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TITLE: USE OF AN ATRIUM FOR THE PASSIVE-SOLAR RETROFIT OF AN OFFICE BUILDING: DESIGN AND INSTALLATION EXPERIENCE

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USE OF AN ATRIUM FOR THE PASSIVE SOLAR RETROFIT OF AN OFFICE BUILDING: DESIGN AND INSTALLATION EXPERIENCE

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ABSTRACT

A clerestory window system has been installed over a courtyard in an existing two-story office building/museum at the Los Alamos National Laboratory, thus creating an atrium. This atrium serves as a passive solar heating and daylighting system for the building and provides new display space for the museum.

The retrofit consists of a roof-mounted clerestory window system with night insulating shutters which: forms an atrium that provides new museum space, buffers the former courtyard walls and windows, preheats ventilation air for the entire building, and provides daylighting and heating for the new museum space. The passive system is coupled to the heating, ventilating, and air-conditioning (HVAC) system of the surrounding building by inducing fresh-air makeup through the solar-tempered atrium; heating, cooling, and daylighting are addressed in the design.

This paper describes the design process, the use of the DOE-2 building energy analysis computer program during design, and the construction of the atrium.

INTRODUCTION

As part of the Solar Federal Buildings Program sponsored by the US Department of Energy, the Los Alamos National Laboratory has installed a clerestory window system over a courtyard in an existing two-story office building/museum, thus creating an atrium. Construction of this atrium, which serves as a passive solar heating and daylighting system for the building and provides 3600 ft^2 of new display space for the museum, was completed in July 1982.

This project, the retrofit of Building SM-200 at Los Alamos, is located on a high mountain plateau (7000 ft elevation) in northern New Mexico. The site has abundant sunshine and a cool climate of over 6300 annual heating °F-days; for office buildings at this location, heating and lighting are the dominant energy uses. Building SM-200 is a 26,000 ft^2, office building/museum of masonry construction that originally surrounded a 60 ft by 60 ft open courtyard. The building walls adjacent to the courtyard were uninsulated and contained considerable glass area. The building contains offices on both the first and second floors, a museum space with a lecture room, a conference room, a cryptography room, and restroom facilities.

The retrofit consists of a roof-mounted clerestory window system with night insulating shutters that serves several purposes: forms an atrium that provides new museum space, buffers the former courtyard walls and windows, preheats ventilation air for the entire building, and provides daylighting and heating for the new museum space. The retrofit integrates the operation of the passive system with the existing heating, ventilating, and air-conditioning (HVAC) system in the surrounding building; heating, cooling, and daylighting of the space are addressed in the design. The passive system is coupled to the HVAC system of the surrounding building by inducing fresh-air makeup through the solar-tempered atrium.

This paper describes the design process, which involved an architect/engineer firm with guidance and analysis of the solar aspects provided by Los Alamos National Laboratory staff. Construction of the atrium and the use of the DOE-2 building energy analysis computer program (Ref. 1) during design will also be described.

DEVELOPMENT OF CONCEPTUAL DESIGN

Predesign Energy Analysis-Identification of the Energy Problem

A comprehensive energy study of the existing building was conducted using the DOE-2.1 program and an hourly Los Alamos weather tape for 1978. The details of this study are presented in Ref. 2. This study revealed a significant potential for energy conservation through reduction of outside air makeup and control modifications to the HVAC system. Whereas outside air makeup reduction has been implemented in the building, the control modifications are not expected to be made. Thus, the study showed that the major energy problems to be addressed in the existing building were space heating (by far dominant) and lighting (Ref. 2); space cooling and domestic hot water loads were very small and therefore are not involved in the passive solar retrofit. Because daylighting was already applied in the existing building architecture, the passive solar retrofit did not seek to reduce artificial lighting in the existing building. Consequently, the design involved only space heating in the existing building and concerned lighting, heating, and cooling (in that order) in the atrium.

Alternative Conceptual Designs

Several generic passive solar heating designs, such as Trombe walls and water walls, were considered and dismissed because they are inappropriate to the energy-use pattern of the building. Because the building is occupied only during daytime hours, the design should provide heat during those hours rather than delay its release to the building until night, when it is unoccupied.

Direct gain options were rejected by the building occupants as causing too much glare. Sun screens or drapes are already installed on all of the south- and west-facing windows of the building. Consequently, small-mass indirect or isolated gain systems remained as the logical passive solar alternatives. The existing interior courtyard provided an attractive opportunity in this regard.

