was not only being tested as a teaching tool, but was also being "debugged". Many students were asking questions that
indicated that they had a direction and were handling the problem fine. Several students said they liked this method. One who had been quite angry at first, had been apprehensive at being asked to answer a building question that an architect would address. She told me that this had showed her that one could go beyond, get out of one's own lack of interest to learn, and to learn about something one didn't know anything about. This is one of the values of the case method.

Saturday, April 21

The case opened up a lot of issues understood by individuals in different ways. There was a great demand on my general knowledge and about the case, having written the case and thought about it over a long period of time. In case method teaching, the teacher must be prepared to know much more than the facts stated in the case. Keeping up with each student was quite challenging. The typical pattern of meetings was for the student to first ask a few general questions about what was expected, then a few specific ones about some aspect of the case they were thinking about. This suggested an approach was already in mind and that they were checking it. Some students formulated an approach and checked with me before finishing. They usually asked specific questions form the text. For example, many asked what thermal shock was.
Monday, April 23

At the beginning of the class, after general comments by the Professor, I showed projections of the case exhibits marked with corrections, which would be made in the case modifications. (These are reproduced in Exhibit B.) He told the class that the objective in using the case was to gain experience in "the application of economic principles in real life situations and to learn to what extent we can actually perceive a connection between the two." He stressed that although there are "normally many wrong things you can do, there are many right things, as well" and we were looking not for "the correct solution, but correct solutions" in the assignment. He led the class discussion and I became an observer. Discussion of the roof system subcase was first. The characters in the case were named and the issues listed. The class brought out several specific points, but there was not much discussion between students. There were many student opinions and comments, but the dialogue was from student to teacher. The students were quite interested in the the specifics of roof performance because they had learned quite a bit and were interested in knowing more. The professor was quite knowledgeable and could answer their questions, which directed the discussion to general topics rather than the specifics of the case. Some issues in the roof system subcase were:
a. initial costs of the four alternatives are irrelevant since they are so close

b. the number of replacements one is likely to have in the lifetime of the project (MIT uses 40 years for analysis) is important, especially in comparing the BUR with Single-ply

c. for political reasons (carefully preference), BUR is most likely to be approved

d. the replacement roof most likely will be a different system

One general issue noted was:

a. the most interesting aspect of the case is not the roof, but the joint venture arrangement selected by the Institute (9)

Some issues in the roof component subcase were:

a. the energy loss through the roof was not great enough

(9) This point had not been made intentionally in the case and its observation was unexpected. Later, another case writer mentioned that he had been sought out by students and had given them additional information about the case, thus ending the mystery. His area of interest was the contractual issues.
to warrant excessive insulation; the money may be spent more cost effectively elsewhere

b. the insulation thickness and location in the roof assembly would affect its performance

The case proved to have too many issues, too many levels for discussion, too many types of analysis to discuss in a group of forty five people. The students did have differing opinions about the case, but these were not made clear to the group.

The class discussion is another aspect of the case method, which is familiar to teachers, yet requires a specific orientation. The Socratic method of discussing the case is different from normal lecture methods. The teacher must not lecture, but must elicit ideas from the students. In this case, the work was thinking about and organizing conflicting information and competing parameters in order to make an economic decision. Verbalizing thoughts sets the student up for criticism as much as pinning up a sketch problem in a studio critique, so the process must be done with care. The students need an atmosphere in which they are willing to share their work. In addition, the priorities for discussion established by the teacher in planning the class must be met.

Wednesday, May 2
I took half an hour before the regular class period to talk to the students about the papers which had been returned to them two days before. I was pleased with their performance in a most complex assignment and I had a good basis for modifying the case.

To evaluate the assignments, I read each at least once before assigning it to one of three groups: first, 30 points, second 28 points, third 26 points. In reading them I was trying to follow the thinking behind the analysis and be convinced by it. The papers in the 30 point group met the following criteria:

a. State the problem being addressed.
b. Show qualitative and quantitative analysis.
c. Draw conclusions from the analysis presented.
d. State selection of roof component or system.
e. Presented logic that I could follow.

The papers in the 28 point group met at least three of the above criteria. The papers in the 26 point group were intentionally, had not addressed the case, or were duplicates of other papers. Most papers were marked with comments to note thoughts I'd had in reading them. I had tried to be an additional resource during their preparation and I intended the notes in the same vein. Out of forty four papers, there
were ten papers in the first group, twenty-one in the second, and fourteen in the third.

The two subcases, which were part of this assignment, required one decision each. First, the roof system subcase required the student to select one assembly type from five proposed in the case - A, B, C, D, or E (exhibit -3-). Second, the roof component subcase required the student to determine whether or not to change the "U" value of the roof insulation by an amount of .01. The following table shows the ranking by cost, from the least expensive (1) to the most expensive (5) of the five roof system choices both from the initial cost of each and from the aggregate results of the student's present worth Life Cycle Cost analyses. Although choice A was the lowest cost initially, Choice D can be expected to cost less over time.

<table>
<thead>
<tr>
<th>Five Roof System Alternatives, Cost Ranking - Lowest 1 to Highest 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>First Cost (Case Exhibit 3)</td>
</tr>
<tr>
<td>Life Cycle Cost *</td>
</tr>
</tbody>
</table>

* determined by aggregating all student analysis ranking

Most students, seventeen, worked on both subcases; fourteen worked on subcase (1) and thirteen on subcase (2). The class concurred with MIT, SJA, and TCC to use roof assembly Option D and a "U" value of .05, as specified. The
following table shows the choices the students made and the number of students who made each choice.

<table>
<thead>
<tr>
<th>STUDENT DECISIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives</td>
</tr>
<tr>
<td>Subcase (1) 14 Students</td>
</tr>
<tr>
<td>Alternatives</td>
</tr>
<tr>
<td>Both Subcases 17 Students</td>
</tr>
<tr>
<td>Alternatives</td>
</tr>
<tr>
<td>Subcase (2) 13 Students</td>
</tr>
<tr>
<td>44 Students Total (Next House installed choice D (BUR-IRMA) and U=.05)</td>
</tr>
</tbody>
</table>

All of the students used text. Some used it to recount the facts in the case, which was not useful. Some used text to describe their work, using the facts in the case as explanation of what each was doing. This was very important in giving me insight into the logic of the case, and what assumptions were made, and where they drew conclusions.

The student's work showed that the problem statement or the choice(s) of analysis defined the problem addressed, depending upon which came first. They are interrelated as one of the students noted in his paper. Many used quantitative and qualitative to support each other, or to narrow the alternatives they were working with. The range of problem statements and analyses that I identified from the papers are
presented graphically in the diagram "The Range of Problem Statements", on page 50. The most successful papers worked with using quantitative and qualitative analysis. All of the students selected problem statements that required additional analysis. However, many noted that they would not consider such in-depth analysis were they not in an economics class. They realized that minimal calculations are generally used in practice.

Because I was interested in the logic of each student's work, I diagrammed the steps that two students made to select a roof system. These diagrams appear on the last two pages, pages 51 and 52, of this chapter. (The original papers are in Appendix C.)

Student A began work on the assignment early. Her first questions were about the exhibits and assignment in general. She felt that she couldn't possibly make a decision about a technical aspect of a First, especially one of which she knew only what was written on the eight pages of text and ten exhibits. The next time she came to ask questions about roofs and building procedure. I made the following notes: "long talk, lots of questions that looked to her like stumbling blocks, but to me it looked like she had done a lot of thinking about the case. At the end [I felt] she realized how much she knew and was excited about the case."
The diagram "Student A", indicates that this student first defined a position from which to work, that of a consultant to the Project Architect. She chose to work on the roof system first. She grouped the alternatives and studied them based on criteria she stated. To make comparisons, she used a matrix. This analysis indicated that one group of choices held more risk than the other. Next she presented a building analysis which considered two different rates of inflation. The two choices with the lowest building were selected for further comparison. Risk was a factor in one and was evaluated in a single calculation which was considered with respect to the whole investment. The risk was not considered to be worth the apparent savings.

Student B also began the assignment early. He asked about roofs generally, how to do building on the solar system (was part of the third case) and indicated that the case didn't have enough information to solve the problem properly. A week later he came back with specific questions that he'd not been able to clear up through his research. Specifically, he could find no acceptable source that would state the life of a roof system. building analysis included roof replacement. An assumption about life span could bias the analysis enough to make it unreliable. He noted that he had anticipated finding clear, rational sources, like the formulas presented in class. There are no definitive sources to my knowledge, or if there are we have no clear way of identifying them.
The work of these two students shows two approaches to the same problem, using some of the same analysis techniques, arriving at the same conclusion, but with two very different steps of logic. Both are architecture students. The indication of the simultaneous and alternate uses of quantitative and qualitative analysis strongly suggests that each made use of design skills. Integrating design and technical subjects is one goal of my investigation of the case method. As students worked on the case, we talked about the technical aspects of the case in most discussions, and rarely about approach to the problem. Discussion of the process of their work may have been beneficial.

There are several ongoing research projects which focus on unraveling the mystery of the design process. I believe these rudimentary analyses indicate that cases may provide a data base which can be used to analyze the thinking process of designers.

In addition to the number of students who seemed to enjoy this assignment, there were some students were not at all happy doing it. Although they put a lot of work and energy into it, they did not focus on a specific problem which interested them, or used individual skills and they did not see the exercise as an opportunity to explore some aspects of the case that interested them.
THE RANGE OF PROBLEM STATEMENTS
STUDENT A - DIAGRAM OF CASE ANALYSIS

Study Case

1. Define Context of Problem
   Identify Author's Role in Decision

2. List 5 options

3. Divide options into groups for research and analysis

4. List aspects for consideration

5. Research and compare Group 1 and Group 2 for Performance (Matrix, Qualitative Analysis)

6. Research and compare Group 1 and Group 2

7. Compare LCC for all five:
   1. Initial Cost
   2. Maintenance, Annual
   3. P.V. Maintenance, rate 1
   4. P.V. Maintenance, rate 2
   5. Total Cost 1
   6. Total Cost 2 (Quantitative)

8. Select two roof options

9. Investigate + (risk) from B - G for any early replacement may be required

10. Conclusion: Use Roof D, Savings for A, no new high risk
   Quantitative Analysis
STUDENT D - DIAGRAM OF CASE ANALYSIS

Study case

1. Select roof system vs. roof component case

2. Select PW type LCC analysis 4 identify areas:
   1. Initial Cost
   2. Maintenance
   3. Replacement

3. Research each system alternative using technical manuals (qualitative analysis)

4. Assign values as required from step 3, to areas of investigation in step 2

5. List all assumptions

6. PW Analysis
   (Qualitative analysis)

7. Note choice D lowest cost

8. Evaluate choice D against knowledge of case and roofs (Qualitative analysis)

9. Identify conditions that would challenge this selection

10. Note Specifications

11. Consider cost of roof in relation to total building

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On the basis of the experience of using "Next House" described in the preceding chapter, the author modified the case for future use. (The seemed case is included in Appendix E.) Observations by the author and the Professor, as well as the feedback from student comments, their papers and response to a questionnaire revised specific information and general comments. (The questionnaire and a tabulation of the results are presented in Appendix D.) In addition to minor changes made to clarify language, particularly with respect to the technical descriptions, four major types of modifications were made, which are described more fully on the following pages, to the text and exhibits:

1. Clarify the assignment
2. Utilize actual exhibits
3. Clarify time order (separate first and second subcase)
4. Eliminate extraneous information
5. Decrease emphasis on time and budget constraints

Some of the student comments are included in the following description of modifications to the case. The modifications are also indicated generally in the documentation "A
First, Clarify the assignment: As outlined in the previous chapter, this case initially caused a great deal of anxiety and confusion among students. Once this was passed, most students delved into the work with interest and energy which was astounding. One initial block was their unfamiliarity with this type of assignment which required the students to pose the problem and then to solve it. At one extreme, students were obviously pleased to define their own work. At the other extreme, a group of students just wanted to be given the right formula to use to run numbers. Both reactions were expected and the range in between. One student commented:

"I think, while it is valuable to have an documentation case, some very specific questions or tasks should be put forward by the case study. Perhaps then the class discussion would be more focused on common issues everyone can identify with." [student response on questionnaire].

Minor changes were made in the wording of the last statement of each subcase; providing additional directions to aid the student to define a specific problem more quickly.

Second, utilize the actual exhibits: The next, larger block was in the exhibits, which contained inconsistencies and
errors. The difficulties with errors in the numbers were evident on the second day that the students had the assignment. The students were looking for additional clues in the exhibits. The wrong numbers were confusing, and caused anger. Although numbers turned out to be a minor aspect to the case and all students were able to deal with them, their initial force was a negative aspect to the assignment. Many students were afraid of numbers to begin with and expected anything from the teacher to be correct.

"While the figures may have been an accurate reflection of those presented by the design team, many were poorly presented, confused and inaccurate. For those of us who are a bit insecure with the handling of formulae, this ends up being a DISTRACTING WASTE OF TIME. [student response from questionnaire]

There are positive and negative points to this issue. On one hand, the case method demands that the students think for themselves. Dealing with errors in numbers that are a minor part of the problem is appropriate. On the other hand, this case had too many such errors and getting around them caused unnecessary work on the part of the students and they were corrected.

The cause of many of the errors was, ironically, the intent to simplify documents to be used as exhibits. The
focused were represented, but not copied exactly. There were some typographical errors and minor deviations from the focused, which led to misleading and incorrect data in the context of the case. To prevent this, every effort has been made to use original documents for exhibits and make clarifications in the text. The GMP Budget (exhibit -7-) has been removed and the important information included in the first subcase. The Heat Loss Estimate (exhibit -8-) has been replaced with focused from the Engineering firm in new (exhibits -7- and -8-) and simplified table of explanation of the formulas placed in the text.

Third, clarify the time order: In structuring the setting for the case, the timing of the second subcase was made intentionally. This contributed to the strong connection made between the two cases, evidenced by the large number of students who worked on both subcases, about one third. One student mentioned this difficulty:

"I was very confused initially about how the problem was divided, especially the system and the component sections." [student response to questionnaire]

In addition, information about insulation costs helpful to solve the second subcase was included on the major exhibit for the first subcase. This was a deviation from the original documents; that data had not been recorded. Exhibit 3 in the
modified case is a reproduction of the original document, used to eliminate confusion, although it is simple enough to be redrawn with the same information. The information on insulation costs was placed in the text with the second subcase. A statement was also included to clarify the timing of the second subcase.

Fourth, eliminate extraneous information: Some of the information in the exhibits was not useful and should be removed. Many students decided that because the roof insulation was a part of the building envelope insulation strategy, that it should be analyzed as such. There was not enough information in the case to do this, nor enough to suggest that this would be an inappropriate step. The wall section on (exhibit -9-) had been included for interest, as a parallel to the roof component decision. A separate decision had been to increase the insulation in the walls for a total cost of $11,000. The students did not accept this decision, which was stated in the text. Instead, they included a change in the "U" value of the wall as an option in their decision making. This required many assumptions, messy calculations, and led to the inability to state a conclusion. Because this direction was not intended, (exhibit -9-) was removed from the modified case.

Fifth, decrease emphasis on time and budget constraints: The statement that the project was affected by time and budget
constraints was made too many times, emphasizing this point too strongly. Although a real part of the case, they are a part of every building project to some extent, and had no special bearing on either the selection of roof system or the decision about roof insulation. Many students used the pressure of time to support their decision, especially the students who selected a single-ply roof membrane. Although this led into a short discussion of the importance of shortening steps on the critical path of construction, only one of the references was deleted. The point will be made strongly enough.

