Using the Earth to Save Energy: Four Underground Buildings

Michael B. Barker

Abstract—*Four energy-conserving buildings are described and the reasons for building underground are explored. Reduction of conduction, flattening peak space conditioning loads, controlling air infiltration and the effects of evaporation are discussed.*

Résumé—*Le document présente quatre cas de construction économisant l'énergie et explore les raisons pour utiliser la construction en sous-sol. La réduction des échanges de chaleur, la diminution des coûts d'energie en heure de pointe, le contrôle d'arrivée de l'air et les effets de l'évaporation sont également discutés.*

Introduction

When I first began writing about the use of the earth in architecture, earth sheltering was viewed as something as a curiosity. Now, 12 years later, established clients and architects are increasingly turning to the use of the earth in building projects. What was once a curiosity is now a recognized design response to building program requirements.

The pioneers on the road to acceptability were those hearty souls, mostly do-it-yourselfers, who discovered the energy-conserving properties of earth sheltering in their own home-building projects. The field owes a great deal to these individualistic home-owners who demonstrated that earth sheltering can be energy efficient, aesthetically pleasing, and highly durable. Today there are thousands of earth-sheltered housing units across the United States.

Unlike residential construction, in which the purpose of using earth is primarily to save energy, institutional and commercial buildings use earth sheltering to: (1) use scarce land more efficiently; (2) protect aesthetic and historic qualities; and, in some cases, (3) provide security. The four buildings discussed in this paper fall into the commercial and institutional categories. Energy conservation, while important, was not the sole determinant in using the earth in the construction of these buildings. Additional non-energy-related benefits of subsurface construction include protection from surface noise and vibration, low exterior maintenance costs, and protection from disasters such as tornadoes.

Since the ITA working group on subsurface planning has been emphasizing energy conservation in its information exchanges in the last two years, it is appropriate to briefly describe the following four basic principles for saving energy through earth sheltering.

(1) reduction of conduction;

(2) flattening peak space conditioning loads;

(3) controlling air infiltration; and

(4) cooling through evaporation.

These energy-saving principles are incorporated in most energy-conserving earth-sheltered buildings.

Reduction of conduction. A popular misconception about earth is that it is a good insulator. On the contrary, earth is a poor insulator, particularly when compared to commonly available insulating materials used in building construction. But even a poor insulating material can insulate effectively if it is massive enough. The fact that heat loss must flow vast distances makes earth a suitable blanket in which to wrap a building.

Flattening peak space conditioning loads. The temperature of the earth just a few meters below the surface is stable in the 5–15°C range all year long. When the weather is extremely cold, the earth is a source of heat. Likewise, when the weather is extremely hot, the earth provides a source of cooling. Energy is needed only to overcome the difference between the earth temperature and a comfortable temperature, thus flattening the peak energy requirements for space conditioning. The result can be smaller heating and cooling systems that lower initial construction costs in addition to reducing operating expenses. In essence, the earth moderates the environment in which the building is located.

Controlling air infiltration. The third factor in saving energy through earth sheltering is the reduction of infiltrated outside air. With the earth covering most of the envelope of a building, the building can be made more airtight. In surface structures, up to 35% of heat loss can often be attributed to air infiltration. However, too "tight" construction can cause the build-up of indoor air pollutants, which some experts say can be far more unhealthy than the worst outdoor urban smog. An earth-sheltered building offers greater opportunity to control the rate of outside air supply to the interior of a building.

Cooling through evaporation. The fourth principle deals with the natural absorption and dissipation of solar energy associated with an earth-covered roof. Such roofs are usually planted with grasses or ground cover to retard erosion and to improve the appearance of the building. The vegetation absorbs the sun's rays before they reach the earth. In addition, the natural evaporative process from plant materials has a cooling effect that helps prevent a build-up of heat on the building's roof, thus reducing cooling costs.

The four buildings discussed in this paper are:

(1) The Civil and Mineral Engineering (CME) Building at the University of Minnesota— completed in 1983.

(2) The Central Pre-Mix Concrete Plant in Spokane, Washington— completed in 1981.

(3) The University of Michigan Law School Addition— completed in 1982.

(4) The Jefferson Elementary School in Walla Walla, Washington— completed in 1982.

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The Civil and Mineral Engineering Building — University of Minnesota

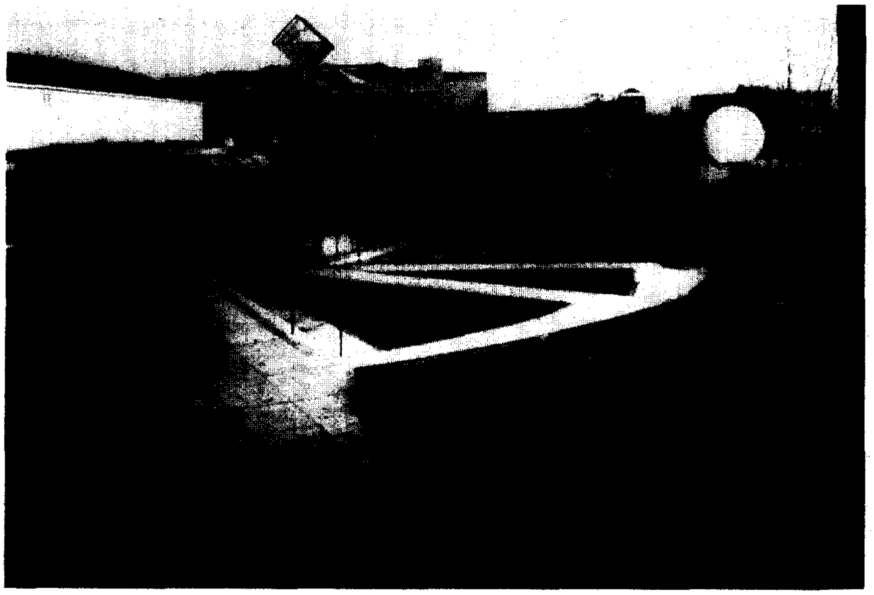

Figure 1. Entrance plaza and west elevation of the University of Minnesota's Civil and Mineral Engineering (CME) Building.

