TECHNOLOGY TRANSFER FOR ENERGY EFFICIENT DESIGN OF MIDSIZE BUILDINGS

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ABSTRACT

This paper presents the initial results of the first year of a four year study which will strive to formulate effective strategies for technology transfer that leads to the energy efficient design of midsize buildings in Minnesota. This pilot study is premised on the assumption that technology transfer requires two kinds of knowledge. The first of these is technical knowledge concerning component performance, component relationships, technological strategies, design methods, and evaluation procedures that form the base of most current explorations of the energy efficient design of midsize buildings. The second is an understanding of the way in which decisions are actually made concerning energy impacting technologies in the market place. The contention of this study is that technical knowledge does not equal technological implementation. It is equally important, we contend, to understand the ways in which that knowledge might be used by developers, architects, and engineers if energy conserving design strategies are to be actually employed.

A 68,000 s.f. suburban speculative office building is the subject of this pilot study. The building is a curtain wall structure heated and cooled by water source heat pumps. It has been occupied for two years but is not entirely rented. The building was built and is managed by what is considered to be one of the most progressive developer/manager organizations in the Minneapolis/St. Paul metropolitan area.

Design decisions that impact energy expenditures in the building were identified for the case study team which, in turn, interviewed all key design and operation participants to obtain information necessary to build a model of how these decisions were arrived at. Results of these interviews and analysis of building performance are compared to the procedures put forth in AIA, SERI and Burt, Hill, Kosar, and Rittleman models of how design decisions concerning energy impacting technologies ought to be made. The results indicate that the design process used by the developer was considerably more sophisticated than that put forth in the procedures reviewed. In addition, an analysis of the kinds of technical solutions advocated by these procedures indicates that design decisions in the case study building would not have been significantly different had these models been employed.

We conclude that if the developer of the case study building is representative of the population of Minnesota developers, energy-efficient design procedures will have to become both more sophisticated in terms of decision making procedures and yield more energy efficient building designs in order to be used in the market place.

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> Nobel prize winner, Barbara McClintock, when asked how she developed her theory of transposition of chromosomes in the hereditory process of maize answered, "You just get down inside the corn and look."

INTRODUCTION

General Study Purpose

This is the first phase of a four year effort to transfer technology necessary for the energy efficient design of midsize buildings to architects and design professionals in Minnesota. The fundamental hypothesis of the study is that past efforts to transfer technologies by altering the energy characteristics of midsize buildings have been driven by technological knowledge. A discovery is made concerning the use of an energy impacting technology, this understanding is converted to a form that might be understood by practicing professionals, and it is transferred to this population in the familiar form of books, workbooks, or seminars. What happens to this transferred knowledge thereafter, in terms of its use under conditions of normal practice, remains a mystery.

A second approach to this problem might be premised on accepting the current state of technological knowledge in order to focus on the opposite end of transfer strategies: how technical information is/or might be employed under normal design practice conditions. In this approach, strategies for technology transfer would emanate first from understanding how technical information is currently used to make design decisions in practice. Then the kind of technical information and form in which this information is presented would be tailored to meet the requirements of this process. We call the first of these knowledge production driven technology transfer strategies and the second knowledge use driven technology transfer strategies.

Our premise is that good technical information is necessary to but not sufficient for effective technology transfer. We contend that unless technical information is specifically designed to meet the procedural needs of targeted decision making populations, it will not have as significant an impact on midsize building design, construction, and operation as it would have if the transfer strategy were premised on an in depth understanding of how that information is used in design and development procedures. Our study therefore focuses on developing knowledge use driven technology transfer strategies.

To do so, we are attempting to understand how technical information is currently used in making energy impacting decisions for specific types of midsize buildings by documenting how these decisions have been made in a range of recently completed projects. We will pair this knowledge with an energy analysis of the impact these decisions have on the design, construction, and operation of these buildings.

Study Structure

This study has six major components:

1. Documentation of existing energy impacting design processes;
2. Development of field-based case studies of actual uses of technological information;
3. Building a model of technical information use in actual design practice;
4. Definition of potential intervention strategies in this process premised on differences between existing technology transfer strategies and actual practice;
5. Testing potential interventions in a learning lab, and finally,
6. Testing in the field those transfer strategies that show promise in the lab tests.

The objective of this work is primarily to develop more effective transfer mechanisms based on how technical information is used under market conditions. The measure of effectiveness of this transfer is improved building performance whether that improvement is fostered by improved design, construction, operational procedures, or by altering the context in which energy-impacting design decisions are made.

The Pilot Study

The purpose of our first year efforts has been to develop and test our research design and hypothesis in a single case study. It therefore should not be considered as a means of reaching conclusions but rather as a test of whether or not we are asking the right questions.