These changes were made specifically for this case and should not be used for general rules in case writing. In fact, although the actual exhibits were preferred for the technical parts of this case, the axonometric view of "Next House" (exhibit 4 in both) was prepared by the author because there were no drawings available depicting the solar collectors. In addition, changes were not intended to entirely eliminate confusing, extraneous and overemphasized information, but to use it appropriately. One general rule which can be stated, however, is that all aspects of a case should be included by design. The writer should select aspects appropriate to the case which are necessary to meet the stated teaching goals of the case. It is important to maintain goals and to keep the project within a manageable level of complexity, although a range of issues from the
smallest details such as joining two dissimilar materials to the largest concepts such as the architect's role in the building industry can be part of a single case.

Teaching notes, as previously mentioned, can be a useful guide to other teachers, unfortunately they are not always prepared. They give the teacher additional insight into the case and preparing them is the best practice. "Notes from the Author" were prepared for "Next House" and are included in Appendix F. The notes include an introduction to the case story, the key participants, and main events, as well as an outline of the promise as intent in writing the case. A single approach to using each subcase is presented along with a listing of additional reading material. In general, cases can be used in various ways according to the specific requirements of a class. Alternative results can be achieved by directed reading, a list of teaching questions, changes in the class discussion setting (for example, through the use of role playing). Teaching notes should be updated to benefit future case use.
Until recently, the normal career path of the architect was in two parts, first, formal education in a university and second, practical education in the field. Today, many practicing architects seek formal education or interrupt their careers for additional education. Changes in architectural practice, the desire to specialize through formal education, or to acquire technical knowledge, are factors that influence this decision. Universities are meeting this need through additional continuing education programs and through the increased enrollment of mid-career professionals. The specific requirements of this new type of student, who are trained in practice, but want additional academic experience, should also be addressed in discussions about architectural education. This new group of students bring to academia, in addition to their specific requirements for education, training in the field; which initiates a new connection between practicing and teaching architects. Changes in architectural education to integrate design and technical teaching are not directed specifically for the graduate level, however, these students will benefit, as well as contribute to change.
This author is one such student, who after experience in practice, returned to graduate school full time in a two year program. During the first year, the faculty, lectures, and newly accessed books were informative. It was not until the second year, during the thesis work, that the interconnections between new ideas and previous experience were made. The four phases of the thesis were - researching, writing, testing, and evaluating and rewriting the case, "Next House". After one year of work, the academic environment was a familiar and the case experience provided a format for personal challenge and testing. At each phase, the most important attitudes, which developed during the thesis, were: of listening to what was being communicated, maintaining an open mind to learn the point of view of the other person, understand what information they were using to make a specific decision; use experience as a guide through the facts of the case, separate personal judgement case facts; invest in adequate time and labor to keep track of details, to save time in the long run and avoid confusion. All are valuable in practice, as well, but more so in the this thesis, which as teaching a case placed the promise as attitudes between the case facts and the students. The intent of the case is to give the student a chance to think, therefore, the facts must be clearly reported, although they had been selected using the judgement of an individual.

In the first phase, the research of the case shared aspects of the student's experience in using the case,
described in "A Chronology of Testing the Case". Issues were confusing and apparently contradictory. At first, there was too much information and gathering initiative to begin was a challenge. Sorting through the documents to gain familiarity with the people, the events and decisions was just the first part of understanding the process they had gone through and the tools of analysis they had used. Previous experience on practice was invaluable up to the point that it obscured the specific events of the case. At this point, new skills in thinking maintained objectivity.

The second phase required an additional skill — communicating in writing. Case writing is not documentary nor creative writing, but shares aspects of each. (Some guidelines for case writing are provided in the section, "Preparing Cases".) The case "Next House" was researched and written during the course of two semesters with corresponding research on related topics — life cycle costing, energy conservation, and architectural education. Professor Ranko Bon was necessarily strong influence in keeping the work focused and continuing development toward a conclusion. (The teamwork of a graduate-researcher and professor-investigator is a model which business schools found successful in case preparation and is supported by this thesis.)

Giving the case to students, the third phase, was a test not only of the text and exhibits, but of a half a year's
thinking about a single aspect of a building and the methods of presenting this to students. The accuracy in collection of facts and technical details, the research required to understand what really happened, the interest of the story, and the ability to communicate what was known about the case, were under the student's scrutiny. They read the case thoroughly (at the end of the assignment most texts were covered with notations); asked about many things they did not understand, (they questioned the meanings of specific words, such as clerestory and thermal shock); or ideas they disagreed with (they followed the logic of the story and found the discrepancies). This inspection exposed issues that had been taken for granted, eliminated, minimized, and obscured, which is part of learning with cases. With experience this can be more carefully planned along with the long term goals of each case. There few rules to the case method, but three aspects are usually associated with it. This thesis addressed each part, but concentrated on the first:

1) a written case prepared from a real building project to meet the teaching goals of the instructor;

2) the case story, which requires action or a decision from the student, using an analytical exercise, a judgement on the basis of information in the case, a sketch problem, or a mixture of these examples:
3) and the case discussion by the students regarding individual work and structured by the instructor, from a number of formats including group discussion, role playing, or a jury, including specialists representing issues from the case.

In the fourth phase, evaluating and rewriting the case, its usefulness as a teaching tool was judged. The case was complex and contained errors. The presentation of two cases together added to the complexity and also prevented the class discussion from being more focused on the issues of broad interest to the students. During the research and preparation of a case, its presentation and discussion with a specific group of students should be considered in great detail, as well as the case itself. The case had been modified, as presented in Appendix E, to address these points. In continued to development of cases and their use in classes equal needs to be placed not only on the case but its use as well; specifically, in the planning and sequencing of cases within the context of a course; utilize degrees of complexity to teach students to use the case method; draw incrementally form a single building until many issues can comfortably be managed by the students.

Despite emphasis on case modifications and the difficulties in using the case method, many aspects of the case remain unchanged and the experience was positive both as
an investigation of a teaching method and as an introduction to teaching. Overall, the students responded positively to the case and the type of assignment, preparing very good papers (two are reproduced in Appendix C). Students identified some of the reasons that the case method is used: it is an interesting way to learn; each student is able to investigate issues of particular interest; it made them think, they were responsible for the applying goals; and they were exposed to architectural practice. The last point is the most important one, that the case method is a very good way to introduce issues of architectural practice into an academic setting and to initiate thinking skills to be continued in practice. Excellence in design isn't drawing, applying technical analysis, or dealing with people—it is thinking. Tools and skills, such as mathematical formulas, sketching, and management are very important, but thinking is essential. Architects need to think about buildings from all aspects, such as: the contexts of form, society, history, economy; the human needs of the owner, user, neighbor; the capacities of the building industry; and one's own individual needs to create, to be part of something, to leave one's imprint on the world. An architect's career is filled with opportunities to make decisions that affect buildings, and make improvements that come with experience. Because of the momentum of projects, among other reasons, the opportunity for reflection on one's experiences and the time to consciously improve one's thinking about buildings must be created. Initiating the
habit of reflection is one additional goal of those who teach with cases.

This thesis supports conclusions made by the MIT Laboratory of Architecture and Planning Case Studies Project that the case method will have a significant place in architectural education in time. However, for the present, the case method will have a small role. This is in part because architectural educators are not looking for sweeping changes and in part, because of the difficulties in establishing a new method of teaching. The development of a reserve of cases to draw from would require a concerted effort and substantial funding to support trained researchers familiar with both architectural practice and buildings; buildings with accessible documentation, including economic data; as well as sufficient time to research, write, test and rewrite each case.

At present, the role of the case method will be significant for individual instructors who are determined to prepare and use cases; a process which provides the opportunity to learn and teach at each phase, and is open to demonstrate issues of specific interest and related aspects, improving understanding of all aspects of architectural practice and the building industry of which it is a part.
EXHIBIT A

Case, "Dormitory - Next House - 500 Memorial Drive"
INTRODUCTION

Jim Herold, Project Manager in the architectural firm Sert Jackson and Associates (SJA), was responsible for the MIT dormitory project provisionally called Next House. Under the leadership of Design Partner Josep Lluis Sert and Partner Huson Jackson, Jim Herold and the other members of the design team were finalizing design decisions and bringing contract documents to the required 75 percent completion stage. They had been working on this project since July 1979. At the same time, the firm's partner, Turner Construction Company (TCC), was taking bids on design and material alternatives and negotiating with potential subcontractors. The partners had formed a joint venture and were working under a design/build contract. Within MIT, the Physical Plant Department staff, with Bill Dickson as Director, was making design and economic decisions about the dorm as well. They reviewed the design and budget proposals of the Joint Venture and consulted other MIT offices and departments when appropriate for the project.

It was late March 1980 and the project had to be completed by mid-August 1981, to be ready for the students arriving for the fall semester. Construction was scheduled to begin in April 1980, a month away. Time was a critical factor throughout the building process. The present urgency to finalize major decisions affecting the Guaranteed Maximum Price (GMP) and the construction schedule was pressing all concerned at this point. In preparation for the next meeting of the Joint Venture and MIT to discuss unresolved issues relating to the roof, Jim Herold reviewed the history of the project.

New House & Next House

In June 1979, MIT contacted Huson Jackson to initiate construction of the new undergraduate dormitory building to alleviate overcrowding in the Institute's dorms. The West Campus site had been designated in the 1960 MIT Master Plan. It was adjacent to New House (exhibit -1-), an undergraduate dormitory constructed during 1974-1976 by SJA and TCC also in a joint venture. The new dorm, Next House, was under time and budget constraints similar to those surrounding New House. The very tight schedule allowed only two years for design and construction. The joint venture arrangement had been initiated for New House with the intent of a shorter construction period and greater control by MIT of design and budget decisions. The architect and contractor

This case has been prepared by Jacquelin McBride, under the supervision of Professor Ranko Bon, as a basis for class discussion, rather than to illustrate effective or ineffective handling of building decisions. This document is confidential pending case release by all parties.
worked on design and bidding at the same time, overlapping the design and
construction phases. The use of fast tracking considerably shortened the
building process.

Program and Preliminary Specifications

A Group/Client Team composed of faculty, students, and administration
representatives had developed a program during the Fall of 1978 to be used in
the next dorm. It reflected the present concepts of dormitory living and was
different from New House, which had a program of house clusters. Next House
program returned to a traditional dormitory concept, like that of Baker House,
designed by Alvar Aalto. Harry Portnoy, the Campus Architect, was responsible
for the coordination of the project within MIT and between MIT and the Joint
Venture. He prepared the project schedule, directed the preparation of the
budget and preliminary specifications, and coordinated the work of the
architect and contractor through his office. In July 1979, Harry Portnoy
delivered the Preliminary Specifications, which included the program prepared
by the Group/Client Team, to SJA. Preliminary Specifications are prepared by
MIT for each project and are based on the collective experiences of the
specialists within the Physical Plant Department, responsible for the
construction and maintenance of all MIT buildings. They are intended to serve
as guidelines for the architect, not as requirements. Next House would be
different from the first dorm in terms of the program, but would be
constructed with similar materials and detailing. The decision to use a
"redesign" approach, to acknowledge and fully utilize the shared knowledge
gained in the construction of New House, was made very early by MIT. The Joint
Venture was agreeable to this as well. Many of the people working on Next
House had been involved in the first project and knew each other. Jim Herold
had been job captain on the New House design team. Jim Betts was the estimator
at TCC for both projects. Harry Portnoy was the Campus Architect for both, but
in New House he was part of the Planning Department and for Next House he was
with the Physical Plant Department. For Jim Herold, using experience from New
House meant that the many design and detailing decisions were narrowed
to a manageable number of alternatives. He could devote more attention to other
design issues, such as solar energy concerns. Both MIT and the Joint Venture
made their preliminary budgets based on the costs from New House with factors
to adjust for inflation and anticipated differences in construction costs due
to the changed program.

Energy and Economics

The Joint Venture investigated the economics of many design,
construction, and equipment alternatives. These ranged from expenditures for
solar energy applications with significant implications to the base price to
specially selected gravel for the low roof over the kitchen area visible from
the upper floors. MIT established the basic parameters for investigative
analysis in the Preliminary Specifications Section "Energy Conservation, and
Facilities Management Systems". (exhibit - 2 - ) The emphasis on determining
appropriate solutions was stated:

"The ultimate objective of efforts in energy conservation is set
forth in the requirement that the present value of construction and
operating costs over a 40 year economic life be minimized."  
[Preliminary Specifications, Next House - July 1979]
The Institute took an active part in the allocation of resources with the Joint Venture. Throughout the bidding procedure open channels of communication were maintained to facilitate decisions on trade-offs that had to be made. Jim Herold felt that sharing information as much as possible at critical decision points made the issues "transparent".

"The more [...] contractors, architects, and owners [...] get together and understand what the others are really thinking about, [the more] we begin to understand that there are kinds of hidden costs that affect the contractor that don't bother us one way or the other. [...] On the other hand, we have things we care very much about, and are small change to them. They begin to understand what matters to us and we see where it hurts them, particularly with respect to the time frame for the contractor and maintenance for the owner. [Jim Herold]

Trade-offs could thus be made in some systematic fashion. Jim Herold kept himself informed about the economic aspects of design decisions, which allowed him to strike a balance between design requirements and budget constraints. The Joint Venture was working with a sophisticated client, one that was a major force in the market of the Boston area. MIT had built extensively and knew what they wanted in a well-designed building. The Joint Venture had to prepare the GMP, the contract sum they guaranteed not to exceed in constructing the dormitory. There was an incentive to continue to reduce costs even after the acceptance of the GMP because the contract provided for MIT and the Joint Venture to share any savings during construction. As Ted Rhoades of TCC stated:

"The arrangement worked well because the incentive reinforced the team approach to construction. [...] Neither party has control over the other. It is a collaboration of mutual respect, with a thorough dialogue between professionals and with the owner. Cost control never takes precedence over design quality and vice versa; the two factors together find the best solution." ["MIT Experiments with Joint Venture Contract", American School and University, Nov. 1981]

Roof Design Issues

The next meeting of the Joint Venture with MIT was tentatively scheduled in a couple of weeks, which would be in mid-April. Among other things, Jim Herold had singled out three items on the design of the roof for final decision. He decided to consider these separately, although they were all energy-related. These were:

System - Roof Design Alternatives
Component - Roof Insulation "U" Value Specification
Building - Roofscape Design

SYSTEM - ROOF DESIGN ALTERNATIVES

Jim Herold had proceeded with the design of Next House using the system design provided in the specification from Harry Portnoy's office. TCC had
carried a value for "Roofing and Flashing" in each budget for a roof system described as follows:

"Roof: MIT basic roofing specification is a 5-ply built-up, tar and gravel roof. [...] "U" value for roof system, including roof, insulation, deck and ceiling shall be no more than .050" [Preliminary Specifications, Next House - July 1979]

More specific information was needed by the Joint Venture to negotiate contracts with contractors and finish the GMP. Jim Herold agreed to research alternative roof systems. The roof is a complex system of interrelated parts and not a simple layering of independent materials. The designer needs to be aware of the implications of their relationships. Change in one component may lead to unpredictable ramifications for the system as a whole. Too much insulation, for instance, may cause thermal shock.

