Session III No. 3

Envelope Strategies for a Corporate Headquarters Office Building

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ABSTRACT

During the design development phase for a corporate headquarters office building, a number of strategies for reducing energy consumption related to envelope loads were analyzed. The energy and economic impacts of each envelope strategy were considered in developing a final recommendation for consideration by the owner. The construction costs and annual energy cost savings were included in the economic analyses conducted for each envelope strategy.

INTRODUCTION

The subject of this study is a four-story, 460,000 ft^2 (42,750 m^2), exposed steel frame corporate headquarters office building, x-shaped with an atrium, to be located on a heavily wooded 120-acre site on the outskirts of Cleveland, Ohio. The owner is TRW, Inc., an international firm with a diversity of products and services ranging from the automotive to the electronic, space-systems, industrial, and energy markets. The architect for the project is FCL Associates, Inc., of Chicago, Illinois and the engineer is Environmental Systems Design, Inc., of Chicago, Illinois. The primary goal in the project was that the design, materials, and atmosphere be of the highest quality--a nice place to work. Additionally, the building was to be as energy-efficient as would be reasonable and cost-effective.

The energy consultant on the project investigated each area of the building, as the design evolved, that directly or indirectly caused energy consumption. During the design development phase, these investigations centered on four major areas: (1) building envelope, (2) lighting systems, (3) HVAC plant, and (4) HVAC air-side systems. This paper concentrates primarily on the investigations related to the building envelope.

Fig. 1 shows an exterior perspective of the building; Fig. 2 shows an interior perspective of the atrium; and Fig. 3 shows the second-floor plan. The floor to ceiling height is 10 ft (3.05 m), with a 14 ft 10 in (4.52 m) floor-to-floor height. The exterior glazing is clear double pane, extending from floor to ceiling with a U-value of 0.52 $Btu/hr{\cdot}ft^2{\cdot}°F$ (0.29 $W/m^2{\cdot}K$). Overhangs, 6 ft (1.82 m) in depth, provide solar shading and glare control for the exterior glazing. The lighting system utilizes standard 2 by 4 ft (0.6 x 1.3 m) four-lamp fluorescent fixtures with an average lighting density of 2.2 W/ft^2 (23.7 W/m^2). The HVAC system is a constant-volume, variable-temperature perimeter system and a VAV interior system with open-drive centrifugal chillers, natural-gas-fired boiler, and natural-gas-fired domestic hot-water heaters. The base building has a predicted annual energy performance of 61,935 Btu/gross ft^2 (195,345 W/gross m^2), with total annual energy costs of $510,550.

DEVELOPMENT AND ANALYSIS OF STRATEGIES

The schematic design building was used as the base (also called the base case building) for all comparisons of cost-effectiveness of the building envelope alternatives. For the project, the building envelope consists of three major components: (1) glazing (both horizontal and vertical, (2) opaque spandrel panels, and (3) roof. Since the opaque spandrel panels and the roof were both well-insulated, having U-values of 0.05 $Btu/hr{\cdot}ft^2{\cdot}°F$ (0.29 $W/m^2{\cdot}K$), only the glazing was considered in developing potential strategies for analysis.

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The architect was very concerned that the glazing be highly transparent to allow unobstructed views of the heavily wooded and landscaped site through the floor to ceiling glazing. With this in mind, the following glazing options were developed for analysis: (1) solex double-pane glazing, U-value = 0.57 Btu/hr·ft^2·°F (3.25 W/m^2·K) and SC = 0.55; (2) heat mirror double-pane glazing, U-value = 0.25 Btu/hr·ft^2·°F (1.43 W/m^2·K) and SC = 0.71; (3) solex and heat mirror double-pane glazing, U-value = 0.25 Btu/hr·ft^2·°F) (1.43 W/m^2·K) and SC = 0.42; (4) clear triple-pane glazing, U-value = 0.40 Btu/hr·ft^2·°F) (2.29 W/m^2·K) and SC = 0.71; (5) spandrel insulation (replace lower 2 ft 6 in (0.76 m) of glazing with opaque spandrel panel insulated to a U-value of 0.05 Btu/hr·ft^2·°F (0.29 W/m^2·K)); (6) reflective double-pane skylight glazing, U-value = 0.31 Btu/hr·ft^2·°F (1.77 W/m^2·K) and SC = 0.17; (7) light-tint skylight, U-value = 0.59 Btu/hr·ft^2·°F (3.37 W/m^2·K) and SC = 0.44; and (8) no shading (all exterior shading devices removed).