Thus, it was proposed that a roof-mounted system of clerestory windows be constructed to enclose the courtyard and provide indirect solar gain to the building. Solar energy transmitted through single-glazed clerestory windows would reach the conditioned spaces by conduction through the uninsulated courtyard walls and windows. Additionally, enclosing the courtyard to form an atrium would thermally buffer the adjoining conditioned spaces from the exterior ambient environment and would make the courtyard usable throughout the year. Figure 1 shows a schematic of the proposed design.

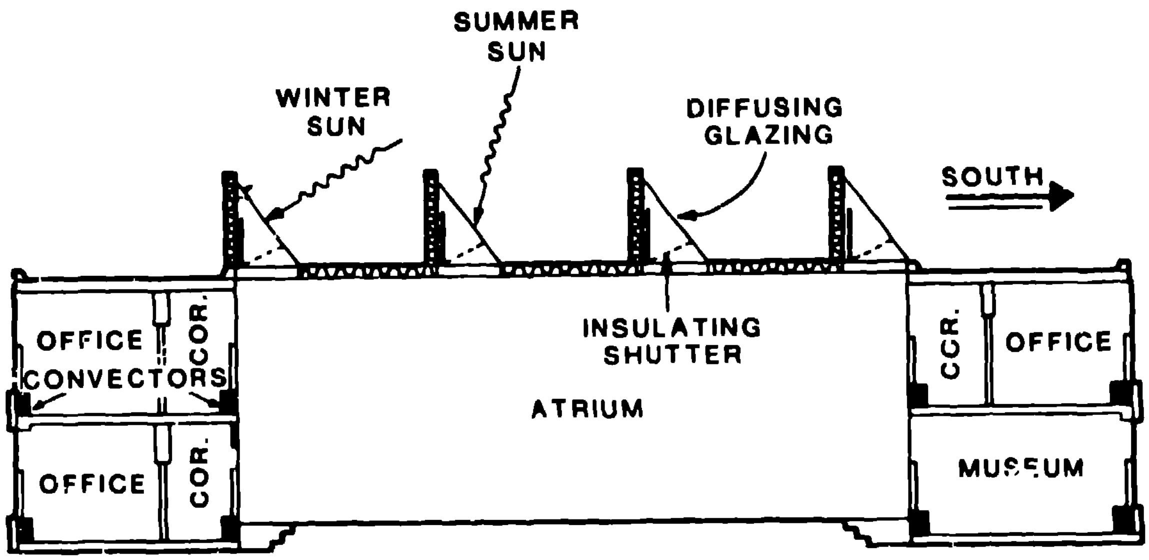

Fig. 1. Schematic cross-section of the atrium.

Because commercial buildings often are ventilation- rather than envelope-dominated, a modified design was proposed wherein the passive solar energy system would be coupled with the central HVAC air-handling equipment. This approach allows the preheating of building ventilation air by inducing all fresh-air makeup to the HVAC equipment through the solar-tempered atrium; this concept is shown in Fig. 2.

DESIGN DEVELOPMENT

Simulation Studies

The schematic design depicted in Figs. 1 and 2 was selected for detailed development, and a series of computer simulations was made using DOE-2.1 to select the design values of system parameters. Simulations were first conducted to optimize the orientation and tilt of the clerestory glazings. Because heating was by far the dominant energy term, optimization was based on minimizing the combined annual heating requirements of the existing building and the proposed atrium. The results of these simulations, discussed in Ref. 2, showed that a glazing azimuth of 170° and a glazing tilt angle of 55° from the horizontal were optimal (see Fig. 3). However, the sensitivity of heating energy to both orientation and tilt was low; variations of ±30° in either case are not important in terms of heating energy use for the whole building. Based on these results, a clerestory window system oriented 10° east of due south (azimuth = 170°) and tilted 55° from the horizontal was selected.