At the start of Next House Jim Herold retrieved the New House files from storage to keep by his desk for reference. He refreshed his memory. On New House two roof types were used - a standard built-up roof (BUR) for the main roof and an inverted roof membrane assembly (IRMA, also called protected membrane roof, PMR) for the terrace areas. Most MIT roofs were the conventional BUR type. The New House installation was a test for MIT. The Physical Plant Department personnel were experienced in BUR routine maintenance and minor repair. For the first time they installed a BUR system with the insulation above the membrane, which was a variation of a standard BUR system. The roofing industry had been developing new products and roofing systems for a number of years. IRMA was developed after roof membrane failures in epidemic numbers, particularly in New England, were attributed to thermal shock. After the Oil Crisis in 1973/1974, the long tradition of placing the roof membrane directly on the deck, with very little or no insulation, was varied by placing insulation layers between the membrane and the tempered building interior. This resulted in increased roof temperatures and premature roof failure in extreme cases. In an IRMA installation, the roof membrane is protected from temperature changes and wear by the insulation and ballast. The terraces of New House were potentially vulnerable to user traffic and were consequently covered with pavers. After several winter seasons, MIT had been generally pleased with the performance of the IRMA roof. The alternatives to the BUR were synthetic single-ply roof systems, long in use in Europe, but were still regarded by many in the U.S... as experimental. However, the systems were gaining popularity among roofers because they were more easily installed, could go down in more extreme weather conditions, and were less hazardous to the workmen. Bill Dickson, recognized by the roofing industry as an expert in roof installation and maintenance, preferred BUR's to the new single-ply systems.

"I have always felt that [...] properly put down, a built-up roof will give you much service. [...] The Institute is careful not to fool around with any new systems. [...] The manufacturer may claim a thirty year life for their product, but their roofs may have only been in service for four years." [Bill Dickson]

Throughout the design development and bidding process, Jim Herold worked closely with John Betts to make the most cost effective decisions without sacrificing design intent. For the March 1980 investigation, John Betts...
referred him to Ken Marshall of Federal Roofing, an experienced firm bidding
the job. Federal Roofing had been the roofing subcontractors on New House and
Ken Marshall had been Project Manager. With the area take-off on the roof plan
(exhibit -5- ) and an estimate of roof penetrations, Ken Marshall was able to
provide cost comparisons of five systems - three with single-ply and two with
built-up membranes. (exhibit -3- ) Jim Herold compared the five systems and
discussed them with Bill Dickson. The Joint Venture would present two options
to MIT in the GMP (exhibit -7- ) scheduled for submission on April 17, 1980,
with drawings, specifications, and a list of exceptions and cost savings
items. Since MIT was anxious to cut the budget and there was a growing trend
among roofers to use the more easily installed single-ply roofs, this deduct
option was offered by the Joint Venture. The GMP carried a line item for
Roofing and Flashing of $164,000 and an option of a deduct of $11,000 for the
use of a Carlisle single-ply roof as a substitute for the BUR. The
construction cost, before consideration of cost savings, was $8,512,050.

COMPONENT - ROOF INSULATION "U" VALUE SPECIFICATION

Jim Herold placed emphasis on energy conservation strategies derived from
the design of the building envelope. He investigated the advisability of
changing the "U" value of both the roof and wall assemblies from the values
noted in the Preliminary Specifications. His concern was in keeping with the
MIT directive, which stated that:

"One of the major concerns in the design of the project is the
conservation of energy because of its impact on the total cost of
building ownership over its useful life. Since we have recently
emerged from an era where they will likely increase to even higher
levels than the present, designs which have been economically
desirable in the past will no longer be either economical or
desirable. At the time when design concepts and technology are
changing, in response to these new conditions, more attention to the
economic implications of a design will be required, than has been
the general practice in the past." [Preliminary Specifications -
July 1979, p.126]

Many roof experts considered increasing the thermal transmission value of
roof insulation to be cost effective. Jim Herold considered the impact of
increasing and decreasing the thermal transmission of the roof insulation on
the amount of money spent for fuel.

"Thermal insulation in an air-conditioned or merely heated building
offers the greatest return on initial investment of any building
material. In view of prospects of energy costs escalating 10 to 15
percent annually far into the foreseeable future, substantial
thermal insulation is indispensable for occupied buildings." [Manual
for Built-up Roof Systems, 2nd Edition, C.W... Griffin, p.53
McGraw-Hill, 1982]

The decisions regarding the building components were made incrementally
as more and more detail was needed for each phase of the design and budget
process. In September 1979, Shooshanian Engineering had been contracted as
engineering consultant by SJA. They had been consultants for an office building in Cambridge, 50 Church Street, designed by SJA and constructed by TCC in a competitively bid contract. For Next House Jim Herold outlined their responsibilities in a letter to Harry Portnoy:

"(1) set criteria; (2) prepare schematic designs and energy conservation analysis; (3) review design development and construction documents; (4) review and approve shop drawings; and (5) perform other normal services during construction." [Jim Herold to Harry Portnoy, 10 September 1979]

The mechanical, electrical, HVAC, and fire equipment subcontractors were to be the engineers of record, which had been the arrangement in New House. Shooshanian was to provide information and opinions to inform the decisions made by the Joint Venture and MIT. Although their practice did not generally undertake projects which would be bid to design/build subcontractors, they agreed to undertake Next House.

Joe Fullam was the Project Manager for Shooshanian Engineering on Next House. From the preliminary drawings and area take-offs provided by Jim Herold, Fullam prepared an analysis of the estimated heat loss. (exhibit -8-)

The ball park energy usage and energy costs derived from standard engineering calculation methods were made to compare alternatives. Methods of estimating energy use are simple in a building which is only heated. The information required includes data from the physical characteristics of the building and regional data from the preliminary building design provided by the Massachusetts Energy Building Code, "Article 20", adopted since the completion of New House. More accurate calculations would require final building characteristics (for example, tightness of construction, orientation and size of glazing, and weather data), as well as information on the use and management of the building (for example, temperature settings, scheduling, and internal heat gains). The amount of heat loss through the roof was required by code not to exceed 109,185 BTU's (exhibit -8-), unless alternative provisions were made in the wall assembly to maintain an overall total building loss. Based on Joe Fullam's energy analysis, the Joint Venture and MIT decided to increase the R value of the wall assembly from R = 11 to R = 19 by placing a 1" sheet of rigid insulation in the wall cavity.

Joe Fullam's analysis of the "U" value of the roof, similar to that for the wall, included consulting the Preliminary Specifications and the Building Code, adopted since the completion of New House. MIT required a "U" value of .05 calculated by ASHRAE (American Association of Heating Refrigerating and Air-Conditioning Engineers, Inc.) methods for the roof assembly at a typical section through the roof. The Energy Code required a "U" value of .07, calculated as an average of the heat losses for the overall roof. The average included penetrations for skylights and the elevator shaft, that is, places where no insulation would be installed. It did not include a value for the clerestory windows, which are accounted for under the wall and window area calculations. The "U" value of the roof of the clerestories, constructed of steel studs with batt insulation, would be 0.05. Jim Herold reviewed an economic analysis comparing the estimated heat loss from Joe Fullam's work with an estimated present value for the cost of fuel. He also had the relative cost of insulation for a .01 increase and decrease in "U" value. (exhibit -3-
The rule of thumb for the life of a roof was considered 20 years under normal conditions. He prepared a report of his analysis. The Contract Specification Section, "Roofing and Flashing" would read:

"Thickness of insulation shall be such that the completed roof construction including interior ceiling finish will produce a "U" value of 0.05"

BUILDING - ROOFSCAPE DESIGN

The emphasis on energy, not only by MIT, but the nation, in the wake of the Oil Crisis, led SJA to propose an investigation of active and passive solar applications for energy savings. These solar studies were in addition to the ongoing investigation of energy conservation measures. The design team had decided at the initial stages of the project to heed well-known strategies of siting and manipulation of glazing to wall area ratios. Two studies were initiated, one on the use of passive systems by Solar Design Associates and one on active solar collector systems by Shooshanian Engineering. The 50 Church Street project had included an active domestic water heating system, which was cost effective and had been successfully incorporated into the design.

Jim Herold had worked closely with Sert for a number of years. One of Sert's design directives was the constant search for new forms to "keep architecture fresh" [Jim Herold]. He was not interested in merely taking "something technological off the line" [Jim Herold] and applying it directly. He looked at technological advances, such as energy hardware, for their potential in architectural expression.

Steve Strong of Solar Design Associates investigated passive solar applications for space heating. He developed several strategies for passive space heating in the dormitory rooms, the dining area, and the Headmaster's apartment. The resulting design requirements were welcomed by the architect as appropriate for integration into the design. The proposals for the student rooms required students to adjust blinds and drapes and to operate windows to control the temperature. Students are not normally in their rooms in the daytime and are often away for weekends and vacations. The Institute would therefore have to provide a conventional back-up heating system in order to guarantee adequate comfort levels. Because of this, one of the benefits often associated with solar gain, the reduction of mechanical equipment costs, could not be realized with the passive strategies. Another economic benefit typically gained in solar installations, a tax credit, was also not available to MIT as a non-profit institution. MIT decided to accept the proposals, which they considered consistent with their program. The benefits of utilizing solar strategies were considered to be worth the costs.

Joe Fullam investigated the application of an active solar collector system for both space and domestic water heating. An early hand calculation showed that space heating would require more square footage of collector area than the roof could support. This limited the study to domestic water heating. He proposed two alternative active collector systems, one using a flat plate collector and one using a parabolic tracking type. The choice was made to use
the flat plate collector. Joe Fullam designed a system, which was incorporated into the design of the roofscape. (exhibit -6-) TCC priced the system and design as a deduct alternate item for the GMP. (exhibit -7-)

The separate studies had been completed and a report dated November 9, 1979 was sent to MIT for their own analysis. Their summary of the systems was outlined in a memo from Bill Dickson to the Building Committee on April 3, 1980. (exhibit -10-) In typical installations of solar collectors on flat roofs, the collectors are placed on metal frames, which the design team and the owner considered too flimsy for this project, both structurally and in appearance. Masonry supports were designed. In Next House the space under the collector was seen as an opportunity to let light into the floor below. Clerestory windows were designed to let daylight into the corridors. MIT had requested that any daylighting be for public spaces. The roof structure was a two-way slab system, selected in part for its flexibility in accommodating the anticipated roof penetrations. The openings could be located late in the design, although additional beams were required at each penetration to take the load of the skylights and collectors. Storage for the heated water was also required, for which tanks in the basement were included in the deduct price prepared by the Joint Venture.

New House had been designed with clerestory windows in each stairwell. (exhibit -1-) An early design decision was made in Next House to use a similar strategy to animate the roofscape, visible from across the Charles River. The solar collectors expressed the use of modern technology at an institution synonymous with technology. But they were expensive. In addition, the active solar industry was perceived to be in its infancy, which meant that rapid advances would soon outdate this installation. Also the anticipated life span of the collectors was much less than that of the masonry construction designed to support it, which might look out of place once the collectors were no longer in use.

At this point, MIT's target budget was exceeded by the GMP. The active and passive systems had been carried as alternates, but the Joint Venture and MIT would have to make a decision soon. Money, time, thought, and design had been invested in the solar collectors and the passive solar solutions for Next House. Jim Herold had to decide either to provide MIT with convincing arguments based on economics, energy, and design, for the acceptance of the active solar system, or to provide an alternative solution for the design of the roofscape. The alternative would have to meet the following partial list of criteria.

1. not exceed $56,000 carried in the GMP
2. not exceed estimated heat loss
3. contribute to the quality of the space on the fifth floor
4. relate to the design of New House
5. animate the roofscape; and to
6. include one stairway to the roof, a requirement added by MIT

He prepared an alternative design for the roofscape presentation to MIT at the next meeting. He would be ready to compare it with the design of the roofscape with active collectors.
(exhibit - 1 -) NEW HOUSE
7.2 SYSTEMS CRITERIA

7.2.1 Energy Conservation, and Facilities Management System

Energy Conservation (ENCON)

One of the major concerns in the design of the project is the conservation of energy because of its impact on the total cost of building ownership over its useful life. Since we have recently emerged from an era of low energy costs, and are entering an era where they will likely increase to even higher levels than the present, designs which have been economically desirable in the past will no longer be either economical or desirable. At a time when design concepts and other technology are changing in response to these new conditions, greater attention to the economic implications of a design will be required, than has been general practice in the past.

With current interest in energy conservation and in alternate sources for energy, the design of a building for an institution such as M.I.T. will come under close scrutiny. Attention can be anticipated from those within the various departments of the Institute as well as those outside. Studies made during the design stages must provide a reasonable basis for justifying alternate courses of action for energy conservation. Reasonable alternatives should be treated sufficiently so that the reasons for those which are not adopted are established.

ENCON Economic Analysis

The economic analysis of program alternatives should be geared to the objective of minimizing the present value of construction costs and of operating costs over a 40 year useful lifetime. The economic analysis should facilitate the comparison of alternate means of achieving various objectives. Assumed values for the future cost of energy and other variables should be developed in consultation with M.I.T., utilizing the best available information. Analysis should be carried out with a range of assumed values whenever appropriate because of uncertainties, to indicate the economic impact of these uncertainties on program alternatives. Some requirements for financial analysis are required by the building code of the Commonwealth of Massachusetts and by ASHRAE Energy Conservation Standard 90-75 as cited below.

Energy Conservation Standards

The ultimate objective of efforts in energy conservation is set forth in the requirement that the present value of construction and operating costs over a 40 year economic life be minimized. As a guide in achieving this objective, various requirements and suggestions are presented throughout the program plan in the various sections to which they are applicable.

As an overall guide, M.I.T. expects the architect and engineers to abide by the standards and procedures set forth in ASHRAE Energy Conservation Standard 90-75. However, it is recognized that there may be desirable technological innovations which were not anticipated by the ASHRAE standard. In such cases, we encourage a departure from the ASHRAE and other standards when they are economically justified. An important part of the ASHRAE Standard is the development of an energy budget for a building and the development of systems that meet building user requirements within that budget.

The Commonwealth of Massachusetts is in the process of revising portions of its Building Code in areas that pertain to energy conservation. Other relevant codes, design guidelines, etc., may receive energy conservation revisions before this facility is built. It is, therefore, very important that latest system design requirements be used all during the design process. If it appears that there are requirements set forth in the latest codes, etc., that impair the attainment of energy conservation goals, consideration should be given to designing systems readily capable of modification in anticipation of subsequent modification of such requirements.

It is proposed that the possible division of the HVAC system into subsystems serving areas with common environmental requirements and/or hours of occupancy be considered. The arrangement of space to facilitate such an HVAC system sub-division should be considered when practical.

If alternate energy sources (e.g. solar energy) and/or technical innovations appear attractive from a technical viewpoint, the building design should foster these innovations and reduce the cost of their implementation to the degree compatible with other considerations.