Each of the glazing alternatives was analyzed individually for annual energy consumption using the DOE-2.1A computerized energy analysis program, i.e., each was analyzed as though it were the only change to the base-case building. For example, in the reflective double-pane glazing skylight alternative, only the thermal characteristics of the skylight were changed and a new DOE-2.1A computer analysis completed. The results for each of the building strategies from the DOE-2.1A computer program are shown in Fig. 4, with a graphic breakdown by component of the major building energy-consuming items along with total energy consumption in watts per square meter per year. For the envelope strategies, the annual energy consumption change ranged from an increase of 955 Btu/ft^2 (3010 W/m^2) for the solex double-pane glazing to a decrease of 3985 Btu/ft^2 (12,570 W/m^2) for the solex and heat mirror double-pane glazing. Summaries of annual energy consumption, annual cost savings, and internal rate of return for each of the envelope options are shown in Tab. 1. Annual cost savings (or increases) were calculated using current Cleveland utility rates and an energy escalation of 15% to account for projected increases in fuel costs before the building is occupied.

After the completion of the energy analyses for each alternative, the construction manager for the project calculated the impact of each alternative construction cost. These were used in economic analyses to determine an internal rate of return (IRR) for each alternative in percent per year. The IRR was calculated using standard economic formulas. The construction cost change and the IRR for each alternative are also shown in Tab. 1.

SUMMARY OF CONCLUSIONS

The owner set two primary criteria for incorporating recommended options: (1) The IRR should be a minimum of 15% and (2) each option must meet all program requirements. From the results for each envelope alternative, a number of conclusions can be made. Each glazing alternative had a relatively low IRR because of large construction cost increases and relatively low annual energy cost savings. Although the spandrel insulation option had a good IRR (135.76%), it did not comply with the architect's requirement for floor-to-ceiling glazing and, thus, was unacceptable. The reflective double-pane glazing skylight option was also inconsistent with the program requirements. Thus, it was recommended that the base case clear double-pane glazing remain and that none of the glazing alternatives be incorporated. Later in the design process, the end walls of the atrium were changed from double-pane clear glazing to triple-pane clear glazing. Because the glazing on the walls is almost four stories high, the triple-pane glazing was used primarily to help maintain greater occupant comfort along those walls during the winter. It also gave a slight annual energy-savings benefit.

Although none of the building envelope strategies proved cost-effective for the project, a number of other alternatives for the lighting system, HVAC plant, and HVAC air-side systems were cost-effective and included in the final analysis during the design development phase. These include: triple-pane glazing on atrium end walls, 1.25 W/ft^2 (13.45 W/m^2) lighting system, variable-speed fan drives, low air speed coils, high-efficiency fan motors, high-efficiency chiller with turbomodulator controller, high-efficiency pump motors and local unitary heat pumps for DHW. The results of the final energy analysis are shown in Fig. 5, comparing the annual energy performance of the base case building, a building which complies with the Ohio State Energy Code (ASHRAE 90-75), the BEPS/NOPR building line energy budget for Cleveland, Ohio, and the combination of recommended strategies. The annual energy savings estimated for this combination of strategies is \$161,224, with an IRR of 56.54% per year, and an increase in construction cost of \$370,146. The annual energy performance of the building incorporating these strategies was predicted to be 46,970 Btu/ft^2 (148,145 W/m^2). Upon receipt of these results, the building owner elected to accept the recommendation, and the set of options has been incorporated into the building design.