The objective of this pilot study is to examine the following three issues:

1. Are the procedures presently used for energy technology transfer for midsize buildings strategies compatible with the procedures used to make energy-impacting decisions in the design and development of the study building?
2. If existing energy-efficient design decision models had been employed in the design of the study building, would the decisions have been different? Would the energy performance of this building have been improved?

3. What would have been the probable impact on the performance of this building had the constraints under which it was designed been altered by adoption of a stricter State Energy Code or by providing economic incentives that promoted the use of energy efficient technologies?

   Because analysis of the third of these issues is incomplete, this paper discusses the study results concerning the first two issues.

CASE STUDY

Study Building

Our choice of initial study subject is a recently constructed three story, 68,000 sq. ft. suburban office building, with a garage tucked below it (See Figure 1). This building was designed and built by a firm that has a progressive reputation in the area. This firm keeps good records of its activities and was anxious to participate in the study as a means to learn how to improve its own practice. Hence both the building and developer made ideal subjects for the study.

The building was constructed in 1985 and is currently 40% occupied. The envelope is a reflective glass curtain wall. Forty percent of the skin is glazed. The heating and cooling system is comprised of hydronic heat pumps with supplemental heating supplied by two gas boilers and supplemental cooling by an evaporative cooling system. Make-up air is delivered to a place near each heat pump by a system that can heat but cannot cool outside air. An energy management system controls optimum start and setback for the heat pumps. The building's current utility budget is $.51/gross sq. ft. (including the garage).

Design Process

The company that developed, owns, and operates this building has created what appear to be some unique development procedures. The foundation of this organization is that once a leasing agent is successful, he or she is given the opportunity to share in the equity of future buildings. Hence the partner in charge of development has a personal stake in their success or failure in the market place. Development decisions are made primarily by this partner but these decisions are based on information provided by a design/development team that works closely together. This team is comprised of in-house personnel including a senior equity partner, the partner in charge of development, the partner in charge of operations, the person in charge of the daily operations of the building and the leasing agent. Decisions made by this group are augmented by a number of consultants including a mechanical and electrical engineering firm, an architectural firm, and a cost and construction consultant. This design team meets weekly during the conceptual and design development phase of the building design. Representatives of the team continue meeting, as appropriate, with the contractor during construction to help solve problems that arise during that phase of the work. This group, plus the contractor who built the study building, has worked together on a number of buildings for this developer.

Technological Decisions

A technical team examined the drawings and specifications and made two site visits to the building as the basis for selecting the following six questions to be asked in interviews with design team participants:

1. How was the hydronic heat pump selected? (McQuay: heating COP=3.7, cooling COP=3.4)
2. Who designed the ventilation air system; have there been any problems with it?
3. How was the percentage, orientation, and kind of glazing used on the building determined? (42% glazing, Solax vision glass: U=.54, SC=.26)
4. How was the light fixture (a two-bulb parabolic reflector with a 2" grate) selected?
5. How were insulation levels in the walls and roof of the building determined? (R-12 below grade walls, R-21 above grade walls, R-16 roof)
6. How and why was the energy management system used in the building selected?

These questions provided the basis for interviews with the mechanical and electrical engineers, the design architect, the construction consulting firm, the partner in charge of operations, the building manager, and finally the partner in charge of development who is in charge of seeing this building through design, construction, and operation. The following information is based on these interviews and attempts to delineate how, when, and why each of these decisions was made.

Case Study of Building Technological Decision-Making Procedures

Heat Pump. Choice of the hydronic heat pump followed a circuitous route in this instance. The mechanical engineer involved in this project had, a number of years earlier, been asked to do the engineering on a building that was the mirror image of an existing building. The initial building used a run around hydronic heat pump system that the client was pleased with. The engineering firm that suggested the use of hydronic heat pumps in the study building therefore initially learned about this system by copying the work of a competitor. The experience this developer gained was then employed in a number of buildings including the predecessor of the study building. The decision to use the heat pump in the study building was based first on a simple first cost, operating cost, maintenance cost comparison developed by the mechanical engineer using the a commercially available simulation program, and second, on aesthetics. The partner in charge of development did not want the roof top of the building marred visually by mechanical units. The terrain around the building offered good opportunities to hide the cooling unit required by the heat pumps and hence a "clean" roof line might be achieved by using them. This information was presented to the design team in conjunction with an economic analysis of different structural systems that might incorporate either a heat pump or a

VAV system. The decision to use heat pumps was made by the partner in charge of development over the protest of the partner in charge of operations who saw heat pumps as a future maintenance problem.