The functional requirements of the building and site characteristics will dictate many aspects of its configuration, construction, and arrangement. To the extent that it is economical and compatible with these requirements, design features should minimize the energy required to maintain comfortable environmental conditions and otherwise enhance energy conservation. The design of the static (non mechanical-electrical energy consuming) portions of the facility is as critical to ENCON in conserving energy as the efficient control of systems. This includes energy efficiency circulation patterns, building heights, surface area, enclosed volume ratios as well as insulation factors, sun control and use of natural light and ventilation. Adequate physical barriers should be provided whenever practical between areas with different environmental requirements. Locations for such barriers might be located between an exterior door and a reception area, or between a room containing steam pipes and adjacent occupied space.
(exhibit - 5 - ) NEXT HOUSE ROOF PLAN & SOLAR COLLECTOR DETAIL
(exhibit - 6 -) NEXT HOUSE - AXONOMETRIC VIEW FROM NCM. DR.
South - East Facades
## GMP Budget
20 February 1980

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<th>Development 3 Fund ($)</th>
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**BASE BUILDING COST**
"Roofing and Flashing" included @ $164,000

### ADD ALTERNATIVES

1. **Active Solar**
   - (roofscape treatment included @ $56,000)
   - Cost: 271,000
   - Fund: 25,000
   - Total: 8,000
   - Total: 294,000

2. **Passive Solar**
   - Cost: 31,500
   - Fund: 3,500
   - Total: 1,000
   - Total: 36,000

3. **Energy Insulation**
   - Cost: 11,000
   - Fund: 660
   - Total: 330
   - Total: 11,990

### DEDUCT ALTERNATES

1. **IRMA Roof**
   - Cost: -11,000
   - Total: -11,000

### PROJECT TOTALS

**Maximum** 1 + 2 + 3 + 4
- Cost: 8,230,800
- Fund: 451,660
- Total: 174,000
- Total: 8,854,040

**Minimum** 1 + 5
- Cost: 7,907,300
- Fund: 422,500
- Total: 164,670
- Total: 8,501,050

---

1. **Building Cost** - "the amount of the guaranteed maximum price of the construction, including the contractor's profit. Money left ... was divided at a percentage among the contractor, architect and owner." New House had been completed with funds in this account.

2. **A/E** - Architectural and Engineering fees in a lump sum

3. **Development Fund** - "a 2% contingency fund to cover the cost of necessary design changes during construction other than those made by the owner. Anything remaining in this fund was to be split between the architect and the contractor upon completion, but overruns were the responsibility of the architect."

4. **Joint Venture** - "covered costs of the joint venture partnership, including legal, accounting, insurance and drawing costs which are usually paid by the owner."

Ted Rhoades, "MIT Experiments With Joint Venture Contracts", American School and University, Nov. 81
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<td>1,134,495</td>
<td>1,112,490</td>
<td>.200</td>
<td>1,000</td>
<td>16,984</td>
<td>1,000</td>
<td>27,415</td>
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<tr>
<td>Below Grade</td>
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<tr>
<td>Infiltration</td>
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<tr>
<td>Ventilation'</td>
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<tr>
<td><strong>SUBTOTAL</strong></td>
<td><strong>1,597,101</strong></td>
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<td><strong>3,427</strong></td>
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<tr>
<td><strong>INFILTRATION + ENVELOPE LOSSES</strong></td>
<td><strong>3,946</strong></td>
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<tr>
<td><strong>TOTAL BUILDING LOSSES</strong></td>
<td><strong>2,719,591</strong></td>
<td></td>
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<td></td>
<td><strong>5,837</strong></td>
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</tr>
</tbody>
</table>

1. Heat Loss in MBTU/hr = A \(\times\) T \(\times\) U; U is assigned value from MASSACHUSETTS STATE BUILDING CODE, ARTICLE 21
2. Heat Loss in MBTU/hr = A \(\times\) T \(\times\) U; U is determined by assembly design (wall assembly exhibit - -)
3. Annual Heat Loss in MBTU = A \(\times\) U \(\times\) 24(hr) \(\times\) 5634(DD); DD are degree days from STATE BUILDING CODE
4. Cost of Fuel assigned @ $6.80/MBTU \times\) Heat Loss
5. ENVE. LOSS = % Heat Loss through Building Envelope
6. INFIL. + ENVE. LOSS = % Heat Loss through Building Envelope, including Infiltration Losses
7. ASHRAE HANDBOOK OF FUNDAMENTALS, current edition; Methods of Calculation

(exhibit - 8 - ) ESTIMATED HEAT LOSS
WALL U-FACTOR

1. OUTSIDE SURFACE
2. FACE BRICK
3. AIR SPACE
4. 15" FELT
5. 1½" GYP. WALLBOARD
6. 3½" FIBERGLASS
7. 1½" GYP. WALLBOARD
8. INSIDE SURFACE

TOTAL RESISTANCE

U-FACTOR

RESISTANCE

0.17
0.44
0.90
0.06
0.45
11.00
0.45
0.68
14.15
0.071 BTUH/SQ.FT./°F.(BETWEEN JOIST

CHANGES IN U-FACTOR FOR ALTERNATE INSULATION

REVISED U-FACTOR

R-7 FIBERGLASS
R-19 FIBERGLASS
1.8" POLYSTYRENE - 3"
2.2" POLYSTYRENE - 3"
3.5" POLYSTYRENE - 3"
1.5" POLYURETHANE - 2"
" - 3"

0.039
0.045
0.066
0.055
0.053
0.064
0.046

NOTE - IF R-11 INSULATION IS RETAINED, AND 1" POLYURETHANE IS ADDED TO AIR SPACE, THE U-FACTOR COULD BE REDUCED TO 0.049
April 3, 1980

Memo to: Members of the Building Committee

From: W. R. Dickson

Re: Solar Heating Alternatives - Next House

At the March 3, 1980 meeting of the Building Committee, insufficient data was available for the members of the committee to give guidance with respect to the possible incorporation of active and/or passive solar systems in the design of Next House.

Following is certain additional data accompanied by specific recommendations for your consideration:

**Active Solar System**

- 4000 square feet of solar collector surface consisting of 190 individual flat-plate collectors would be installed using an ethylene glycol solution as the heat transfer medium.
- The present value of the entire system (collectors, supports, piping, tanks, pumps, wiring, and design fees) as estimated by the design team (Sert and Turner) is $294,000.
- The present value of the 190 collectors (included above) is $70,000.
- The projected design life of the collectors recommended by the manufacturer, Daystar, is 25 years. The actual warranty is 5 years.
- The design team is carrying $56,000 for roof/skyline treatment should we not elect to install an active solar system. Therefore, the net additional cost of the system is $238,000 ($294,000-$56,000).
- The system will provide 685 million Btu per 9 month school year (summer occupancy not anticipated). Assuming an exchange efficiency of 70%, 980 million Btu of steam would be required to provide the same amount of hot water. At $8 per million Btu of steam, the annual saving would be $7,840.

-85-
EXHIBIT B
Case Exhibit Corrections
7.2 SYSTEMS CRITERIA

7.2.1 Energy Conservation, and Facilities Management System

Energy Conservation (ENCON)

One of the major concerns in the design of the project is the conservation of energy because of its impact on the total cost of building ownership over its useful life. Since we have recently emerged from an era of low energy costs, and are entering an era where they will likely increase to even higher levels than the present, designs which have been economically desirable in the past will no longer be either economical or desirable. At a time when design concepts and new technology are changing in response to these new conditions, greater attention to the economic implications of a design will be required, than has been general practice in the past.

With current interest in energy conservation and in alternate sources for energy, the design of a building for an institution such as M.I.T. will come under close scrutiny. Attention can be anticipated from those within the various departments of the Institute as well as those outside. Studies made during the design stages must provide a reasonable basis for justifying alternate courses of action for energy conservation. Reasonable alternatives should be treated sufficiently so that the reasons for those which are not adopted are established.

ENCON Economic Analysis

The economic analysis of program alternatives should be geared to the objective of minimizing the present value of construction costs and of operating costs over a 40 year useful lifetime. The economic analysis should facilitate the comparison of alternate means of achieving various objectives. Assumed values for the future cost of energy and other variables should be developed in consultation with M.I.T., utilizing the best available information. Analysis should be carried out with a range of assumed values whenever appropriate because of uncertainties, to indicate the economic impact of these uncertainties on program alternatives. Some requirements for financial analysis are required by the building code of the Commonwealth of Massachusetts and by ASHRAE Energy Conservation Standard 90-75 as cited below.

Energy Conservation Standards

The ultimate objective of efforts in energy conservation is set forth in the requirement that the present value of construction and operating costs over a 40 year economic life be minimized. As a guide in achieving this objective, various requirements and suggestions are presented throughout the program plan in the various sections to which they are applicable.

As an overall guide, M.I.T. expects the architect and engineers to abide by the standards and procedures set forth in ASHRAE Energy Conservation Standard 90-75. However, it is recognized that there may be desirable technological innovations which were not anticipated by the ASHRAE standard. In such cases, we encourage a departure from the ASHRAE and other standards when they are economically justified. An important part of the ASHRAE Standard is the development of an energy budget for a building and the development of systems that meet building user requirements within that budget.

The Commonwealth of Massachusetts is in the process of revising portions of its Building Code in areas that pertain to energy conservation. Other relevant codes, design guidelines, etc., may receive energy conservation revisions before this facility is built. It is, therefore, very important that latest system design requirements be used all during the design process. If it appears that there are requirements set forth in the latest codes, etc., that impair the attainment of energy conservation goals, consideration should be given to designing systems readily capable of modification in anticipation of subsequent modification of such requirements.

It is proposed that the possible division of the HVAC system into subsystems serving areas with common environmental requirements and/or hours of occupancy be considered. The arrangement of space to facilitate such an HVAC system sub-division should be considered when practical.

If alternate energy sources (e.g. solar energy) and/or technical innovations appear attractive from a technical viewpoint, the building design should foster these innovations and reduce the cost of their implementation to the degree compatible with other considerations.

The functional requirements of the building and site characteristics will dictate many aspects of its configuration, construction, and the arrangement of space. However, to the extent that it is economical and compatible with these requirements, design features should minimize the energy required to maintain comfortable environmental conditions and otherwise enhance energy conservation. The design of the static (non mechanical-electrical energy consuming) portions of the facility is as critical to ENCON in conserving energy as the efficient control of systems. This includes energy efficiency circulation patterns, building heights, surface area, enclosed volume ratios as well as insulation factors, sun control and use of natural light and ventilation. Adequate physical barriers should be provided whenever practical between areas with different environmental requirements. Locations for such barriers might be located between an exterior door and a reception area, or between a room containing steam pipes and adjacent occupied space.
( exhibit - 5 - ) NEXT HOUSE ROOF PLAN & SOLAR COLLECTOR DETAIL
Next House - Axonometric View from N.E. Dr.
South - East Facades
## GMP BUDGET
20 February 1980

<table>
<thead>
<tr>
<th></th>
<th>Building 1 Cost</th>
<th>A/E 2</th>
<th>Development 3 Fund</th>
<th>J/V 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE BUILDING COST</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Roofing and Flashing&quot;</td>
<td>7,917,300</td>
<td>422,500</td>
<td>164,670</td>
<td>30,000</td>
<td>8,542,470</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ADD ALTERNATIVES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Active Solar</td>
<td>271,000</td>
<td>25,000</td>
<td>8,000</td>
<td></td>
<td>-294,000</td>
</tr>
<tr>
<td>(roofscape treatment included @ $56,000)</td>
<td></td>
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<tr>
<td>2. Passive Solar</td>
<td>31,500</td>
<td>3,500</td>
<td>1,000</td>
<td></td>
<td>36,000</td>
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<tr>
<td>3. Energy Insulation</td>
<td>11,000</td>
<td>660</td>
<td>330</td>
<td></td>
<td>11,990</td>
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<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>DEDUCT ALTERNATES</strong></td>
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<td></td>
</tr>
<tr>
<td>1. IRMA Roof</td>
<td>-11,000</td>
<td></td>
<td></td>
<td></td>
<td>-11,000</td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td><strong>PROJECT TOTALS</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Maximum 1 + 2 + 3 + 4</td>
<td>8,230,800</td>
<td>451,660</td>
<td>174,000</td>
<td>30,000</td>
<td>8,524,460</td>
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<tr>
<td>Minimum 1 + 5</td>
<td>7,907,300</td>
<td>422,500</td>
<td>164,670</td>
<td>30,000</td>
<td>8,523,470</td>
</tr>
</tbody>
</table>

1. **Building Cost** - "the amount of the guaranteed maximum price of the construction, including the contractor's profit. Money left ... was divided at a percentage among the contractor, architect and owner." New House had been completed with funds in this account.

2. **A/E** - Architectural and Engineering fees in a lump sum.

3. **Development Fund** - "a 2% contingency fund to cover the cost of necessary design changes during construction other than those made by the owner. Anything remaining in this fund was to be split between the architect and the contractor upon completion, but overruns were the responsibility of the architect."

4. **J/V** - "covered costs of the joint venture partnership, including legal, accounting, insurance and drawing costs which are usually paid by the owner."

Ted Rhoades, "MIT Experiments With Joint Venture Contracts", American School and University, Nov. 81

(exhibit - 7 - ) GUARANTEED MAXIMUM PRICE 20 February 1980
Shooshanian Engineering

ESTIMATED HEAT LOSS
MIT - NEXT HOUSE

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>AREA</th>
<th>$\Delta T$</th>
<th>$u^1$</th>
<th>LOSS $^1$</th>
<th>$u^2$</th>
<th>LOSS $^2$</th>
<th>$u$</th>
<th>ANNUAL $^3$</th>
<th>ANNUAL $^4$</th>
<th>ENVE. LOSS $^5$</th>
<th>ANNUAL $^6$</th>
<th>INFIL $^6$</th>
<th>ANNUAL $^7$</th>
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</thead>
<tbody>
<tr>
<td>Roof (flat)</td>
<td>23,681</td>
<td>63</td>
<td>.05</td>
<td>74,595</td>
<td>.59</td>
<td>40,030</td>
<td>.07</td>
<td>24,758</td>
<td>42,098</td>
<td>.066</td>
<td>1,086</td>
<td>.040</td>
<td>1,090</td>
</tr>
<tr>
<td>Roof (skylt)</td>
<td>1,077</td>
<td>1</td>
<td>.05</td>
<td>40,030</td>
<td>.59</td>
<td>74,595</td>
<td>.07</td>
<td>24,758</td>
<td>42,098</td>
<td>.034</td>
<td>577</td>
<td>.020</td>
<td>584</td>
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<tr>
<td>SUBTOTAL</td>
<td>24,758</td>
<td>63</td>
<td>.05</td>
<td>114,625</td>
<td>.073</td>
<td>82,215</td>
<td></td>
<td></td>
<td></td>
<td>.160</td>
<td>2,714</td>
<td>.100</td>
<td>2,709</td>
</tr>
<tr>
<td>Wall</td>
<td>42,098</td>
<td>.07</td>
<td>185,500</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>.742</td>
<td>12,587</td>
<td>.840</td>
<td>23,032</td>
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<tr>
<td>Wall</td>
<td>42,098</td>
<td>.30</td>
<td>1,007,865</td>
<td>2,409</td>
<td>16,382</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.160</td>
<td>2,714</td>
<td>.100</td>
<td>2,709</td>
</tr>
<tr>
<td>Window</td>
<td>21,050</td>
<td>.62</td>
<td>822,215</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.742</td>
<td>12,587</td>
<td>.840</td>
<td>23,032</td>
</tr>
<tr>
<td>SUBTOTAL</td>
<td>63,148</td>
<td>.30</td>
<td>1,007,865</td>
<td>2,409</td>
<td>16,382</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.160</td>
<td>2,714</td>
<td>.100</td>
<td>2,709</td>
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<tr>
<td>ENVELOPE</td>
<td>87,906</td>
<td>.07</td>
<td>1,302,680</td>
<td>1,12,490</td>
<td>2,719,591</td>
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<td></td>
<td></td>
<td>.160</td>
<td>2,714</td>
<td>.100</td>
<td>2,709</td>
</tr>
<tr>
<td>Below Grade</td>
<td>64,500</td>
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<td></td>
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<tr>
<td>Infiltration</td>
<td>716,121</td>
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<tr>
<td>Ventilation</td>
<td>816,480</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SUBTOTAL</td>
<td>1,597,101</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