TABLE 1

Summary of Results

Envelope Strategies	Energy Consumption in Btu/ft²	(W/m²)	Annual Energy Cost Savings	IRR (% per year)	Construction Cost Changes
Solex double-pane glazing	62,890	(198,355)	$ 4,188	7.65	+ $185,000
Heat mirror double-pane glazing	58,290	(183,845)	$ 5,375	2.91	+ $499,000
Solex heat mirror double-pane glazing	57,950	(182,775)	$ 8,808	3.98	+ $684,000
Clear triple-pane glazing	59,665	(188,185)	$ 3,942	5.24	+ $250,000
Spandrel insulation	60,060	(189,430)	$ 6,189	135.76	− $ 5,000
Reflective double-pane glazing skylight	61,415	(193,705)	$ 2,084	19.08	+ $ 25,000
Light-tint double-pane glazing skylight	62,115	(195,910)	+$ 1,179	†	+ $ 23,000
No shading	61,500	(193,970)	+$11,539	*	*

†For the light-tint skylight option, an increase in annual energy consumption and cost occurred, caused primarily by the increased U-value of the glazing as compared to the base case double-pane clear glazing. Thus, an internal rate of return could not be calculated.

*The internal rate of return and construction cost impacts were not calculated for the no shading option. It was analyzed so that the separate annual energy consumption and cost impacts of the shading devices could be estimated. Although a slight savings in energy performance is indicated, annual energy costs increased as did the required chiller size, due to increased cooling loads.