Ventilation Air System. The fresh air that is introduced in this building is brought in through a central supply where it can be heated but not cooled by a direct fired make-up air unit. This air is then dumped in the ceiling plenum approximately five feet from each heat pump. Air from each floor is exhausted first through the toilets of that floor and then down and out through the garage. The amount of fresh air and its pattern of distribution was the decision of the mechanical engineer who contends that State Codes are inadequate in this regard. He thus specified that the ventilation system be sized to deliver approximately three times the amount of fresh air required by the Code. The amount of make-up air that is actually delivered is determined by the partner in charge of operations who duty cycles the system so that fresh air is supplied 15 minutes out of each hour. When the building is fully occupied the fresh air supplied will be increased. There have been no air quality complaints by tenants to date in this building.

Percent and Orientation of Glazing. The orientation and glazing in this building, as in most other office buildings, is driven by marketing issues. The kind of tenants that the building is designed to attract and the opportunity that the site provides for views determine the amount of glazing and its orientation. Floor to ceiling glazing is considered to be "upmarket", especially when there is a good view, while strip glazing or similar punched openings are targeted at average tenants. Buildings are generally described as being A, B, or C grades which signifies the amount of glazing, lobby design, quality of finishes used, and elevator cab design for progressively less affluent rental markets. The first decision concerning envelope form and hence glazing orientation is made by the architect when he generates site plan alternatives. When a general floor plate is selected that maximizes site potentials in terms of land coverage, relationship of the building entry to parking, and the relationship of building shape to views, the general form of the building is fixed. Once the architect understands which rental level he is designing for and the probable floor to floor height of the building (which is based on knowing both which structural and mechanical system will be used), he develops a series of alternative building facade designs which are taped to the wall. Occasional visits, by the partner in charge of development eventually lead to the selection of one of these facades as most marketable. This choice is made on the basis of the partner in charge of development's judgement concerning potential tenant taste. He attempts to select facades that are ahead of competitors in terms of current taste patterns but not so far ahead as to be thought of as radical departures from current vogue.

The kind of envelope enclosure used in this building was suggested by a member of the design team who had seen it on a building in another state. The curtain wall was tested by a Florida firm for water leakage and air infiltration. It conformed to standards set in both cases. The glass used is reflective and hence limits the solar gain. It was selected primarily because it afforded good views while minimizing solar gain problems. The architect, partner in charge of operations, and the partner in charge of development made this decision jointly.

The amount of glazing used is somewhat limited by the current Minnesota State Energy Code which calls for an average wall U value of 0.28 $BTU/ft^2 \cdot H.F$. As a result floor to ceiling glazing is normally reserved for those portions of the floor plan that are designated for prestigious activities -- conference rooms and executive offices.

Light Fixtures. The selection of two-bulb parabolic lighting fixtures for this building was the result of a marketing decision made for the first large building the developer built in this area. His desire was to distinguish himself from the rest of the suburban office building market by creating a building that was perceived by prospective tenants to be of higher quality than existing alternatives. The design package that was employed to convey this impression included 9 ft. ceilings, 7 ft. flush panel doors, upgraded ceiling tile, and parabolic light fixtures. At the time, these fixtures were perceived by the market as being more expensive than normal florescent fixtures and hence "upmarket". They have become less expensive and therefore are now standard suburban office building fare. The two-bulb fixture was selected instead of a three-bulb fixture because the owner feels that in a normal 10′ x 15′ office two three-bulb fixtures deliver excess light while one is insufficient. The five foot ceiling grid and modular whip lighting hookups employed in this building allow two-bulb fixtures to be more intensely grouped should higher light levels be desired. Power consumption lighting, when using efficient ballasts in these fixtures, is 1.3 w/sq. ft. Specific lighting buildouts are designed by an electrical engineer to suit the needs of each tenant. All but one tenant of the study building selected the design team electrical engineer to do this work. Lighting special areas like the entry lobby and grounds is done at the developer's discretion and is again based on market perceptions. The quality of the lobby space is a prominent portion of the impression a building makes on a prospective tenant. Special care was given to design of the lighting of these areas by both the architect and the electrical engineer.

Envelope Insulation. The average overall insulation levels selected for the below grade walls, above grade walls, and roof of this buildings are R-12, R-21, and R-16, respectively and were selected by the architect with guidance from the mechanical engineers. They were selected to satisfy requirements for the overall U-value of the envelope required by the Minnesota State Energy Code. Each is overinsulated to avoid any potential Code compliance problems created by the glazing of the building. The owner/developer conducts an infrared scan of every building he owns when construction has been completed as a standard procedure. The contractor is informed of this practice before construction begins and is told that any problems located by this scan will have to be corrected before payment for construction is completed. The simple threat of having to tear out portions of the interior finishes to repair insulation gaps has apparently been enough to command the contractor's attention, as no problems have been found by this company in over 1.5 million square feet of construction in 26 buildings.