TOTAL BUILDING LOSSES: 2,719,591

1. Heat Loss in MBTU/hr = $A \times \Delta T \times u^1$; $u^1$ are assigned values from MASSACHUSETTS STATE BUILDING CODE, ARTICLE 21
2. Heat Loss in MBTU/hr = $A \times \Delta T \times u^2$; $u^2$ is determined by assembly design (wall assembly exhibit - A -)
3. Annual Heat Loss in MBTU = $A \times u^1 \times 24$hr x $5634$DD; DD are degree days from STATE BUILDING CODE
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5. ENVE. LOSS = % Heat Loss through Building Envelope
6. INFIL + ENVE. LOSS = % Heat Loss through Building Envelope, including Infiltration Losses
7. ASHRAE HANDBOOK OF FUNDAMENTALS, current edition; Methods of Calculation

( exhibit - 8 - ) ESTIMATED HEAT LOSS
Shooshanian Engineering Associates

**WALL U-FACTOR**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Resistance</th>
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<tbody>
<tr>
<td>1. Outside Surface</td>
<td>0.17</td>
</tr>
<tr>
<td>2. Face Brick</td>
<td>0.44</td>
</tr>
<tr>
<td>3. Air Space</td>
<td>0.50</td>
</tr>
<tr>
<td>4. 15&quot; Felt</td>
<td>0.06</td>
</tr>
<tr>
<td>5. 1¼&quot; Gyp. Wallboard</td>
<td>0.45</td>
</tr>
<tr>
<td>6. 3½&quot; Fiberglass</td>
<td>1.00</td>
</tr>
<tr>
<td>7. 1¼&quot; Gyp. Wallboard</td>
<td>0.45</td>
</tr>
<tr>
<td>8. Inside Surface</td>
<td>0.68</td>
</tr>
<tr>
<td><strong>Total Resistance</strong></td>
<td>14.15</td>
</tr>
<tr>
<td><strong>U-FACTOR</strong></td>
<td>0.077 BTUM/SQ.FT./PF (Between Joist)</td>
</tr>
</tbody>
</table>

**CHANGES IN U-FACTOR FOR ALTERNATE INSULATION**

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Revised U-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-7 Fiberglass</td>
<td>0.089</td>
</tr>
<tr>
<td>R-19 Fiberglass</td>
<td>0.045</td>
</tr>
<tr>
<td>1.8&quot; Polystyrene - 3&quot;</td>
<td>0.066</td>
</tr>
<tr>
<td>2.2&quot; Polystyrene - 3&quot;</td>
<td>0.055</td>
</tr>
<tr>
<td>3.5&quot; Polystyrene - 3&quot;</td>
<td>0.053</td>
</tr>
<tr>
<td>1.5&quot; Polyurethane - 2&quot;</td>
<td>0.064</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.046</td>
</tr>
</tbody>
</table>

**NOTE**: If R-11 insulation is retained, and 1" Polyurethane is added to air space, the U-factor could be reduced to 0.049
April 3, 1980

Memo to: Members of the Building Committee
From: W. R. Dickson
Re: Solar Heating Alternatives - Next House

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- The design team is carrying $56,000 for roof/skyline treatment should we not elect to install an active solar system. Therefore, the net additional cost of the system is $238,000 ($294,000-$56,000).

- The system will provide 685 million Btu per 9 month school year (summer occupancy not anticipated). Assuming an exchange efficiency of 70%, 980 million Btu of steam would be required to provide the same amount of hot water. At $8 per million Btu of steam, the annual saving would be $7,840.
EXHIBIT C

Student Homework
Student A

Part A: deals with roof design alternatives in a specific scenario. The 5 roofing options are analyzed, and some useful and other not-so-useful conclusions are made.

Part B: A step back and comments on some issues (not all) raised during reading or dealing with the case.
PART A
Scenario

1980 Jim Herold has to decide a roof design alternative for NEXT HOUSE. His options are framed by the design and the specifications given by H. Pochay & TCC: a built-up gravel roof. MIT's requirement is 0=0.05 for typical section of completed roof, including interior ceiling. Mass Code however asks 0=0.07 as an average of heat loss for overall roof. Herold examines both the SUR system and the new synthetic ply, as well as the PTP concept. Ken Marshall provides initial cost comparisons for 5 options (Exh 3) for Herold to decide. (This is a first narrowing down of options.)

She will play the role of a consultant to Herold at this point, with the objective of making a choice of roof design to be presented in the next meeting. It is assumed that she have no control on design change options on components other than the roof (such as walls, windows and glazing, etc.)

The options

<table>
<thead>
<tr>
<th>Conventional Membrane Position</th>
<th>Protected Membrane Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ophene</td>
<td>Ophene</td>
</tr>
<tr>
<td>Ophene</td>
<td>Ophene</td>
</tr>
<tr>
<td>Ophene</td>
<td>Ophene</td>
</tr>
<tr>
<td>Ophene</td>
<td>Ophene</td>
</tr>
</tbody>
</table>

3 basic aspects are considered to select a roof system

- Performance Comparisons
- Cost (present value)
- MIT's position (experience vs innovation, image, etc.)
- Other requirements

Performance Comparisons

<table>
<thead>
<tr>
<th>Traditional vs Inverted</th>
<th>Traditional</th>
<th>Inverted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of water vapor</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>installation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard of membrane</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>epipheny and thermal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>expansion contraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance of sub-</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>freezing temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Beckert case)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof traffic damage</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Accessibility to insula</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td></td>
<td>for repairs &amp; maint.</td>
<td></td>
</tr>
<tr>
<td>Absorption of dark</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>irradiation heat (void</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>water ponding)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. a. b. c. d. e. add up to faster degradation of traditional system due to climate & wear. Thus PTP (inverted) can be expected to have longer life and require less maintenance. Main drawback to PTP: since there is no absorption of dark irradiation (↑), water ponding may occur; furthermore, this hazard is excluded from insurance clauses.

PTP requires excellent deck.
## Cost Comparisons (Present Value)

1. **2. In the initial analysis, let's consider the maintenance costs over an expected 20-year life, which is a rule of thumb that experience has shown to be correct.**

2. **3. Replacement costs and other expenses must also be calculated. We assume that new systems and technologies will be developed over the next 20 years.**

3. **4. The length of time for which these systems are expected to last, and the amount required to maintain them, are both uncertain.**

4. **5. All price figures are presented with a 0% discount rate.**

5. **6. The decision to be made is whether to use conventional or synthetic materials.**

### Table: Multi-Plyroof vs Synthetic Ply

<table>
<thead>
<tr>
<th>Feature</th>
<th>BUR</th>
<th>Synthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Changes in moisture</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>2. Performance at subfreezing</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>3. Comfort of installation</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>4. Absorption of dark</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>5. Aesthetic quality</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>a. Mechanical resistance</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>b. Expansion due to temperature</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

### Notes:
- Many of these advantages are described as "potential," since they are not enough in the initial analysis.
- They require consideration in future work.
- The symbols used are: ↑ for better, ↓ for worse, ± for similar results.
- Ply is involved in a "naive" vulnerability to traffic.
- Traffic is mitigated.
- PLY is involved in "naive" vulnerability to traffic.
- Traffic is mitigated.
- Accelerated weather tests are questionable, and there is little of source data.

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Table 3: Life cycle cost for the first 20 years

<table>
<thead>
<tr>
<th></th>
<th>Initial Cost</th>
<th>Annual Maint. (t)</th>
<th>P.V. Maint. t=20 r=8</th>
<th>P.V. Maint. t=20 r=12</th>
<th>Total Cost t=20 r=8</th>
<th>Total Cost t=20 r=12</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100,000</td>
<td>1% = 1,000</td>
<td>9,818</td>
<td>7,469</td>
<td>109,818</td>
<td>107,469</td>
</tr>
<tr>
<td>B</td>
<td>111,125</td>
<td>1% = 1,111</td>
<td>10,908</td>
<td>8,298</td>
<td>122,033</td>
<td>119,423</td>
</tr>
<tr>
<td>C</td>
<td>123,750</td>
<td>0.4% = 495</td>
<td>4,850</td>
<td>3,696</td>
<td>128,600</td>
<td>127,440</td>
</tr>
<tr>
<td>D</td>
<td>110,000</td>
<td>1% = 1,100</td>
<td>10,800</td>
<td>8,215</td>
<td>120,800</td>
<td>118,215</td>
</tr>
<tr>
<td>E</td>
<td>112,000</td>
<td>4% = 4,480</td>
<td>43,985</td>
<td>33,462</td>
<td>155,985</td>
<td>145,462</td>
</tr>
</tbody>
</table>

a. From columns 1 and 2 we already know that system E is much more costly (both Initial Cost and Maint are higher) than D. From the previous comparison, BUR/BURPHR we know that D has better performance and potentially longer life. This info is enough to eliminate E. However, the table includes the calculations for illustrative purposes.

b. Systems B and D have very similar costs. B can possibly have better performance but lack of evidence in HTR Maintenance Dept. and lack of in-use precedents in U.S. make it a more risky option. Y suggest that D (BUR-IRRA) is a more secure choice. It is widely used in the U.S. has good performance in Boston's weather and is known and proved by HTR already. System C as well, has the disadvantages of new materials, potential long life and ease of maintenance, but no in-use precedent in the US. nor experience on the part of HTR, as well as higher cost.

c. Y suggest that a second option be offered to MIT that meets its discu to cut budget: A offers a cheaper alternative. Although having some disadvantages of B, more than 10% reduction in roof costs might be attractive to MIT from the financial point of view. With respect to image, this choice may enhance MIT's image of leader and innovator in new technologies. The latter could be exploited to develop a more secure insurance contract with the manufacturers to cover more risks. (MIT using this product with success is an image that favors the manufacturer).

d. It is important to note that the cost of roofing is only 1% of the total costs of the building. The cost differences between options A→D and D→C are approx. 10% of cost of roof. That means, approx. only 0.1% of building costs. This makes it unclear that it is worth spending that percentage in the best (more secure) roof system.

e. Early failure in the roof means a major change in life cycle cost. Instead of one replacement at the 20th year (to cover 40 years of the life of building) it will require at least two replacements, replacement being his highest
cost of life cycle after initial investment, and its Present Value much higher than the initial cost differences between systems:

\[
\text{let's assume a failure in roof A at the 10th year:} \quad (t=8)
\]

<table>
<thead>
<tr>
<th>Initial cost</th>
<th>Replacement cost 10(^{th}) year</th>
<th>PV.replace</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 100,000</td>
<td>100,000</td>
<td>76,380</td>
</tr>
</tbody>
</table>

approx differences between costs of different options: \(11,950\) (Table (8))

* The cheapest additional replacement is far more expensive than investing in the more secure solution (year off not included)

To ensure a 20yr life option is now cost effective

- It is also important to note that the comparison of costs when disc. rate = 8 and not radically altered when disc rate = 12. System C becomes relatively more expensive and System E relatively less exposure, but this does not affect the decisions already discussed.

* For next discussion

---

**Meeting the Code - U values for the roof**

According to Shooman's Eng. 1.4 if \(U = 0.05\) the heat loss of roof is above the maximum allowed by MASTE Code. Some adjustment has to be made. One option is to increase the \(U\) value of the roof. With \(U = 0.045\) \((\Delta U = 0.005)\) the code would be met. I will examine the cost implications of this option (building costs and fuel costs). Other options would be: increasing insulation of walls, reduces window area, reduces skylight, increase width of glazing, etc. I recommend that these options be examined as their cost implications be compared to the cost of changing \(U\) value of roof.

<table>
<thead>
<tr>
<th>System</th>
<th>(\Delta U)</th>
<th>Air change</th>
<th>Annual heat loss cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.005</td>
<td>0.035</td>
<td>(A \times U \times 24\times 365\times 10^8 \times 6,80 \times 10^{-8})</td>
</tr>
</tbody>
</table>

\(25,000 \times 0.005 \times 24 \times 365 \times 6,80 \times 10^{-8} = 115\)

<table>
<thead>
<tr>
<th>System</th>
<th>Initial cost</th>
<th>Maint (annual) ($)</th>
<th>PV maint. (t=20) (r=8)</th>
<th>Total cost (r=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>101,375</td>
<td>1% = 1,013</td>
<td>9,945</td>
<td>111,320</td>
</tr>
<tr>
<td>B</td>
<td>123,000</td>
<td>1% = 1,130</td>
<td>11,084</td>
<td>124,094</td>
</tr>
</tbody>
</table>

---

-102-
(6) Cost of fuel for roof with 0,045 and 0,05

<table>
<thead>
<tr>
<th>U</th>
<th>Annual loss cost</th>
<th>P.V. t=20 r=8 (Rail)</th>
<th>P.V. t=20 r=2,86 (ex. pesc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,045</td>
<td>115 x 9 = 1,035</td>
<td>10,161</td>
<td>15,600</td>
</tr>
<tr>
<td>0,05</td>
<td>115 x 10 = 1,150</td>
<td>11,280</td>
<td>17,330</td>
</tr>
</tbody>
</table>

P.V. calculated:
- Considering flat panel and r=8
- Considering escalation (5% real terms)
  r=2.86

Assumption on escalation has significant influence on cost: 50% increase in cost of fuel.

(7) Summary

a) Roof A

<table>
<thead>
<tr>
<th>Total Cost of Fuel</th>
<th>Total Cost of Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.V. t=20 r=8</td>
<td>P.V. t=20 r=2,86</td>
</tr>
<tr>
<td>U=0,05</td>
<td>109,100</td>
</tr>
<tr>
<td>U=0,045</td>
<td>111,300</td>
</tr>
</tbody>
</table>

Cost 1,500. 1,700 saving.
Changing U value for roof results in savings (260).

b) Roof B

<table>
<thead>
<tr>
<th>Total Cost of Fuel</th>
<th>Total Cost of Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.V. t=20 r=8</td>
<td>P.V. t=20 r=2,86</td>
</tr>
<tr>
<td>U=0,05</td>
<td>120,800</td>
</tr>
<tr>
<td>U=0,045</td>
<td>124,100</td>
</tr>
</tbody>
</table>

Cost 3,300. 1,700 saving.
Changing U value for roof results in costs (1,500).

If roof A is selected, it seems convenient to reduce the U value for the roof.
If roof B is selected, roof U value should be increased.

However, these values are irrelevant in the context of total costs, especially if one considers drastically on escalation assumption, and the low % of roof heat loss with respect to wall-window heat loss.
PART B

comments

The former part dealt with the selection of roof alternatives, which had to be made on a limited frame of action.

The first part—rough life cycle costing—helped in the decision making.

The second part—an initial change in materials that too much hard can sometimes be spent on non-natural issues: the 80/20 change is too subtle a conclusion in relation to total costs. Time & effort should be better put into analysing each component that could deliver more benefits.

Regarding to Building, roof has the smallest % of total costs of a typical building. From the energy point of view roofing accounts for 1% of total cost impact, compared to external cladding, for example, that accounts for 10%.

According to exhibit 8 loss of heat through walls is approx. 10 times the loss of heat through the roof. From this, it is clear that time & effort should be put into studying the wall composition.

Working within a limited frame with no knowledge of context of other components limits efficiency. In this case, (New House) the roof cannot be seen as an isolated component. The U value for the roof is interdependent with window design, skylights, walls, size of the building, orientation, etc.

Communication is vital for a more efficient decision making process.

One of the remarkable issues that emerge from the case is the potential of working in joint-venture arrangement. The close contact between SRC and TEC as well as their direct access to B. Dickson (MIT) seems to have been a major factor in the efficiency of the process, especially since there were tough time & budget constraints.