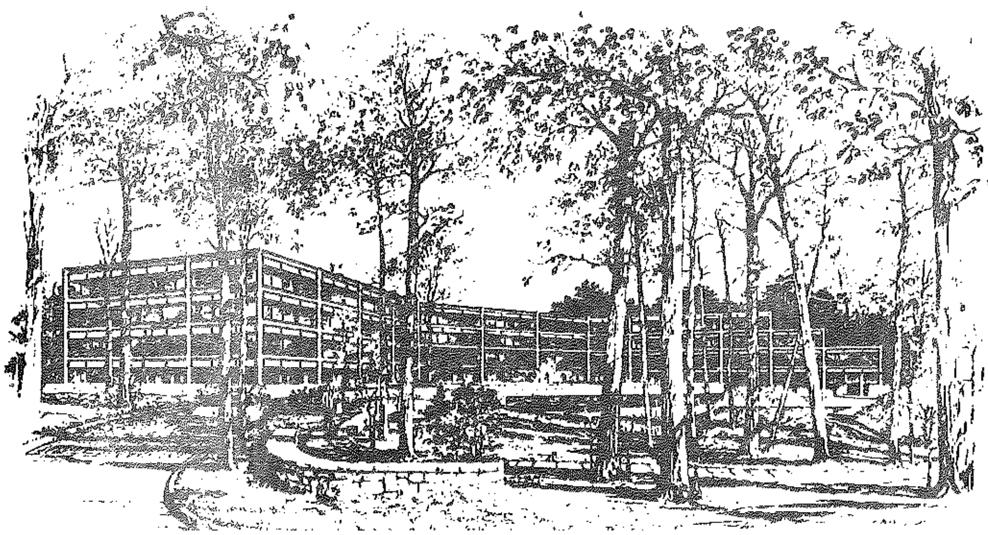

Figure 1. Exterior perspective

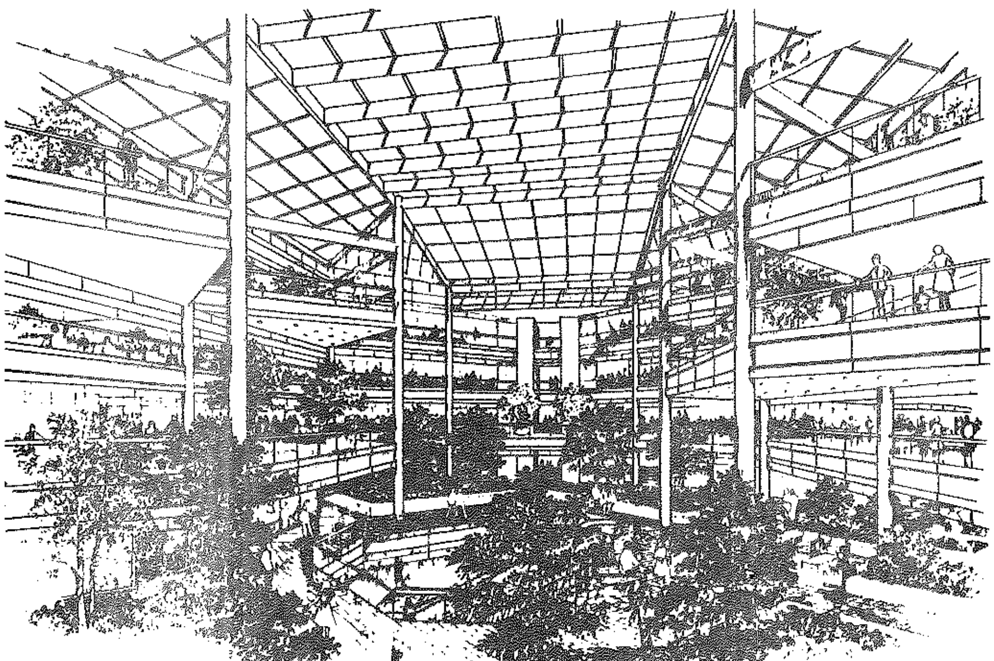

Figure 2. Interior atrium perspective

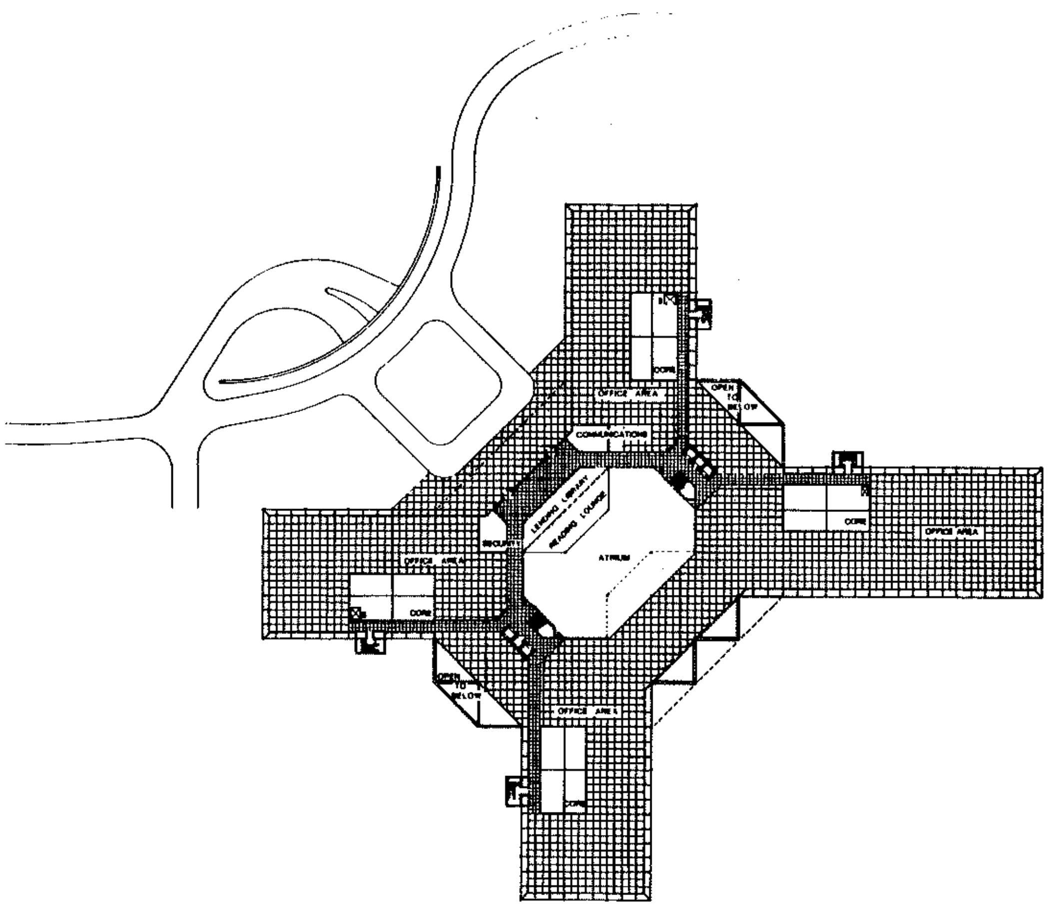