Energy Management System. Finally, an energy management system is used to operate the mechanical system of this building and an adjacent building. The partner in charge of operations initiated this decision and designed the system with the aid of an outside consultant. The vendor who provided the system was required to spend two days with the owner/developer team to explain how the system works and to solve any operational problems. This system is generally selected as one of the first design decisions because the partner in charge of operations is so familiar with these systems that he can accurately specify the system's composition and hence the system cost early in the design process. The partner in charge of development oversees this decision but is only concerned that it "doesn't require a rocket scientist to operate." He uses it as a marketing tool to show prospective tenants how easily space conditions can be altered from a central location should they decide to use their office during unexpected hours. The system is used primarily to turn the heat pumps in the building on and off for optimum start and night setback. It can also be programmed to accomplish several other tasks. The partner in charge of operations sees the use of this system as a means of solving 90% of the energy management issues of the building. He contends that it is when EMS systems are required to solve the final 10% of operation issues that they both become uneconomic and break down. He cites, as an example, the problem of getting night cleaning personnel to turn off the lights when they have finished their task. He contends that it is more effective to have a supervisor follow this crew around for a week until they get used to turning off the lights than it is to attempt to automate this procedure using the EMS system.

The pattern of decision making that emerges from these interviews is a complex and overlapping structure that is highly dependent on past experience, complex reasoning, and projection of market demands. It may be characterized by defining:

1. Who initiates the decision
2. What other team members are involved in procuring information for that decision
3. What general design components are altered and,
4. When in the design process the decision is made.

(See figure 2)

EXISTING ENERGY IMPACTING DESIGN DECISION MODELS

Three energy impacting design models that exemplify different approaches to this problem were examined in this study (See figure 2). The discussion of each of these strategies will be necessarily limited by the constraints imposed by the length of this paper. Each will be summarized in terms of its major premise, the way in which energy impacting decisions are made and the way in which these decisions might influence design decisions relating to a building's envelope, lighting system, HVAC, and control systems.

Energy in Design: Practice

The AIA workbook method, Energy in Design: Practice (American Institute of Architects, 1981), typifies design models that presume that an improved understanding by the architect of the potential impacts of envelope and lighting decisions on the building heating and cooling loads will stimulate the search for more energy-efficient design alternatives. In this approach, a series of envelope and lighting choices are traced through numerous nomographs to develop a general idea of the heating and cooling loads. These decisions are developed both in terms of building zones (north, south, east, west and core) and as a function of heat losses, heat gains, solar gains, and internal gains. The results of this graphically derived simulation are then used to select strategies from 15 alternate design categories that may be used to decrease these loads. Each selection of a design strategy becomes a new set of decisions to follow through the nomographs. When potentially effective strategies have been determined, they are evaluated in greater detail in an energy and economic cost/benefit analysis (See figure 2).

Small Office Building Handbook

The approach to energy efficient design found in the Small Office Building Handbook (Burt, Hill, Kosar and Rittlemann Assoc., 1985) like the AIA strategy, is directed primarily to architects. But it differs from the preceeding method in that it focuses on a limited set of technical decisions that prior computer analysis has demonstrated will have major impacts on office building energy use. The computer simulation analysis that BHKR has conducted takes into account the interactions of these variables to allow specification of the options in each category that have the greatest energy savings potential when combined with other technological choices. Hence, this is a whole building or integrated technology approach for determining the effectiveness of individual technological choices.

In this method, once the general size and number of stories of the building have been specified, the designer is faced with a series of simple choices. The percent of glazing is first identified to be 20% or 40% of the wall area. Then an HVAC system is selected from among systems suggested as appropriate to the building size and climate and a fuel, natural gas or electricity, is selected for each. These choices constrain the kinds of lighting and HVAC modifications that may be selected by the designer. The outcome of the process is an energy savings and an economic payback analysis that accounts for both demand and consumption utility charges. The relative cost effectiveness of various percentage of glazing, HVAC system, fuel type, and lighting packages are compared on this basis. Those sets of technological choices that offer the shortest payback period would presumably be selected. This method goes beyond the AIA method by dealing with specific HVAC decisions and by suggesting further design refinements and providing a checklist to ensure successful turnover and proper building operation (See figure 2).