Former experience was another key factor, both in terms of design solutions and team composition: In New House project, the same team participated in a project with a similar project. This made decision making faster allowing for search of improvements in what considered wrong in New House.

On the other hand, this may constrain search for new options, if there is a working solution at hand from the former case.

Contractual arrangement is another issue raised in the case. The formula of matching reduction of costs has the risk of leading to low-cost-low-performance buildings. On the other hand, the 90% formula, leads to increase in costs.

Uncertainty and questionable reliability of data are part of the process. In this case, the synthetic ply offers potential advantages and a certain risk. How to measure risk? Guarantees on the other hand are questionable, because of their immovable exemption clauses.
Construction issues are most complex: the building is an interaction of components. One component on its own might be excellent and widely practiced, but it is in the interactions or in a too specialized maintenance that dis-functionality may creep in.

The case reveals the innumerable successive assumptions and decisions that have to be made in planning such a complex process as a building. The whole picture of options and the implications is impossible to be thoroughly fore-planned. The number of tasks, issues, responsibilities and people involved make it impossible. The process is handled by or requires a combination of both rationalization & quantification of decision options and the intuition of experience-based decisions.

The scenario I developed reveals how going deeper in the analysis of specific decisions can be useful & clarifying, and at the same time, a non-affected process where the new data does not really disbalance options.
In evaluating the major components of the roof of MIT's Next House Dormitory, it seemed most important to research the various systems and their cost advantages and disadvantages, particularly considering the life of the building as well as the building components. I have concentrated my efforts in the evaluation of the roofing system itself, taking the U-value of the insulation as a given. I have emphasized this rather than look at insulation based on the small part the roof insulation plays with respect to the building's total heat loss (3.6%), as designed and documented in Exhibit 8.

Having narrowed the field of building costs to a specific aspect, I have evaluated the five alternatives estimated by Ken Marshall, relying heavily on Griffin's book on roofing and roofing system design. I have also used Dell'Isola and Kirk's book offering Life Cycle Cost Data for some information as well as a general format for my present worth Life Cycle Cost Analysis.

The most important issue to be considered in comparing these alternatives has turned out to be maintenance. In Griffin's discussion of inverted membrane roofs (whether built-up or single-ply membranes), he cites evidence that although membrane inversion might be initially more expensive, "... a 70 to 80 percent estimated reduction in operating and maintenance costs, plus longer anticipated service lives, more than pays back the added first cost, making PMR a highly profitable long-term investment." (Griffin p.226,7)

Thus I have looked at the Life Cycle Costs of each roofing alternative, using the following information
and assumptions:
- Initial costs as estimated by Ken Marshall
- Annual maintenance costs, based on Griffin's survey of maintenance costs, at 5% of initial costs for all non-inverted membranes and 1% of initial cost for inverted systems.
- Lifetime for BURs are 15 years, based on industry standard quoted by Griffin at 5 years per ply (these alternatives are 3-ply)
- Lifetime for single-ply membrane (in this case the Carlisle EPDM or neoprene membrane) is 20 years, based on Griffin's estimated life for EPDM and Dell'Isola/Kirk's estimation of 20 yrs for butyl rubber sheet roofing, the closest alternative included in Life Cycle Cost Data
- 12% discount rate
- 2% escalation rate for maintenance costs (best approximation from Dell'Isola/Kirk's examples—written, I presume, in 1981)
- Replacement cost for membrane only with alternatives A, B, C, and D—replacement cost for E must include insulation replacement (Life Cycle Cost Data puts insulation replacement lifetime at 40 years for these types (polystyrene bead, extruded polystyrene, perlite-board etc.) with A, B, and C neither the membrane nor the insulation are adhered—both are held in place with ballast; with D the insulation isn't adhered and can be reused, but with E the membrane will be adhered to the insulation, necessitating insulation replacement alongside membrane replacement
- 40 year economic life, suggested by Bill Dickson:
  "...that the present value of construction and operating costs over a 40 year economic life be minimized."

(see next page for analysis figures)
## Present Worth Life Cycle Cost Analysis: Next House Roofing System

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposed Carlisle</td>
<td>Exposed Carlisle</td>
<td>Inverted Carlisle</td>
<td>Exposed Built-up</td>
<td>Inverted Built-up</td>
</tr>
<tr>
<td></td>
<td>20 yr lifetime</td>
<td>20 yr lifetime</td>
<td>20 yr lifetime</td>
<td>15 yr lifetime</td>
<td>15 yr lifetime</td>
</tr>
<tr>
<td><strong>Initial Costs (from Marshall)</strong></td>
<td>$100,000.</td>
<td>$111,125.</td>
<td>$123,750.</td>
<td>$110,000.</td>
<td>$112,500.</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12% discount</td>
<td>@5%</td>
<td>@5%</td>
<td>@1%</td>
<td>@1%</td>
<td>@5%</td>
</tr>
<tr>
<td>2% escalation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWA 9.958, TOTAL</td>
<td>$89,790.</td>
<td>$55,326.</td>
<td>$12,318.</td>
<td>$10,953.</td>
<td>$56,013.</td>
</tr>
<tr>
<td><strong>Replacement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yr. PW factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 .103667</td>
<td>$9,589.</td>
<td>$9,641.</td>
<td>[$2,645.</td>
<td>$3,755.</td>
<td></td>
</tr>
<tr>
<td>30 .033379</td>
<td></td>
<td></td>
<td>$2,645.</td>
<td>$3,755.</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL LCC COSTS</strong></td>
<td>$159,731.</td>
<td>$176,040.</td>
<td>$145,709.</td>
<td>$138,076.</td>
<td>$192,821.</td>
</tr>
</tbody>
</table>

*A Note on this process:

The LCC analysis presented here is, at best, the product of a few hard figures and a great deal of surmise, albeit educated surmise. As everyone well knows, the lack of reliable and complete lifetime estimations is the major hindrance to accuracy. I found conflicting information in many cases, but tried to establish some degree of consistency in relying largely on one source (Griffin) rather than taking a bit of data here, a bit there, etc.
The LCC analysis indicates that option D is the best long-term choice. Although this option is $10,000 more in initial costs compared to the cheapest alternative A, it yields a 40 year LCC savings of $20,655 over the same alternate A.

To further support this choice, Griffin suggests that some additional savings might be realized due to a predicted longer life of membranes protected by insulation. These predictions were not figured into replacement costs because of the lack of empirical data to support improved membrane lifetime with PIR.

It is important, however, to include the following in roofing specifications for Alternative D:

--employ only fiberglass felts for the built-up bituminous PMR membrane

--utilize a non-shingled, separate layer waterproofing pattern for felts in the BUR PMR membrane, and ensure good interply mopping adhesion

--design loose aggregate (ballast) size to resist wind uplift and scour, and utilize concrete pavers in high wind areas or along exposed roof perimeter

--include a filter-separator fabric between loose aggregate surfacing and surface of insulation to prevent penetration of insulation by ballast aggregate

Also note that, due to moisture penetration of the insulation, a 10% reduction in the estimated "r" value of insulation will change "U" value of current design of roof to .055.

In reference to the attractiveness of the Carlisle single-ply system because of the ease and rapidity of installation, etc., it should be recognized that the inverted single-ply alternative C was second runner in the LCC analysis, coming in at $145,709. for the 40 yr. life (present worth). While this is only $7633. above...
option D's $138,076., the initial cost of C is $13,750. more than the favored alternative D. The additional expense, both initial and lifetime, of the inverted Carlisle alternative might be considered if the roof were a factor in the building's critical path of construction, or if the speed of construction was a major factor. Likewise, the Carlisle system might be attractive in terms of weather problems during installation (the Carlisle system is not substantially affected by poor weather as is a BUR- moisture build-up between felt layers during installation can result in blistering and poor adhesion.) However, I suspect that, knowing Bill Dickson's apparent prediction for BURs and traditional methods and materials in general, the MIT contingent would opt for the inverted BUR (in spite of the possible vulnerability to weather etc.) Their total familiarity with maintenance and installation would serve to augment the winning argument of Life Cycle Costs.

Fitting the specific information from the roofing system alternative analysis into the larger picture of building costs and the GMP as suggested by Exhibit 7 is difficult, because the figure of $164,000. quoted for roofing and flashing either includes something I am not aware of (like skylights?...) or is an early over-estimation to begin with. (This assumes that Marshall's rough quotes include flashing - "with the area take-off on the roof plan and an estimate of roof penetrations...")

If I were Jim Herold, I would present option D, the inverted BUR system as the best, most cost-effective roof system among the alternates considered, support my suggestion with the LCC analysis, and move on to design alternatives for the roofscape.
EXHIBIT D

Questionnaire
April 23, 1984
Introduction to Building Economics

Please answer the following questions with reference to the
"Dormitory _ Next House - 500 Memorial Drive" class assignment.

Which case did you address?
___ System - Roof Design Alternatives
___ Component - Roof Insulation "U" Value Specification

Did you go to see
___ Ranko Bon? (number of times________)
___ Jackie McBride (number of times________)

At what point in your work did you ask questions?
___ before reading the case
___ after reading the case, but before defining the assignment
___ after defining the assignment and selecting your approach
___ after finishing the assignment
___ other, please state-

Did you think the case text and exhibits gave
___ too much information?
___ the appropriate amount of information?
___ too little information?

Did you ask for clarification of the
___ text?
___ exhibits? (exhibit number________)
___ assignment in general?

Did you use additional reading material?
___ yes
___ no

List sources and note if each was (H)elpful, (S)omewhat helpful,
(N)ot helpful:

Title/Topic

 Did you work in a group?
___ yes - was this helpful?
___ no - do you think it would have been helpful?

Have you used cases in other classes?
___ yes
___ no

What suggestions do you have for modification of the case as written?
please use other side

Thank you for your input.

Jackie

-112-
QUESTIONNAIRE TALLY

Total Number of Students 44
Received questionnaire 39
Returned questionnaire 12
Commented 8

April 23, 1984
Introduction to Building Economics

Please answer the following questions with reference to the
"Dormitory _ Next House - 500 Memorial Drive" class assignment.

Which case did you address?
7 System - Roof Design Alternatives
3 Component - Roof Insulation "U" Value Specification
3 Both

Did you go to see
5 Ranko Bon? (number of times_________)
10 Jackie McBride (number of times_________)

At what point in your work did you ask questions?
1 before reading the case
12 after reading the case, but before defining the assignment
8 after defining the assignment and selecting your approach
6 __ after finishing the assignment
其他，请说明

Did you think the case text and exhibits gave
2 too much information?
5 the appropriate amount of information?
6 too little information?

Did you ask for clarification of the
6 text?
7 exhibits? (exhibit number_________)
10 assignment in general?

Did you use additional reading material?
12 yes
1 no
List sources and note if each was (H)elpful, (S)omewhat helpful, (N)ot helpful:

Title/Topic

H SN

1. Life Cycle Costing for Design Professionals, Dell'Isola & Lirk (assigned homework reading)
2. Life Cycle Cost Data, Dell'Isola & Lirk
3. Manual for Built-Up Roofs, Griffin
4. Economic principles, Stone
5. "Sweets Manuals: Properties of Products"
6. ASHRAE
7. ENR
8. Massachusetts State Building Code
10. Dwelling House Construction, Dietz
12. Means cost Data
13. Corporate Finance, Mayer

Did you work in a group?
- yes
- no

- "debating the issues"
- "absolutely"
- "to a point"

- do you think it would have been helpful?
- "perhaps, but normally one gets more confused"

- yes
- no

"met with some people to get an idea of the case, but afterwards worked by myself"

Have you used cases in other classes?
- yes
- no

What suggestions do you have for modification of the case as written?

some comments are included in the text
EXHIBIT E

Modified Case, "Dormitory - Next House - 500 Memorial Drive"
INTRODUCTION

Jim Herold, Project Manager in the architectural firm Sert Jackson and Associates (SJA), was responsible for the MIT dormitory project provisionally called Next House. Under the leadership of Design Partner Josep Lluis Sert and Partner Huson Jackson, Jim Herold and the other members of the design team were finalizing design decisions and bringing contract documents to the required 75 percent completion stage. It was late March 1980 and they had been working on this project since July 1979. At the same time, the firm's joint venture partner, Turner Construction Company (TCC), was taking bids on design and material alternatives and negotiating with potential subcontractors. The partners had formed a joint venture and were working under a design/build contract. Within MIT, the Physical Plant Department staff, with Bill Dickson as Director, was making design and economic decisions about the dorm as well. They reviewed the design and budget proposals of the Joint Venture and consulted other MIT offices and departments when appropriate for the project.

The project had to be completed by mid-August 1981, to be ready for the students arriving for the fall semester. Construction was scheduled to begin in April 1980, a month away. The Joint Venture and MIT were negotiating to finalize major decisions affecting the Guaranteed Maximum Price (GMP) and the construction schedule. At the next meeting issues relating to the roof would be resolved.

New House & Next House

A brief review of the history of the project begins in June 1979, MIT contacted Huson Jackson to initiate construction of the new undergraduate dormitory building to alleviate overcrowding in the Institute's dorms. The West Campus site had been designated in the 1960 MIT Master Plan. It was adjacent to New House (exhibit -1-), an undergraduate dormitory constructed during 1974-1976 by SJA and TCC also in a joint venture. The new dorm, Next House, was under time and budget constraints similar to those surrounding New House. The very tight schedule allowed only two years for design and construction. The joint venture arrangement had been
initiated for New House with the intent of a shorter construction period and greater control by MIT of design and budget decisions. The architect and contractor worked on design and bidding at the same time, overlapping the design and construction phases. The use of fast tracking considerably shortened the building process.

Program and Preliminary Specifications

A Group/Client Team composed of faculty, students, and administration representatives had developed a program during the Fall of 1978 to be used in the next dorm. It reflected the present concepts of dormitory living and was different from New House, which had a program of house clusters. Next House program returned to a traditional dormitory concept, like that of Baker House, designed by Alvar Aalto. Harry Portnoy, the Campus Architect, was responsible for the coordination of the project within MIT and between MIT and the Joint Venture. He prepared the project schedule, directed the preparation of the budget and preliminary specifications, and coordinated the work of the architect and contractor through his office. In July 1979, Harry Portnoy delivered the Preliminary Specifications, which included the program prepared by the Group/Client Team, to SJA. Preliminary Specifications are prepared by MIT for each project and are based on the collective experiences of the specialists within the Physical Plant Department, responsible for the construction and maintenance of all MIT buildings. They are intended to serve as guidelines for the architect, not as requirements. Next House would be different from the first dorm in terms of the program, but would be constructed with similar materials and detailing. The decision to use a "redesign" approach, to acknowledge and fully utilize the shared knowledge gained in the construction of New House, was made very early by MIT. The Joint Venture was agreeable to this as well. Many of the people working on Next House had been involved in the first project and knew each other. Jim Herold had been job captain on the New House design team. John Betts was the estimator at TCC for project. Harry Portnoy was the Campus Architect for both, but in New House he was part of the Planning Department and for Next House he was with the Physical Plant Department. For Jim Herold, using experience from New House meant that the many design and detailing decisions were narrowed to a manageable number of alternatives. He could devote more attention to other design issues, such as solar energy concerns. Both MIT and the Joint Venture made their preliminary budgets based on the costs from New House with factors to adjust for inflation and anticipated differences in construction costs due to the changed program.