Figure 3. Second floor plan

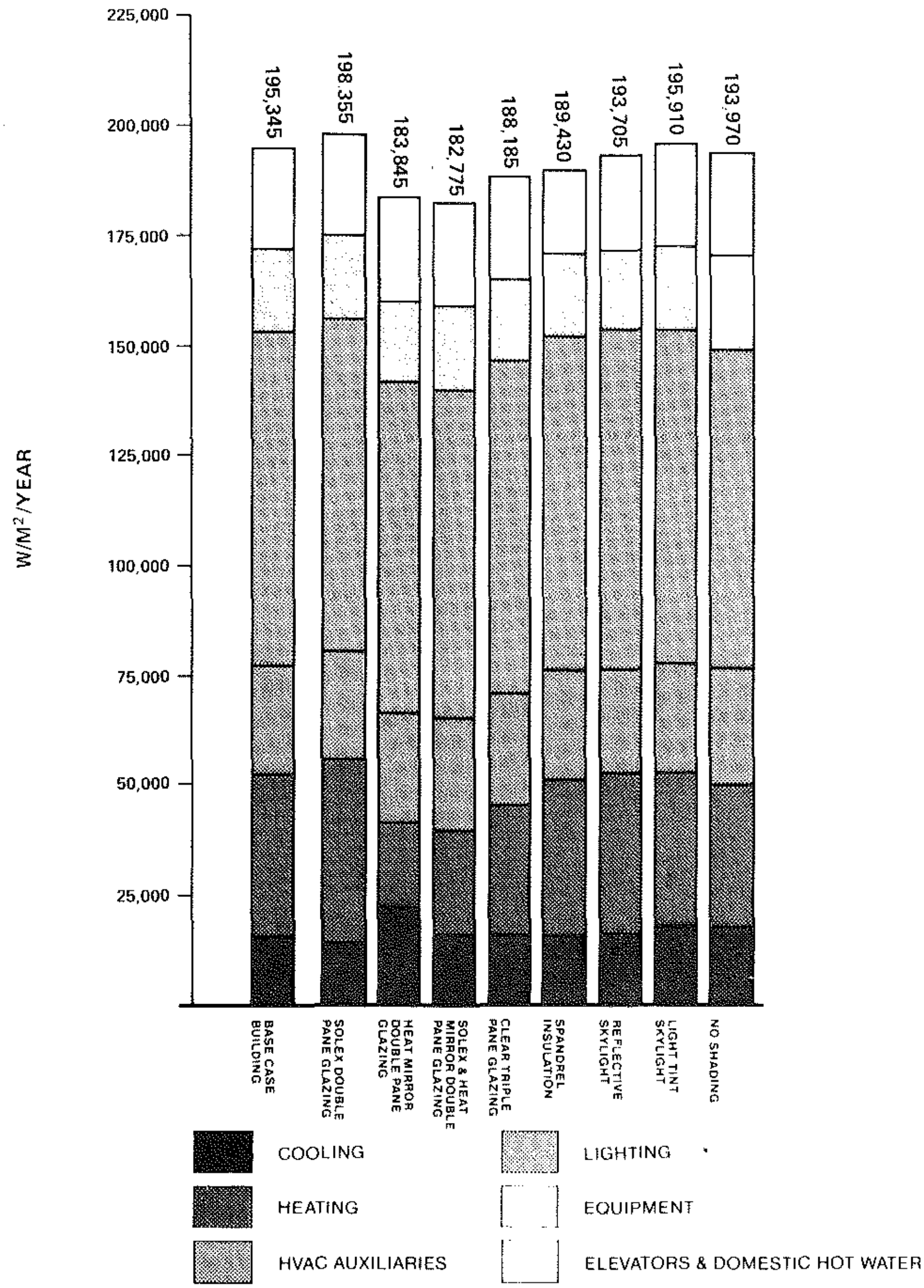

Figure 4. Envelope energy conservation opportunities comparison of energy analysis results