The Design of Energy-Responsive Commercial Buildings

The Solar Energy Research Institute (SERI, 1985) takes a different approach to this problem of energy efficient design. Instead of delineating the energy load problem or probable solutions to reducing energy and utility expenditures in a specific building type, it focuses on the kinds of analysis that might be helpful to designers in arriving at both economically acceptable and energy responsive solutions. In this method, construction and operation costs are treated as both design constraints and relative measures of effectiveness. Computer simulation analysis uses "elimination parametrics" to identify the impact of specific systems on building energy expenditures. Potential design solutions are compared to a base case which meets the general programmatic requirements of the building and delineates the construction costs and utility (consumption and demand) operating expenses of that building. Initial investment in energy-efficient technologies is bounded by a pre-design analysis that specifies how much a developer might be willing to invest in these technologies. Final outcomes are analyzed both in terms of profitability and cash flow that would accrue to the developer (See figure 2).

DISCUSSION

Comparison of Decision Making Procedures

Comparison of the decision making procedures advocated in the three design models examined in this study with those followed in actual practice in the study building yield the following differences:

First, the role of the architect in making energy impacting decisions is seen as being more central in the design models than it appears to be in the case study building. In the case study building the architect is primarily responsible for insulation and glazing decisions. The first of these is simply a matter of code compliance while the second is driven primarily by site and market considerations. It might be argued that the limited role the architect plays in making energy impacting decisions is, in fact, the root of the problem. To do so, however, would be to negate what is made patently clear in the case study building: design decisions in office buildings are made by design teams rather than by individuals. The question is thus one of whether or not the architect is the team member who ought to be primarily responsible for major envelope, lighting, HVAC or control system decisions in buildings. The case study decision making process would seem to suggest that while the architect might contribute to making these decisions, other team members including the mechanical engineer, partner in charge of operations, and the building manager have a good deal of knowledge and experience to contribute in evaluating the use of such energy responsive technologies.

Second, the kinds of technological issues considered in the case study were different from those dealt with by the design models. In the study building the selection of lighting fixtures was predetermined, while their allocation took place after construction was completed to comply with the requirements of specific building tenants. Fixture type, ballast efficiency, lamp selection and lighting controls were, conversely, major design variables in the BHKR and SERI strategies. On the other hand, selection of an HVAC system was a major variable in the case study building but was not a decision dealt with in any detail in any of the design models. The design models seemed to focus, in general, on those kinds of technological decisions that might be addressed by modifying envelope design. Building energy impacting decisions in the case study focused on mechanical systems, operating issues, and maintenance problems.

Third, the mechanism for making decisions utilized for the case study building was much different from that proposed by the design models. In the AIA and BHKR design models an energy and economic analysis done by a single design team member appears to be considered adequate to propel acceptance of technological change. In the case study building, such decisions to change a way of dealing with a technological problem required that support be garnered from as many team members as possible. In actual practice the more design team members who can support an innovation the greater the chance that technical innovations will be implemented. The use of hydronic heat pumps, in the case study building was advocated by the mechanical engineer and construction consultant with support from the structural engineer and the partner in charge of development. The partner in charge of operations disagreed with this decision because of the maintenance problems that such a system may cause. He could not garner support from other team members, however, and hence was overruled. This kind of multiple evidence/consensus model of decision making seems to typify most of the technical decisions made in the case study building. Decision strategies, particularly like those put forth by the AIA and BHKR approaches, do not acknowledge the need to build broad support for technical innovation. While the SERI method recognizes the need to gain the support of the developer by establishing initial economic criteria, it does little to include the concerns of other design professionals or building operation personnel in arriving at these recommendations.

Fourth, the kinds of evidence used in support of technological options in the case study building were much broader than those employed in any of the transfer strategies. The selection of the heat pump system for the case study building, for instance, was a matter of first cost, operating costs, maintenance cost, the "brain drain" caused by maintenance worry, flexibility, budget trade-offs, site considerations, structural system costs, and building aesthetics. This breadth of support might be compared to design decision models that use only energy savings and payback periods to support recommendations. Though these issues are important, they do not represent many issues that a developer must consider in making decisions to employ energy-efficient technologies.

Fifth, the objective of the case study design team in making energy impacting decisions was to develop good but not maximally efficient, energy saving strategies. The objective of the design models was to promote maximally efficient energy impacting decisions. The developer team and its consultants seemed to implicitly agree that technological decisions that sought to solve the first 80% of an energy problem were more effective in using design resources and during operation than those that sought to solve 100% of the problem. Solving the last 10% or 20% of any problem was seen by this team as being potentially uneconomic. Thus, the energy management system was asked to do less than it might, the ventilation system was over sized because it could be under-utilized to reduce energy because a system that was too small could not be easily expanded to provide more ventilation, and two bulb lighting fixtures were used because they solved the vast majority, but not all, of the lighting problems that might occur in the building. Each is less than a maximally efficient solution but resolves a majority of the problems it addresses with a minimum of effort.