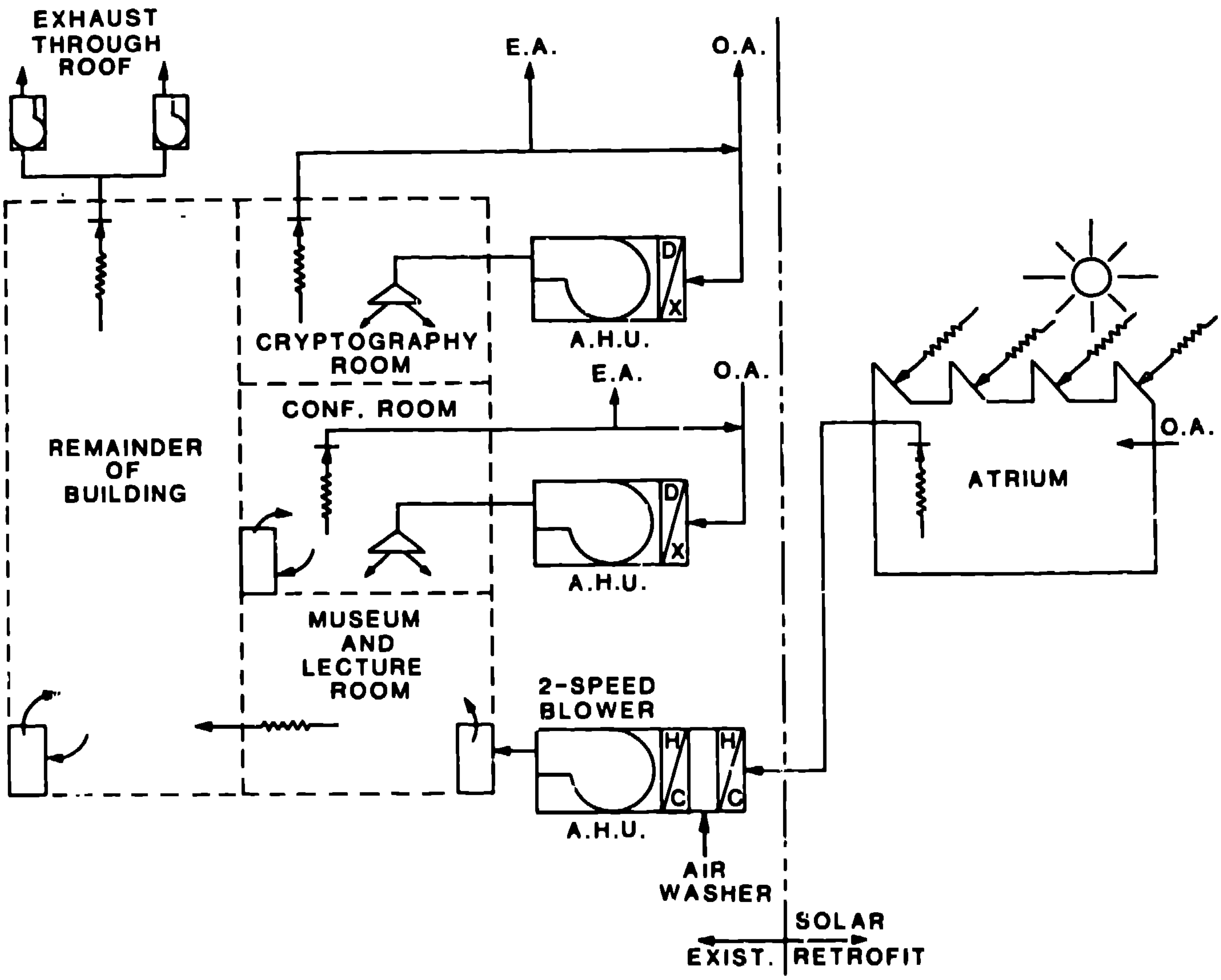

Fig. 2. Schematic of the winter operating mode showing the passive solar/HVAC system integration.

Additional DOE-2.1 simulations were run to determine the effect of coupling the atrium with the HVAC system by ducting return air from the museum/lecture rooms and the conference room to the atrium, thus using the atrium as a plenum to mix outside (makeup) and return air. We also analyzed an alternative that assumed that all of the return and outside air was diverted directly to the air-handling unit. The results of the analysis (Ref. 2) showed no significant advantage in coupling the atrium to the HVAC system as described above. These results suggested a more promising coupling, the one actually implemented, where the makeup air is induced through the atrium (using it as a preheater) but where the return air is ducted directly to the air-handling unit.

The most significant advantage of exhausting the ventilation air through the atrium is the maintenance of acceptable comfort conditions in the atrium during the summer months. The high flow rate of ventilation air through the atrium during the summer keeps the atrium near the outside ambient temperature and provides the air flow quantities required for ventilative and evaporative cooling of conditioned spaces within the building.

Finally, the simulations showed (Ref. 2) that as the glazing area is increased, there is a steady decline in the building heating energy requirement. However, it was determined that a maximum glazing area of 1600 ft^2 was all that could be installed over the 3600 ft^2 courtyard without significant shading of the aperture in midwinter.