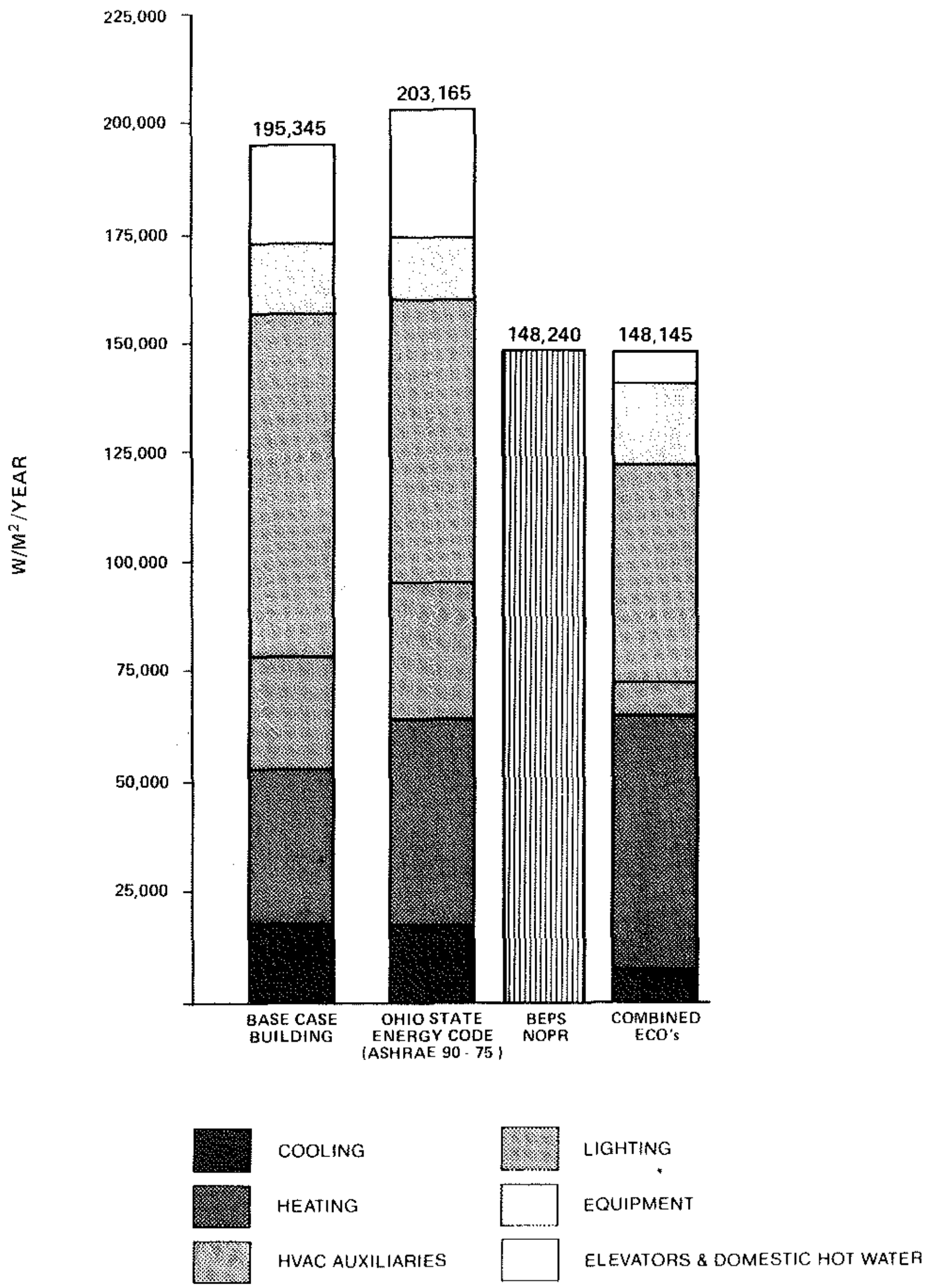

Figure 5. Design development comparison of energy analysis results

Discussion

Robert Sonderegger, Staff Scientist, Lawrence Berkeley Lab., Univ. of California, Berkeley: Were maintenance and replacement costs over the lifetime of the building taken into account in your ECOs?