Sixth, the case study design team kept a book in which team participants explained any decisions they made that led to a problem. This document, called the Red Book, is kept by the developer as a running record of what not to do in future designs. The lessons from preceding design, construction, and operation errors are recorded so that they do not reside only in the thoughts of a design team member. As the composition of the design team changes, information garnered through experience remains available to new team members. None of the transfer strategies examined considered this kind of learning within the procedures they set forth.

In sum, the decision making procedures advocated in the design decision models examined would appear to be made by the architect who was not charged with a majority of this responsibility in the case study design team. The proposals he or she is able to make based on the use of these procedures are found to affect a more limited range of issues than that considered by the case study design team, are not designed to build support among other design team members, and seek maximum energy savings rather than generate good solutions to energy problems. In this single comparison, there would appear to be little match between the decision making procedures put forth by the three design decision models examined and the decision making procedures employed in the case study.

Potential Impact of the Transfer Strategies on Improving Building Energy Performance

Two of the three transfer strategies were analyzed in this regard. Because the SERI method prescribes criteria for evaluating design decisions but not a method for making those decisions, it was not examined in this analysis.

The same assumptions used in the case study building analysis were used to develop design recommendations using the AIA workbook method and the Small Office Building Handbook (BHKR). The conceptual analysis of the AIA Workbook method took six hours to carry out. The more detailed follow-up energy and economic analysis has not been done. The BHKR method required one hour. Comparison of the results of these analyses with the process used in the study building yield the following results.

First, the design decisions recommended by the methods either were not significantly different than those in the case study building or were decisions which would have been unacceptable and therefore not implemented by the developer. Concept analysis used in one AIA workbook method yielded the conclusion that winter heat loss should be reduced or winter solar gain should be increased. The specific strategies suggested which would apply included: increased insulation, decreased floor-to-floor height, putting a portion of the building below grade, installing clear glazing and dark walls and roof. The selection of insulation by the developer is governed by the State Energy Code. The floor-to-floor height is governed by the structural system and the HVAC system. The other envelope decisions are governed by marketing factors. As a result, none of these suggestions would have been implemented by the developer. The BHKR method suggests that the percentage of glazing should be reduced from 40% to 20%. However, the amount of glazing used by the developer is governed by Code compliance and market perceptions. The view of nearby lakes and open areas in the suburban area of the case study building is a major selling feature.

Second, the economic analysis used by the developer is less sophisticated than those incorporated in the AIA Workbook and the SERI method. The only economic analysis carried out for the study building was for the selection of the HVAC system: a comparison of VAV with gas and electric boilers and heat pumps with gas and electric boilers. Heat pumps with electric boilers had the lowest first cost, $6.00/sq.ft. Heat pumps with gas boilers were selected based on a simple payback of 8.5 years over heat pumps with electric boilers because of lower projected utility costs. VAV with a gas boiler had a payback of 11.7 years and VAV with an electric boiler did not pay back. As discussed earlier, this information was only a minor part of the overall decision to select the heat pump. The AIA method uses the internal rate of return as its economic indicator in the more detailed analysis. The SERI method uses cash flow and profitability analysis. These more sophisticated analyses apparently are not currently required for decision making by the developer.

Third, the estimates of utility costs provided by these methods might cause decision makers to question the credibility of the methods. Both the AIA and the BHKR methods estimate utility costs for a building similar to the study building that appear to be somewhat low. Data available from the Building Owners and Managers Association (BOMA, 1987) and the Institute for Real Estate Management (IREM, 1987) indicate that buildings of similar size or age in Minnesota generally have utility costs between approximately $1 and $1.50/sq. ft. The BOMA data indicates that the middle 50% of the sample of suburban office buildings between 50,000 and 100,000 sq. ft. in Minnesota have utility costs ranging from $.89 to $1.18/sq. ft. The IREM data indicates that the middle 50% of buildings built after 1987 in Minnesota have utility costs between $.92 and $1.42/sq. ft.

The AIA method estimated utility costs for the same design at approximately $.54/sq. ft. while the BHKR method estimated utility costs at $.45/sq. ft. The AIA method does not include demand charges. The BHKR method estimates demand charges to be $.03/sq. ft. The actual utility costs for the 40% occupied case study building are $.62/sq. ft (not including the garage). Fully occupied buildings operated by the developer tend to have utility costs around $1/sq. ft. Demand charges in the partially occupied study building were $.16/sq. ft., six times that estimated by the BHKR method. This disparity between real and simulated utility costs might make it difficult for a design team member to defend estimates developed using either the AIA or BHKR to support design changes.