Energy and Economics

The Joint Venture investigated the economics of many design, construction, and equipment alternatives. These ranged from expenditures for solar energy applications with significant implications to the base price to specially selected gravel for the low roof over the kitchen area visible from the upper floors. MIT established the basic parameters for investigative analysis in the Preliminary Specifications Section "Energy Conservation, and Facilities Management Systems". (exhibit - 2 - ) The emphasis on determining appropriate solutions was stated:
"The ultimate objective of efforts in energy conservation is set forth in the requirement that the present value of construction and operating costs over a 40 year economic life be minimized." [Preliminary Specifications, Next House - July 1979]

The Institute took an active part in the allocation of resources with the Joint Venture. Throughout the bidding procedure open channels of communication were maintained to facilitate decisions on trade-offs that had to be made. Jim Herold felt that sharing information as much as possible at critical decision points made the issues "transparent".

"The more [...] contractors, architects, and owners [...] get together and understand what the others are really thinking about, [the more] we begin to understand that there are kinds of hidden costs that affect the contractor that don't bother us one way or the other. [...] On the other hand, we have things we care very much about, and are small change to them. They begin to understand what matters to us and we see where it hurts them, particularly with respect to the time frame for the contractor and maintenance for the owner. [Jim Herold]

Trade-offs could thus be made in some systematic fashion. Jim Herold kept himself informed about the economic aspects of design decisions, which allowed him to strike a balance between design requirements and budget constraints. The Joint Venture was working with a sophisticated client, one that was a major force in the market of the Boston area. MIT had built extensively and knew what they wanted in a well-designed building. The Joint Venture had to prepare the GMP, the contract sum they guaranteed not to exceed in constructing the dormitory. There was an incentive to continue to reduce costs even after the acceptance of the GMP because the contract provided for MIT and the Joint Venture to share any savings during construction. As Ted Rhoades of TCC stated:

"The arrangement worked well because the incentive reinforced the team approach to construction. [...] Neither party has control over the other. It is a collaboration of mutual respect, with a thorough dialogue between professionals and with the owner. Cost control never takes precedence over design quality and vice versa; the two factors together find the best solution." [Ted Rhoades] (1)

Roof Design Issues

Jim Herold worked closely with Sert throughout the design of both dorms. In Next House he was in a position to work with TCC, as well. He was responsible for the production of the project, maintaining the design concepts developed by the design team, led by Sert, and keeping the design within the budget determined by the Joint Venture. He considered the dynamics of his relationships with Sert and TCC an important part of the

"creative tension" required for excellence in building. He had to make difficult decisions when budget and design issues were in conflict. He had to be knowledgeable about all aspects of the building in great detail. He had to present his decisions clearly to the firm’s partner and their client.

The next project meeting was in two weeks. Although there were many issues on the agenda, Jim Herold spent some time making decisions about the roof design. These were:

1. System - Roof Design Alternatives
2. Component - Roof Insulation "U" Value Specification
3. Building - Roofscape Design

The roof system (1) selection needed to be analyzed from an economic point of view. A related decision of one component (2), the insulation had been made during the previous Fall as part of an energy conservation strategy study. The third issue was one of that affected the overall building (3) design. The decisions regarding the building components were made incrementally as more and more detail was needed for each phase of the design and budget process.

(1) SYSTEM - ROOF DESIGN ALTERNATIVES

Jim Herold had proceeded with the design of Next House using the system design provided in the specification from Harry Portnoy’s office. TCC had carried a value for "Roofing and Flashing" in each budget for a roof system described as follows:

"Roof: MIT basic roofing specification is a 5-ply built-up, tar and gravel roof. [...] "U" value for roof system, including roof, insulation, deck and ceiling shall be no more than .050"

[Preliminary Specifications, Next House - July 1979]

More specific information was needed by the Joint Venture to negotiate contracts with subcontractors and complete the GMP. Jim Herold agreed to research alternative roof systems. The roof is a complex system of interrelated parts and not a simple layering of independent materials. The designer needs to be aware of the implications of their relationships. Change in one component may lead to unpredicted ramifications for the system as a whole. Too much insulation, for instance, may cause thermal shock.

At the start of Next House Jim Herold retrieved the New House files from storage to keep by his desk for reference. He refreshed his memory. On New House two roof types were used - a standard built-up roof (BUR) for the main roof and an inverted roof membrane assembly (IRMA, also called protected membrane roof, PMR) for the terrace areas. Most MIT roofs were the conventional BUR type. The New House installation was a test for MIT. The Physical Plant Department personnel were experienced in BUR routine maintenance and minor repair. For the first time they installed a BUR
system with the insulation above the membrane, which was a variation of a standard BUR system. The roofing industry had been developing new products and roofing systems for a number of years. IRMA was developed after roof membrane failures in epidemic numbers, particularly in New England, were attributed to thermal shock. After the Oil Crisis in 1973/1974, the long tradition of placing the roof membrane directly on the deck, with very little or no insulation, was varied by placing insulation layers between the membrane and the tempered building interior. This resulted in increased roof temperatures and premature roof failure in extreme cases. In an IRMA installation, the roof membrane is protected from temperature changes and wear by the insulation and ballast. The terraces of New House were potentially vulnerable to user traffic and were consequently covered with pavers. After several winter seasons, MIT had been generally pleased with the performance of the IRMA roof. The alternatives to the BUR were synthetic single-ply roof systems, long in use in Europe, but were still regarded by many in the U.S. as experimental. However, the systems were gaining popularity among roofers because they were more easily installed, could go down in more extreme weather conditions, and were less hazardous to the workmen. Bill Dickson, recognized by the roofing industry as an expert in roof installation and maintenance, preferred BUR's to the new single-ply systems.

"I have always felt that [...] properly put down, a built-up roof will give you much service. [...] The Institute is careful not to fool around with any new systems. [...] The manufacturer may claim a thirty year life for their product, but their roofs may have only been in service for four years." [Bill Dickson]

Throughout the design development and bidding process, Jim Herold worked closely with John Betts to make the most cost effective decisions without sacrificing design intent. For the current investigation, John Betts referred him to Ken Marshall of Federal Roofing, an experienced firm bidding the job. Federal Roofing had been the roofing subcontractors on New House and Ken Marshall had been Project Manager. With the area take-off on the roof plan (exhibit -5-) and an estimate of roof penetrations, Ken Marshall was able to provide cost estimates for comparisons of five systems - three with single-ply and two with built-up membranes. (exhibit -3-) The prices were based on 250 squares and included "base flashing, drains, also coping". [Jim Herold's Notebook] Jim Herold evaluated the five systems. Since MIT was anxious to cut the budget and there was a growing trend among roofers to use the more easily installed single-ply roofs, he felt that it was important to investigate and propose viable alternatives to MIT. The building budget was a working document that was changing at each meeting as decisions were made. The current base building price (1) was $7,919,300. The Architect and Engineering fees were a lump sum of $400,000. The

(1) Building Cost - "the amount of the guaranteed maximum price of the construction, including the contractor's profit. Money left [...] was divided at a percentage among the contractor, architect, and owner." New House had been completed with funds in this account.
Development Fund was $230,000 (1) and the Joint Venture (2) was $30,000.

(2) COMPONENT - ROOF INSULATION "U" VALUE SPECIFICATION

Jim Herold placed emphasis on saving energy, both through the building design and equipment selections. He conducted three separate investigations. One was focused on alternative energy conservation strategies that could be obtained through the design of the building envelope. At this time he considered options of increasing or decreasing the amount of insulation planned for the roof. The base insulation was that noted in the Preliminary Specifications. His concern was in keeping with the MIT directive, which stated that:

"One of the major concerns in the design of the project is the conservation of energy because of its impact on the total cost of building ownership over its useful life. Since we have recently emerged from an era where they will likely increase to even higher levels than the present, designs which have been economically desirable in the past will no longer be either economical or desirable. At the time when design concepts and technology are changing, in response to these new conditions, more attention to the economic implications of a design will be required, than has been the general practice in the past." [Preliminary Specifications - July 1979, p.126]

Many roof experts considered increasing the thermal transmission value of roof insulation to be cost effective. Jim Herold considered the impact of increasing and decreasing the thermal transmission of the roof insulation on the amount of money spent for fuel.

"Thermal insulation in an air-conditioned or merely heated building offers the greatest return on initial investment of any building material. In view of prospects of energy costs escalating 10 to 15 percent annually far into the foreseeable future, substantial thermal insulation is indispensable for occupied buildings." [Manual for Built-up Roof Systems, 2nd Edition, C.W... Griffin, p.53 McGraw-Hill, 1982]

(1) Development Fund - "contingency to cover the cost of necessary design changes during construction other than those made by the owner. Anything remaining in this fund was to be split between the architect and the contractor upon completion, but overruns were the responsibility of the architect."

(2) Joint Venture - "covered costs of the joint venture partnership, including legal, accounting insurance and drawing costs which are usually paid by the owner." [Ted Rhoades, "MIT Experiments With Joint Venture Contracts", American School and University, November 81]
In September 1979, Shooshanian Engineering had been contracted as engineering consultant by SJA. Joe Fullam was the Project Manager. For Next House Jim Herold outlined their responsibilities in a letter to Harry Portnoy:

"(1) set criteria; (2) prepare schematic designs and energy conservation analysis; (3) review design development and construction documents; (4) review and approve shop drawings; and (5) perform other normal services during construction." [Jim Herold to Harry Portnoy, 10 September 1979]

The mechanical, electrical, HVAC, and fire equipment subcontractors were to be the engineers of record, which had been the arrangement in New House. Shooshanian was to provide information and opinions to inform the decisions made by the Joint Venture and MIT. Although their practice did not generally undertake projects which would be bid to design/build subcontractors, they agreed to undertake Next House.

Fullam prepared an analysis (exhibit - 3 - ) of the estimated heat loss from the preliminary drawings and area take-offs provided by Jim Herold. The base envelope design was the same as that for New House. The ball park energy usage and energy costs derived from standard engineering calculation methods were made to compare alternatives. Methods of estimating energy use are simple in a building which is only heated. The information required includes data from the physical characteristics of the building and regional data from the preliminary building design provided by the Massachusetts Energy Building Code, "Article 20", adopted since the completion of New House. More accurate calculations would require final building characteristics (for example, tightness of construction, orientation and size of glazing, and weather data), as well as information on the use and management of the building (for example, temperature settings, scheduling, and internal heat gains). The amount of heat loss through the roof was required by code not to exceed 109,185 BTU's, as shown on the following table, unless alternative provisions were made in the wall assembly to maintain an overall total building loss.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>AREA SF</th>
<th>U(1) LOSS(1)</th>
<th>U(2) LOSS(2)</th>
</tr>
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<tr>
<td>Envelope Losses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof (flat)</td>
<td>23,681</td>
<td>.07</td>
<td>.05 74,595</td>
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<tr>
<td>Roof (skylt)</td>
<td>1,077</td>
<td>.59</td>
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<td>Window</td>
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<td>.62</td>
<td>822,215</td>
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<tr>
<td>Subtotal</td>
<td>63,148</td>
<td>.30 1,193,495</td>
<td>1,007,865</td>
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<tr>
<td>Envelope Total</td>
<td>87,906</td>
<td>1,302,680</td>
<td>1,112,490</td>
</tr>
</tbody>
</table>

-122-
Below Grade Infiltration Ventilation Subtotal

64,500 716,121 816,480 1,597,101

TOTAL BUILDING LOSSES 2,719,591

(1) Heat Loss in BTU/hr = A x x U; T = 63 deg F, both T and U are assigned from the building code
(2) Heat Loss in BTU/hr = A x x U; T = 63 deg F, both T is assigned value from building code; U is design value determined from assembly design
(3) Joe Fullam also calculated the Annual Heat Loss using the Degree Day Method from ASHRAE; A x U x 24(hr) x 5634(DD) = MBTU; DD value is assigned by the building code. See (exhibits - 7&8 - )

Based on Joe Fullam's energy analysis, the Joint Venture and MIT decided to increase the R value of the wall assembly from R = 11 to R = 19 by placing a 1" sheet of rigid insulation in the wall cavity.

The MIT Preliminary Specifications required a "U" value of .05 calculated by ASHRAE (American Association of Heating Refrigerating and Air-Conditioning Engineers, Inc.) methods for the roof assembly at a typical section through the roof. The Energy Code required a "U" value of .07, calculated as an average of the heat losses for the overall roof. The average included penetrations for skylights and the elevator shaft, that is, places where no insulation would be installed. It did not include a value for the clerestory windows, which are accounted for under the wall and window area calculations. The "U" value of the roof of the clerestories, constructed of steel studs with batt insulation, would be 0.05. Joe Fullam prepared calculations to compare changing the "U" values of the roof and wall assemblies, as well as the glazing area. He calculated estimated fuel savings assuming costs for fuel of $6.80 and 7.20 per million BTU. John Betts provided relative square foot costs of each choice investigated. Based on this analysis the Joint Venture proposed an increase in the wall assembly insulation from R = 9 to R = 11, among other energy conservation measures. They did not propose a change in the roof. The Contract Specification Section, "Roofing and Flashing" would read:

"Thickness of insulation shall be such that the completed roof construction including interior ceiling finish will produce a "U" value of 0.05"

At this time roof insulation prices ranged from $.55 to $1.23 per square foot for the least expensive beadboard to the most expensive Styrofoam RM type manufactured by Dow. The life of a roof was considered 20 years under normal conditions.

(3) BUILDING - ROOFSCAPE DESIGN
The emphasis on energy, not only by MIT, but the nation, in the wake of the Oil Crisis, led SJA to propose an investigation of active and passive solar applications for energy savings. The design team had decided at the initial stages of the project to heed well-known strategies of siting and manipulation of glazing to wall area ratios. They had recent experience in the application of an active solar system. A recent project had included an active domestic water heating system, which was cost effective and had been successfully incorporated into the design. One of Sert’s design directives was the constant search for new forms to "keep architecture fresh" [Jim Herold]. He was not interested in merely 'taking "something technological off the line" [Jim Herold] and applying it directly. He looked at technological advances, such as energy hardware, for their potential in architectural expression. These solar studies were in addition to the ongoing investigation of energy conservation measures.

Two studies were initiated, one on the use of passive systems by Solar Design Associates and one on active solar collector systems by Shooshanian Engineering.

Steve Strong of Solar Design Associates investigated passive solar applications for space heating. He developed several strategies for passive space heating in the dormitory rooms, the dining area, and the Headmaster’s apartment. The resulting design requirements were welcomed by the architect as appropriate for integration into the design. The proposals for the student rooms required students to adjust blinds and drapes and to operate windows to control the temperature. Students are not normally in their rooms in the daytime and are often away for weekends and vacations. The Institute would therefore have to provide a conventional back-up heating system in order to guarantee adequate comfort levels. Because of this, one of the benefits often associated with solar gain, the reduction of mechanical equipment costs, could not be realized with the passive strategies. Another economic benefit typically gained in solar installations, a tax credit, was also not available to MIT as a non-profit institution. MIT decided to accept the proposals, which they considered consistent with their program. The benefits of utilizing solar strategies were considered to be worth the costs.

Joe Fullam investigated the application of an active solar collector system for both space and domestic water heating. An early hand calculation showed that space heating would require more square footage of collector area than the roof could support. This limited the study to domestic water heating. He proposed two alternative active collector systems, one using a flat plate collector and one using a parabolic tracking type. The choice was made to use the flat plate collector. Joe Fullam designed a system, which was incorporated into the design of the roofscape. (exhibit -6-) TCC priced the system and design as a deduct alternate item for the GMP.