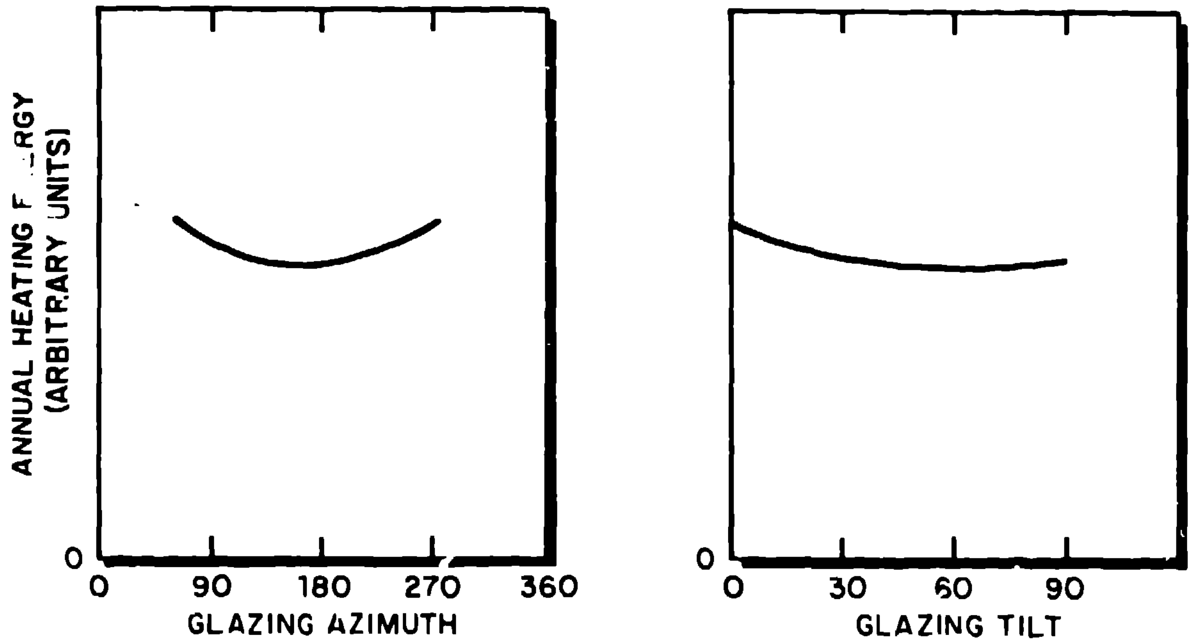

Fig. 3. Glazing orientation and tilt angle optimization.

Design Issues

The schematic design described above (Figs. 1 and 2) was refined to working drawings by the architect/engineer (A/E) firm of Gordon Herkenhoff and Associates, Albuquerque, New Mexico. During design development, several issues had to be resolved within the constraint of a fixed (and limited) budget.

First, the cross-sectional shape of the clerestory windows had to be determined. Two approaches were proposed by the A/E: a sloped-back design and a vertical-back design (see Fig. 4). Both approaches met the criterion that no greater than 10% of the aperture be shaded at noon on December 21, and both incorporated a 55° glazing tilt angle determined to be optimal for space heating. Whereas the vertical-back design offered greater structural simplicity, allowed for a simpler design for the moveable insulating shutter (with less area to cover), and was estimated by the A/E to cost less than the sloped-back design, it had the disadvantage of greater reflective losses from the back (or north) clerestory member.

However, the key to the decision on this matter rested with the daylighting and architectural considerations. The sloped-back design admitted more direct sunlight into the space and would cause severe glare problems without an extensive (and expensive) system of baffles. Furthermore, the sloped-back design produced an atrium ceiling that would be imposing to visitors viewing the ceiling and the museum displays; a less-imposing, softer architectural feel to the ceiling was desired for the considerable number of visitors expected for the museum. To test the daylighting and aesthetic aspects of the two designs, a scale model of the atrium was built. This model incorporated interchangeable clear and diffuse glazings so that their effect on the daylighting could be assessed. The model was viewed outside under clear, cloudy, and partly cloudy conditions. While no light level readings were taken in the model, we concluded that the vertical-back design provided high quality daylighting as well as a softer feel to the ceiling. It was also concluded that the diffusing glazing provided more even lighting without high contrast bright/shadow areas. Therefore, the vertical-back design with diffusing glazing was selected with a net aperture area of 1520 ft^2. The metal acoustical ceiling deck and all metal surfaces in the clerestory are painted white for an even solar reflection and daylighting effect.