Potential Impact of Altering Design Decision Constraints

An analysis of ASHRAE Standard 90.1P and Energy Edge economic incentives is now being conducted but the results of this analysis are not yet available.

CONCLUSIONS

First, we assume that if technology transfer is to take place as a function of the diffusion of new technical information, then it is the progressive developer that is exemplified in this case study who would be the most likely target of such information. If that assumption is valid, then it is clear that technology tranfer strategies targeted at such an audience will have to become far more sophisticated in terms of their understanding of practice design procedures in order to be effective. To achieve that level of sophistication, such a transfer strategy should:

1. Address a whole team of players;
2. Address concerns of each team member;
3. Provide supporting evidence relating to a wide range of issues;
4. Include assurance of minimal risk;
5. Provide credible evidence; and
6. Result in a more energy efficient building than those now being built by developers

Second, it is not clear that use of existing design decision models would, at least in this case, generate implementable technology alternatives that would lead to improved building energy performance. Though this may simply be an anomoly predicated on the design procedures used by a single developer, it suggests that futher exploration is required to understand what technologies are acceptable to the building community that promote energy conservation.

Finally, a number of questions for futher study are suggested by this single case, including:

1. Could the study building have been more efficient and still satisfied the developer's requirements for marketability and headache free operation?
2. What is the level of sophistication of the whole spectrum of developers? What impact might this knowledge have on development of technology transfer strategies?
3. Do less sophisticated developers build and operate less efficient buildings?
4. Is an appropriate technology tranfer strategy for midsize office building simply a strategy that transfers the sophistication of the case study developer to less sophisticated developers?
5. What might be the relative roles of technical information dissemination, design assistance, regulatory codes and economic incentives as technology transfer strategies for different stratuma of the building design/development community?
6. How can new energy-savings technologies that are cost effective be successfully introduced into actual building design practice?

REFERENCES

American Institute of Architects (AIA), "Energy in Design: Practice", Washington, D.C., 1981

Burt, Hill, Kosar, Rittelmann Associates (BHKR), "Small Office Building Handbook: Design for Reducing First Cost & Utility Costs", Van Nostrant Reinhold Company, Inc., New York, NY 1985

Solar Energy Research Institute (SERI), "The Design of Energy-Responsive Commercial Buildings", John Wiley & Sons, New York, Chichester, Borisbane, Toronto, Singapore, 1985

Institute of Real Estate Management, "Income/Expense Analysis, Office Buildings, Downtown and Suburban", Institute of Real Estate Management, Chicago, IL, 1987

BOMA International, "1987 BOMA Experience Exhange Report. Income/Expense Analysis For Office Buildings", Building Owners and Mangers Association International, Washington, D.C., 1987

Brown, Johns, Kobb, Snell, "Technology Transfer for DOE's Office of Buildings and Community Systems: Assessment and Strategies", Oak Ridge National Laboratory, Oak Ridge, TN, 1986