The three separate studies on energy strategies had been completed in November. A report dated November 9, 1979 was sent to MIT for their own analysis. MIT’s summary of the systems was outlined in a memo from Bill Dickson to the Building Committee on April 3, 1980. (exhibit -9-) Their decision was noted by Harry Portnoy, "active no", "passive yes"." In typical installations of solar collectors on flat roofs, the collectors are
placed on metal frames, which the design team and the owner considered too flimsy for this project, both structurally and in appearance. Masonry supports were designed. In Next House the space under the collector was seen as an opportunity to let light into the floor below. Clerestory windows were designed to let daylight into the corridors. MIT had requested that any daylighting be for public spaces. The roof structure was a two-way slab system, selected in part for its flexibility in accommodating the anticipated roof penetrations. The openings could be located late in the design, although additional beams were required at each penetration to take the additional loading of the skylights and collectors. Storage for the heated water was also required, for which tanks in the basement were included in the deduct price prepared by the Joint Venture.

New House had been designed with clerestory windows in each stairwell. (exhibit -1-) An early design decision was made in Next House to use a similar strategy to animate the roofscape, visible from across the Charles River. The solar collectors expressed the use of modern technology at an institution synonymous with technology. But they were expensive. In addition, the active solar industry was perceived to be in its infancy, which meant that rapid advances would soon outdate this installation. Also the anticipated life span of the collectors was much less than that of the masonry construction designed to support it, which might look out of place once the collectors were no longer in use.

At this point, MIT’s target budget was exceeded by the GMP. Money, time, thought, and design had been invested in the solar collectors and the passive solar solutions for Next House. Jim Herold had been aware of the economic analysis of the active system and was not surprised at MIT’s decision to eliminate the active part of the solar strategies for the project. He had anticipated investigating the design of the roofscape without the collectors. The design would have to meet the following criteria:

1. not exceed $56,000 carried in the GMP
2. not exceed estimated heat loss
3. contribute to the quality of the space on the fifth floor
4. relate to the design of New House
5. animate the roofscape; and to
6. include one stairway to the roof, a requirement recently stated by MIT

He prepared an alternative design concept for the roofscape presentation to MIT at the next meeting.
NEW HOUSE
7.2 SYSTEMS CRITERIA

7.2.1 Energy Conservation, and Facilities Management System

Energy Conservation (ENCON)

One of the major concerns in the design of the project is the conservation of energy because of its impact on the total cost of building ownership over its useful life. Since we have recently emerged from an era of low energy costs, and are entering an era where they will likely increase to even higher levels than the present, designs which have been economically desirable in the past will no longer be either economical or desirable. At a time when design concepts and other technology are changing in response to these new conditions, greater attention to the economic implications of a design will be required, than has been general practice in the past.

With current interest in energy conservation and in alternate sources for energy, the design of a building for an institution such as M.I.T. will come under close scrutiny. Attention can be anticipated from those within the various departments of the Institute as well as those outside. Studies made during the design stages must provide a reasonable basis for justifying alternate courses of action for energy conservation. Reasonable alternatives should be treated sufficiently so that the reasons for those which are not adopted are established.

ENCON Economic Analysis

The economic analysis of program alternatives should be geared to the objective of minimizing the present value of construction costs and of operating costs over a 40 year useful lifetime. The economic analysis should facilitate the comparison of alternate means of achieving various objectives. Assumed values for the future cost of energy and other variables should be developed in consultation with M.I.T., utilizing the best available information. Analysis should be carried out with a range of assumed values whenever appropriate because of uncertainties, to indicate the economic impact of these uncertainties on program alternatives. Some requirements for financial analysis are required by the building code of the Commonwealth of Massachusetts and by ASHRAE Energy Conservation Standard 90-75 as cited below.

Energy Conservation Standards

The ultimate objective of efforts in energy conservation is set forth in the requirement that the present value of construction and operating costs over a 40 year economic life be minimized. As a guide in achieving this objective, various requirements and suggestions are presented throughout the program plan in the various sections to which they are applicable.

As an overall guide, M.I.T. expects the architect and engineers to abide by the standards and procedures set forth in ASHRAE Energy Conservation Standard 90-75. However, it is recognized that there may be desirable technological innovations which were not anticipated by the ASHRAE standard. In such cases, we encourage a departure from the ASHRAE and other standards when they are economically justified. An important part of the ASHRAE Standard is the development of an energy budget for a building and the development of systems that meet building user requirements within that budget.

The Commonwealth of Massachusetts is in the process of revising portions of its Building Code in areas that pertain to energy conservation. Other relevant codes, design guidelines, etc., may receive energy conservation revisions before this facility is built. It is, therefore, very important that latest system design requirements be used all during the design process. If it appears that there are requirements set forth in the latest codes, etc., that impair the attainment of energy conservation goals, consideration should be given to designing systems readily capable of modification in anticipation of subsequent modification of such requirements.

It is proposed that the possible division of the HVAC system into subsystems serving areas with common environmental requirements and/or hours of occupancy be considered. The arrangement of space to facilitate such an HVAC system sub-division should be considered when practical.

If alternate energy sources (e.g. solar energy) and/or technical innovations appear attractive from a technical viewpoint, the building design should foster these innovations and reduce the cost of their implementation to the degree compatible with other considerations.

The functional requirements of the building and site characteristics will dictate many aspects of its configuration, construction, and the arrangement of space. However, to the extent that it is economical and compatible with these requirements, design features should minimize the energy required to maintain comfortable environmental conditions and otherwise enhance energy conservation.

The design of the static (non mechanical-electrical energy consuming) portions of the facility is as critical to ENCON in conserving energy as the efficient control of systems. This includes energy efficiency circulation patterns, building heights, surface area, enclosed volume ratios as well as insulation factors, sun control and use of natural light and ventilation. Adequate physical barriers should be provided whenever practical between areas with different environmental requirements. Locations for such barriers might be located between an exterior door and a reception area, or between a room containing steam pipes and adjacent occupied space.
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tr>
<td>Ken Marshall</td>
<td>Carusle 45 ml</td>
<td>Carusle</td>
<td>IRM</td>
<td>IRM</td>
<td>( 2^\circ \text{C} ) to ( 3^\circ \text{C} ) above base</td>
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<tr>
<td>&quot;Bercard&quot;</td>
<td>Dow S/M (Blue)</td>
<td>Dow RM</td>
<td>BUR (3 ply Dow RM)</td>
<td>IRM</td>
<td>1&quot; Perute</td>
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<td>( $50.00 )</td>
<td></td>
<td></td>
<td>( $95.00 )</td>
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</table>
ENVELOPE AREAS -
ROOF 23,681 sq
SKYLIGHT 1,077 sq
WALL 42,098 sq
WINDOWS 21,050 sq

CODE REQUIREMENTS -
ROOF 63 x .07 x 24,758 = 109,185
WALL 63 x .30 x 63,148 = 1,143,495
1,302,680 / 63 = 20,677
20,677 x 24 x 5634 = 2,796,000,000 BTU/YEAR MAX.

MISC. LOSSES
BELOW GRADE 64,500
INfiltration 716,121
VENTILATION 816,480

DESIGN VALUES
ROOF 63 x .05 x 23,681 = 74,595
SKYLIGHT 63 x .59 x 1,077 = 40,030
WALL 63 x .07 x 42,098 = 185,650
WINDOWS 63 x .62 x 21,050 = 822,215
1,122,490
MISC. 1,597,101
TOTAL = 2,719,591

ENVELOPE LOSSES 1,122,490 / 63 = 17,817
17,817 x 24 x 5634 = 2,409 MBTU
ENVELOPE + VENT 1,838,611 / 63 = 29,184
29,184 x 24 x 5634 = 3,946 MBTU

ENVELOPE
ROOF = .066 1,086
SKLT = .034 577
WALL = .160 2,714
WINDOW = .742 12,587

ENVELOPE + INFILTRATION
ROOF = .040 1,090
SKLT = .020 584
WALL = .100 2,709
WINDOW = .840 23,032

FUEL 6.80 MBTU
Shooshanian Engineering Associates

Subject

By

Sheet No.

--- ROOF ---

\[ \#1090 \]

\[ \#674 \]

\[ \#3709 \]

\[ \#12500 \]

\[ \#22451G1 \]

\[ CHANGE AREA OF GLASS \]

\[ \#670 - 40\]

\[ \#634 \]

\[ 73 \text{ MIL} \]

--- WALL ---

\[ \#3709 \]

\[ \#1970.01 \text{ U-FACTOR} \]

\[ 57 \text{ MIL} \]

--- GLASS ---

\[ \#218.01 \text{ U-FACTOR} \]

\[ 32 \text{ MIL} \]

--- INUL ---

\[ \#10,951 \]

\[ \#218.01 \text{ U-FACTOR} \]

\[ 57 \text{ MIL} \]

--- ESTIMATED HEAT LOSS ---

\[ \#17R \]

\[ \#17R \]

\[ \#17R \]

\[ \#5837 \]

\[ 51,701 \]

\[ 7,20 \]

\[ 7,692 \]

\[ 12,009 \]

\[ 174.6 \]

\[ 246 \]

\[ 85.9 \]

\[ 358.5 \]

\[ 1764.7 \]

\[ 3301.7 \]

\[ 1537.5 \]

\[ 1394 \]

\[ 1752.4 \]

\[ 1089 \]

\[ 594 \]

\[ 2710 \]

\[ 12,007 \]

\[ 10,452 \]

\[ 942 \]

\[ 11,916 \]

\[ 5837 \]

\[ 37,692 \]

\[ 12,009 \]

--- EXHIBIT - 8 - ---
April 3, 1980

Memo to: Members of the Building Committee
From: W. R. Dickson
Re: Solar Heating Alternatives - Next House

At the March 3, 1980 meeting of the Building Committee, insufficient data was available for the members of the committee to give guidance with respect to the possible incorporation of active and/or passive solar systems in the design of Next House.

Following is certain additional data accompanied by specific recommendations for your consideration:

Active Solar System

- 4000 square feet of solar collector surface consisting of 190 individual flat-plate collectors would be installed using an ethylene glycol solution as the heat transfer medium.

- The present value of the entire system (collectors, supports, piping, tanks, pumps, wiring, and design fees) as estimated by the design team (Sert and Turner) is $294,000.

- The present value of the 190 collectors (included above) is $70,000.

- The projected design life of the collectors recommended by the manufacturer, Daystar, is 25 years. The actual warranty is 5 years.

- The design team is carrying $56,000 for roof/skyline treatment should we not elect to install an active solar system. Therefore, the net additional cost of the system is $238,000 ($294,000-$56,000).

- The system will provide 685 million Btu per 9 month school year (summer occupancy not anticipated). Assuming an exchange efficiency of 70%, 980 million Btu of steam would be required to provide the same amount of hot water. At $8 per million Btu of steam, the annual saving would be $7,840.
NOTES FROM THE AUTHOR

The case introduces the people who were responsible for the construction of the MIT dormitory. The story describes key events leading up to their finalizing the GMP. Information available to Jim Herold, the Project Manager from the architecture firm, Sert Jackson and Associates (SJA); the contractor, Turner Construction Company (TCC); and the owner, MIT is presented. The included information relates to their decisions regarding roof design. Three aspects of the roof design are highlighted and the story stops at the point where decisions must be made. They range from very technical decisions about the roof assembly to the conceptualization of the design of the roofscape.

PROJECT HISTORY

1974- New House
1976
1978- Next House Program
June 1979- MIT Contacts SJA
July - MIT Preliminary Specifications
Sept - Energy Conservation and Solar Design Studies
Mar 1980- NOW Subcase (1)
NOW Subcase (2)
Apr 1980 GMP Scheduled
Construction Scheduled
Aug 1981- Completion Scheduled

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In general, the case is intended to demonstrate the interrelationships of decisions made at various stages in the design process, the potential complexity of an apparently straight-forward decision. Reader involvement in a situation that has occurred in architectural practice allows the technical aspects in the case to become intriguing. The reader is faced with deciding how to manage the information given. It will be too much, too little, the right amount, or apparently in conflict with personal knowledge. Nevertheless, the reader is expected to define and solve a problem. Additional information may be sought in technical books. Students unfamiliar with the case method may initially be overwhelmed at having to define what steps they will take.

In addressing the unresolved issues in the case, students use basic economic principles, the concept of life-cycle costing, and basic energy calculations. Students should be directed to selections of additional reading in accordance with their individual needs on the technical aspects of the case as well as on architectural practice.

The case is organized in four parts: Introduction, the history of the building; sub-case (1) Roof Assembly-Five Roof Alternatives; subcase (2) Component-Roof Insulation "U" Value Specification; subcase (3) Building-Roofscape Design. The subcases are interrelated and should be used in various sequencing and combinations.
Subcase (1)
The Problem - Select one roof system from the five in Exhibit 3.
The Context - The owner prefers BUR. The subcontractor can provide Carlyle more cheaply.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initial Cost</td>
<td>$100,000</td>
<td>$111,250</td>
<td>$110,000</td>
<td>$110,000</td>
<td>$112,500</td>
</tr>
<tr>
<td></td>
<td>exhibit 3 (25,00 x cost)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>values from 1/2 - 5 % from reading (Griffin)</td>
<td>least</td>
<td></td>
<td></td>
<td>most</td>
<td></td>
</tr>
<tr>
<td>3. Replacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIT Design Life 40 yrs.</td>
<td>one - two replacements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tear Down</td>
<td></td>
<td></td>
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<tr>
<td>Salvage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Recurring Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>fuel same for all with same U value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. LCC total</td>
<td>low</td>
<td></td>
<td>low</td>
<td></td>
<td>most</td>
</tr>
</tbody>
</table>

Assumptions lead to variation in the following terms,—interest rates, escalation factors and maintenance. Most students identified risk as a factor form qualitative analysis. Although there is a great variation in inputs, Choice A and D are usually the two lowest in terms of LCC. The conclusion is usually to use D because the savings is a small one relative to the GMP in view of the owner's stated preference. Many students note that the changes in the roofing industry suggest that the first re-roofing will be done with a single-ply roof.

Subcase (2)
The Problem - Review Jim Herold's decision to maintain the roof insulation at the value proposed by MIT, question his method of analysis and his choice.
The Context - The insulation component had been assigned a value from an energy conservation study. It was not changed from "U" = .05. There are three separate specifications of roof insulation, seemingly in conflict.
The Analysis - The student must select an appropriate type of analysis. Several examples are: Simple payback, Discounted payback,

Students should determine fuel escalation rates, and whether or not to include them. Heat gain was not considered by Shooshanian because the building was not air-conditioned. Students may realize that this heat gain may be important to the inhabitants of the building. Some may question the advisability of using "ball park" energy calculations - ones that do not account for scheduling of use, heat gain, etc. Potential savings from roof insulation may not be considered worth the time to do them. Prices are noted for insulation. One can determine an optimum thickness of insulation with respect to fuel use and insulation cost.

Subcase (3)

The Problem - Design the rooftscape, the part of the building above the roof deck

The Context - MIT has decided to abandon the active solar collector system proposed for the roof. The architects had incorporated the technology into the design for animation of the skyline. At this point, they had a design minus the collectors. They could leave it or revise it, or start anew, following the parameters in the case.

The Analysis - Students should consider the implications of the energy gain and loss, lighting, match with the plan feasibility of construction. Considering the budget can be only by assumptions based on an understanding of the original design (exhibits 4, 5, 6).

The Solution - Since small scale drawings are provided in the case, schematic level sketches can be expected to describe a design concept. Rough quantitative analysis of heat loss is possible. The student could do rough area take-offs of the clerestory structures.
BIBLIOGRAPHY


Goldstein, S. James, AIA, "Two Faces of Architecture", Architecture New Jersey, 1983


Towel, Andrew R., To Study Administration by Cases, Harvard University, 1969,