A rendering of the final clerestory design is shown in Fig. 5. Note the detail of the moveable insulating shutters. They are hinged at the bottom on the vertical-back member and are stowed in the vertical position. They close by rotating to a near-horizontal position, resting on a stop just below the south glazing. The shutters consist of 2-1/2 in. of mineral wool insulation enclosed in a 22-gage sheet metal casing, resulting in a R-5 overall insulating value. The 10-ft long sections are actuated by cables driven by motors controlled by a time clock.

The clerestory window and roof system is made of tubular trusses that span the full 60 ft in both directions and are pitched to roof drains on the existing building. The opaque portions of the roof are insulated to R-30.

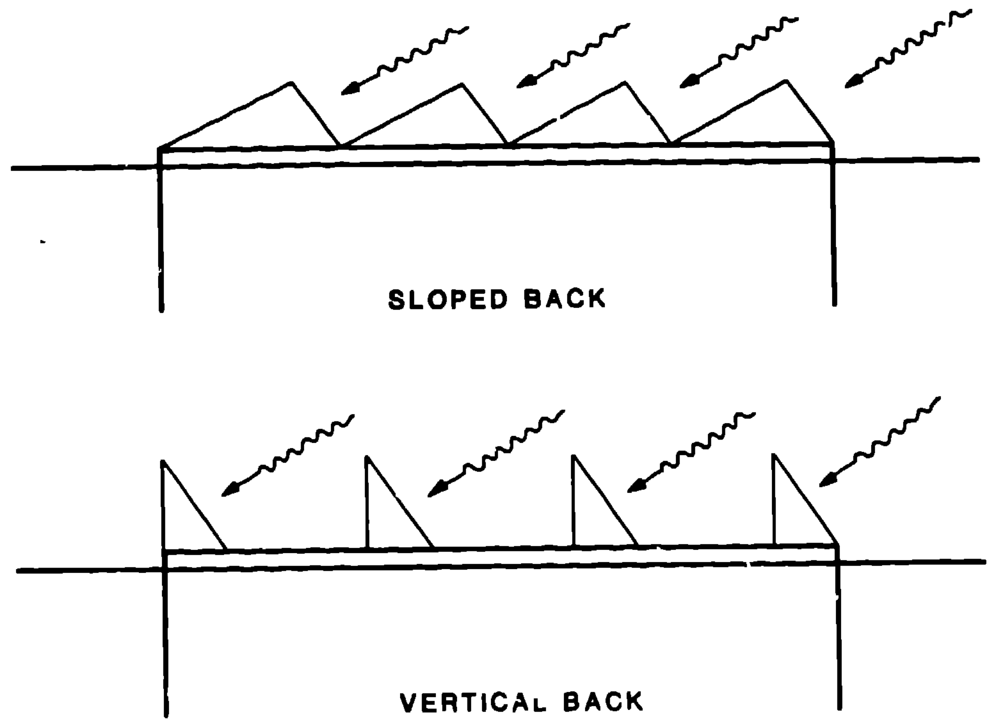

Fig. 4. Sloped-back and vertical-back clerestory design concepts.