D.B. Crawley: Since we were interested primarily in the internal rate of return for each of the ECO's, only the differential investment costs and energy savings were included in the analysis. The envelope options had no major replacement costs differences and no differences in maintenance costs. Thus, maintenance and replacement costs were not included in the economic analyses.

K. Patel, Staff Engr., Argonne (IL) Lab.: What was the total cost of combined ECO and IRR? What was the capacity of storage?

Crawley: The recommended combination of ECO's had a total additional investment cost of $370,145 and an IRR of 56.54% per year with annual energy cost savings of $161,224. The chilled water storage system had a total capacity of 265,000 gallons.

S. Tuma, Mgr., State Bldg. Pgm., Illinois Dept. of Energy and Natural Resources, Springfield: How were HVAC auxilliaries and DHW reduced in energy intensity more than ASHRAE 90-75?

Crawley: In ASHRAE/IES Standard 90A-1980, the air transport factor (ATF) in Section 5 is very low: 5.5 Our base case building had an ATF in excess of 10.0. To show the differences from the Ohio State Energy Code, we simulated the exact requirements of ASHRAE/IES Standard 90-A-1980. Thus, the fan energy consumption was much higher using the ATF of 5.5. The DHW system used to meet the ASHRAE/IES Standard 90A-1980 requirements was standard natural gas-fired equipment.

R.M. Ward, Proj. Dir., TRA, Seattle, WA: Did building envelope U_o and OTTV meet ASHRAE Standard 90A-1980?

Crawley: The building envelope for this building does not meet the U_o and OTTV requirements of ASHRAE/IES Standard 90A-1980.

A. Cieslak, Proj. Engr., Upjohn Co., Kalamazoo, MI: Regarding the heating system for the building, where was the warm air supplied to the room? I understand that variable frequency speed control was used for fan speed control for the VAV type air-conditioning system. How does the payback for variable frequency compare to inlet vane type of fan capacity control.

Crawley: The warm air is supplied to the space by a constant volume system through floor grills located beneath the windows. In the analysis, the base case had inlet vane fan capacity control. Our comparison of the variable frequency fan speed control with the base case shows a simple payback of 4.2 years with an IRR of 36.58%/year.

E. Dahan, Product Mgr., W.R. Grace, Cambridge MA: In comparing glazing alternatives, what provisions were made for energy costs escalating after 1984? Why did heating costs rise significantly in the final ECO recommendations?

Crawley: The DOE predictions for energy cost escalation in the Cleveland, Ohio area were used for escalation of the energy costs for all future years.

The lighting load had dropped significantly from 2.2 to 1.25 watts/sf, lowering its offsetting effect on heating. Thus, heating energy consumption increased significantly.

M. Addison, Grad. Student, Arizona State Univ., Tempe: Was daylighting considered? If not, why not, and if you had been given the opportunity to optimize based on daylighting considerations, what would you expect the result to be?

Crawley: Daylighting was considered as a possibility in the building during the early phases of design. Since the highly efficient lighting system (1.25 watts/sf) had already significantly reduced the cooling loads and lighting consumption, the additional savings due to daylighting were less than one percent.

C.L. Tilford, The Southwall Corporation, Palo Alto, CA: High-performance glazings, such as those incorporating transparent inculation, have significantly higher inside surface temperatures in winter than units with higher U-factors. In many cases, this eliminates the need for perimeter draft heaters. And, room air temperature can be lowered with equal occupant comfort, because of the higher mean radiant temperature. Were these first cost and operatiing cost savings considered in your economic analysis?

D.B. Crawley: We did not consider them in the analysis presented, although we were aware of these possibilities. Because of the size of the project, and this product's relatively short track record, the client decided to have us drop our invertigation of this option.