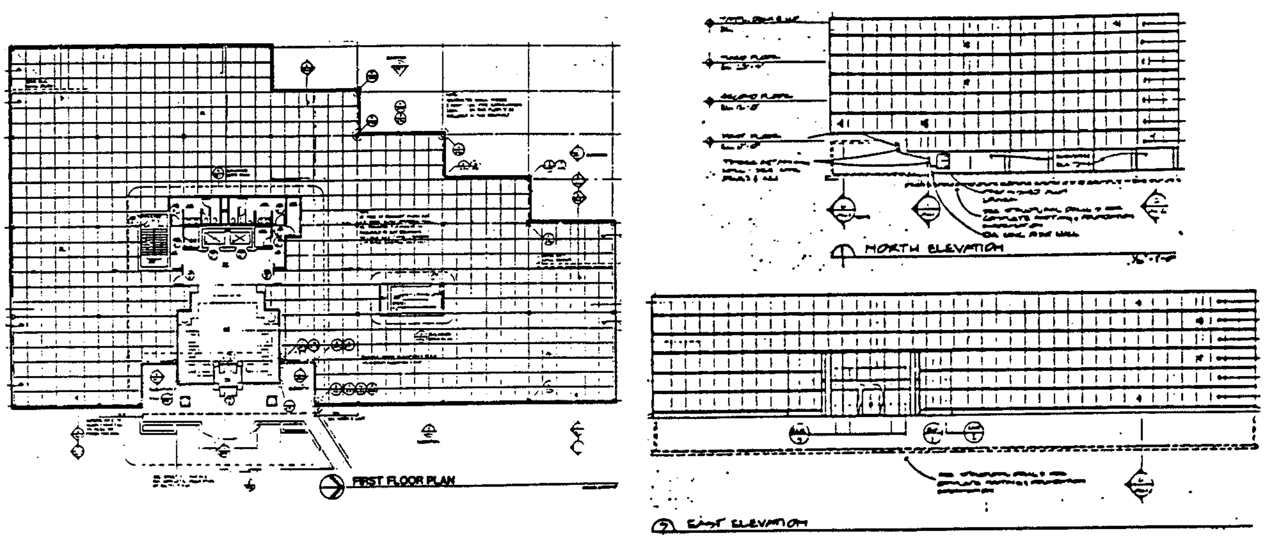

Figure 1. Case study building plan and elevations.

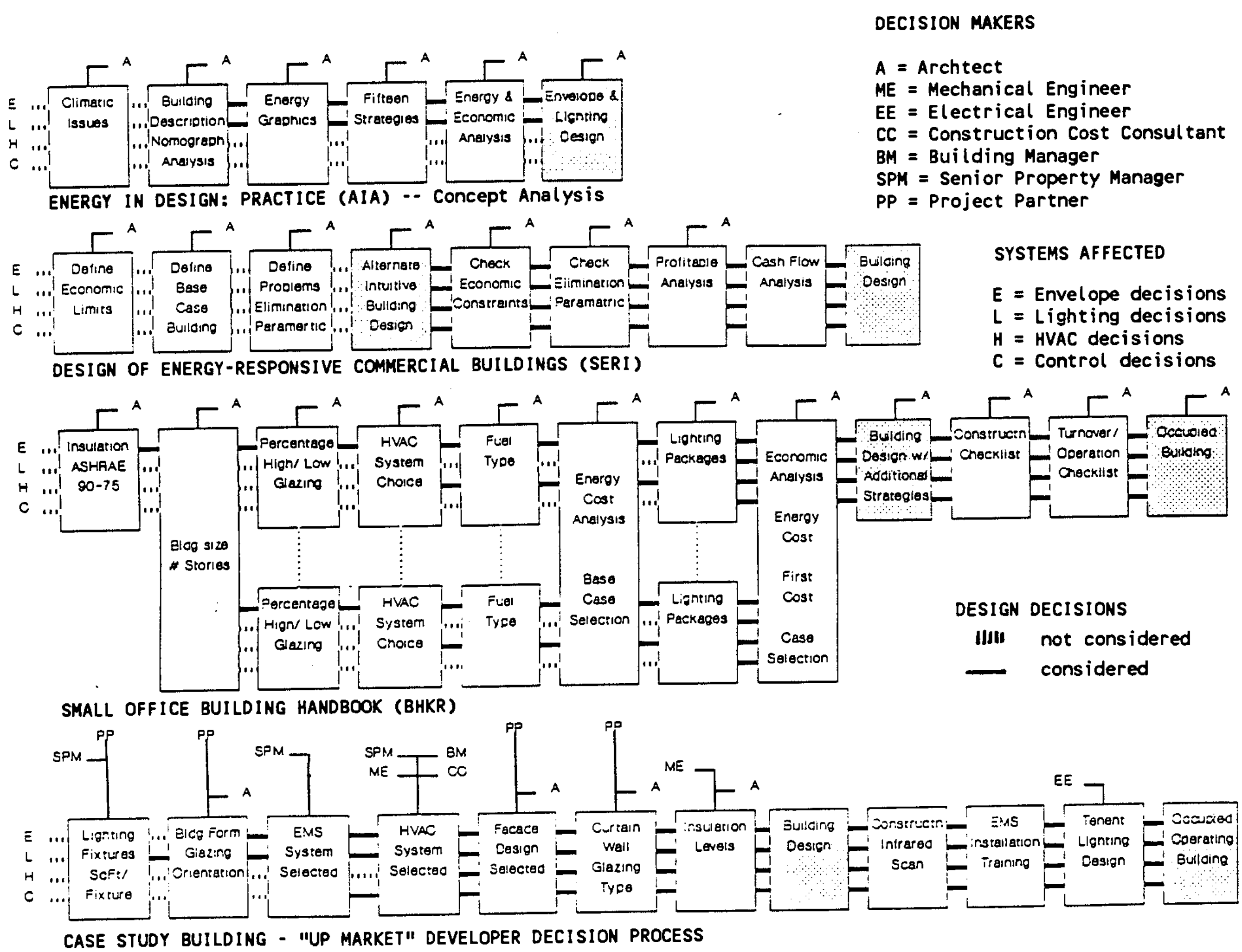

Figure 2. Model energy efficient design decision processes compared to case study developer decision process.