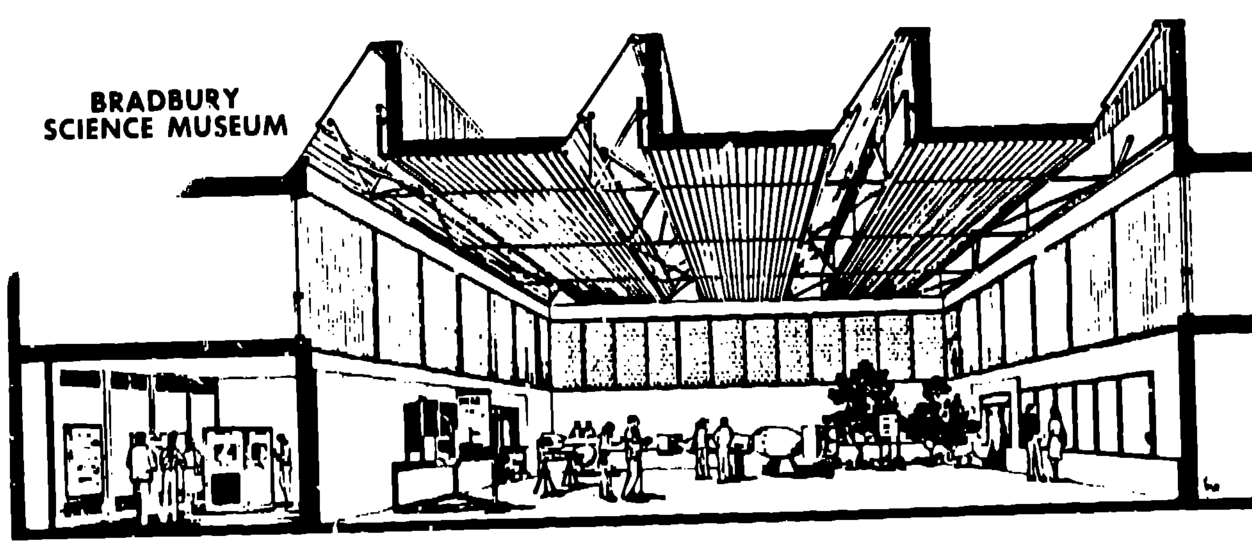

Fig. 5. Rendering of the final design for the atrium.

Operating Modes

During the daytime, the insulating shutters are open. In the winter (Fig. 2), solar energy enters the clerestory windows and heats the walls, the floor, and the air in the atrium. The warm air stratifies in and just below the clerestories. When the building is occupied, the air-handling unit blowers are on and outside air is drawn into the east end of the clerestory through motor-operated dampers. This outside air is heated as it travels the length of the clerestory and is drawn through ducts located at the west end of the clerestories; this air is then drawn into the air-handling unit for the museum where heating coils boost the air temperature, as needed. The air is then discharged into the museum, heats this space, and finally is exhausted by the exhaust fans on the roof of the existing building. The HVAC system for the cryptography and conference rooms operate independently.

In the summer, the blower speed is tripled over that for the winter. In this case, outside air is drawn directly into the air-handling unit for the museum. The museum supply air is evaporatively cooled, as necessary, and is discharged into the museum. A fraction of the museum supply air is exhausted from exhaust fans on the roof of the existing building; the remaining fraction returns to the atrium through louvers above the doorways between the museum and the atrium and is exhausted through the dampers at the east end of the clerestories. The high air flow through the atrium, coupled with the discharge of evaporatively cooled air from the museum through the atrium, maintains comfortable conditions in the atrium.

Cost Analysis

A cost breakdown for this project is shown below.

Design	\$ 24.4K
Construction Contract	182.3K
Contingency Expended	17.7K
Total Project Cost	\$224.4K

For purposes of comparison with other projects, the total constuction cost was \$200.0K. In terms of the added 3600 ft^2 museum space that was created by the project, this amounts to \$55.6/ft^2 of space provided. This compares very favorably with typical construction costs for office space at the Laboratory that are approximately \$85 ft^2. As a passive solar retrofit, the normalized construction cost is \$131/ft^2 of aperture. This illustrates the considerable expense of a retrofit of this type. Note that this includes the cost of a temporary security fence required for construction and modifications to the existing building required to integrate with the passive solar system.

PROBLEMS ENCOUNTERED

The major problem encountered on this project was the decision between the sloped-back and the vertical-back clerestory designs. This had to be resolved early in the A/E design process. The crude, quickly built scale model used to test the daylighting and architectural appearance of the roof system proved to be a most valuable tool. If quantitative daylighting data were required, greater care in constructing the model would have been necessary.

A second problem was the details of the insulating shutter design. The original approach using horizontal sliding garage doors that moved on tracks was abandoned because of their appearance and potential maintenance problems. The rotating panel arrangement in the final design proposed late in the design and required considerable redrawing. However, the better appearance and simpler operation of this approach were well worth the redesign effort required.

During construction, the major problem encountered was an undersizing of the insulating panels that necessitated changes in the panel closures. This undersizing occurred because the dimensions on the shop drawings were not carefully checked for consistency with the construction drawings. This situation was related to the general problem of shop drawing reviews we encountered. Because the shop drawings were not reviewed in a timely manner by the owner, construction delays resulted. Other problems, standard to any design and construction project, were certainly encountered but will not be discussed here.

CONCLUSIONS

The design and construction of this passive solar retrofit has resulted in the following conclusions.

1. This passive solar retrofit has provided 3600 ft^2 of new museum space whose heating and lighting (excluding museum exhibit task lighting) are entirely supplied by passive solar means. In addition, a slight decrease (5-10%) in the heating energy use of the existing office building/museum is expected because of the passive solar retrofit.

2. To avoid many problems, the A/E selected for a passive solar commercial building design should be experienced and knowledgeable in passive solar design, especially in the design details.

3. DOE-2 was an effective design tool during the conceptual design of this project.

REFERENCES

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