When the Minnesota State Legislature was considering adding a major new engineering building to the University of Minnesota campus in Minneapolis, it was decided that the building should itself be an example of innovative construction and energy efficiency. There is a high consciousness of energy efficiency in the state of Minnesota because it has a harsh climate and few indigenous energy resources. The fact that Minnesota winters are particularly long and extremely cold partially accounts for the great interest in earth-sheltered construction in Minnesota. Indeed, the University of Minnesota's Underground Space Center is the most active group examining the advantages of subsurface construction in the United States. Fittingly, the Center's headquarters are in the new CME building at the University of Minnesota.

The State Legislature of Minnesota got what it bargained for in the new CME building. It is considered to be one of the most innovative buildings in the United States today, from both the design and the energy conservation points of view. The building received the 1983 Outstanding Civil Engineering Achievement Award from the American Society of Civil Engineers, as well as many other awards.

The building contains classrooms, laboratories, faculty offices, and a large testing hall. The construction budget was approximately $13 million for the 13 950 m^2 area of the building. Approximately 95% of the volume of the building is subsurface, and approx. one-third of the floor area (comprising 4464 m^2) is located in deep underground mined space, 33 m below the surface of the earth.

The unique geology of the area made the deep mined-out space economically and structurally feasible. Beginning approx. 24 m below the surface is a large strata of easily mined sandstone. Above that is a 9-m layer of strong limestone that provides the structural strength for the roof of the mined-out area. Finally, on top of the limestone is an additional 15 m of soil. In essence, a cavern was created and a free-standing building was then constructed in the mined-out space. The constant temperature in the mined-out space substantially reduces the need for energy in both the heating and cooling cycles. Furthermore, water—which could have been a problem in a mined out space—is used to cool the building's computer systems.

The deep-mined space has a unique system of solar optics that brings light and outside images to the lowermost level. The architects discovered that natural lighting went a long way toward alleviating the sense of claustrophobia one might feel in being located so deep below the surface of the earth. Solar optics systems also bring light into the less deep portions of the building.

On the exposed surfaces of the building, both passive and active solar

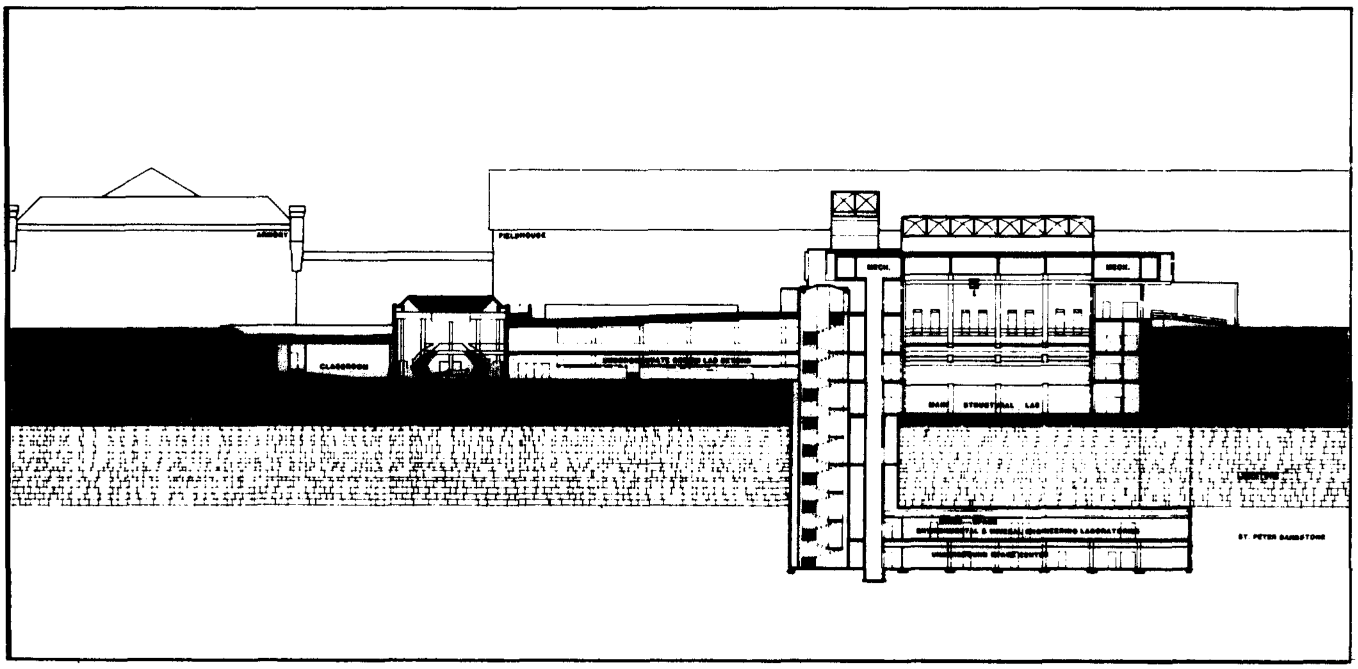

Figure 2. Section of CME Building showing mined space.

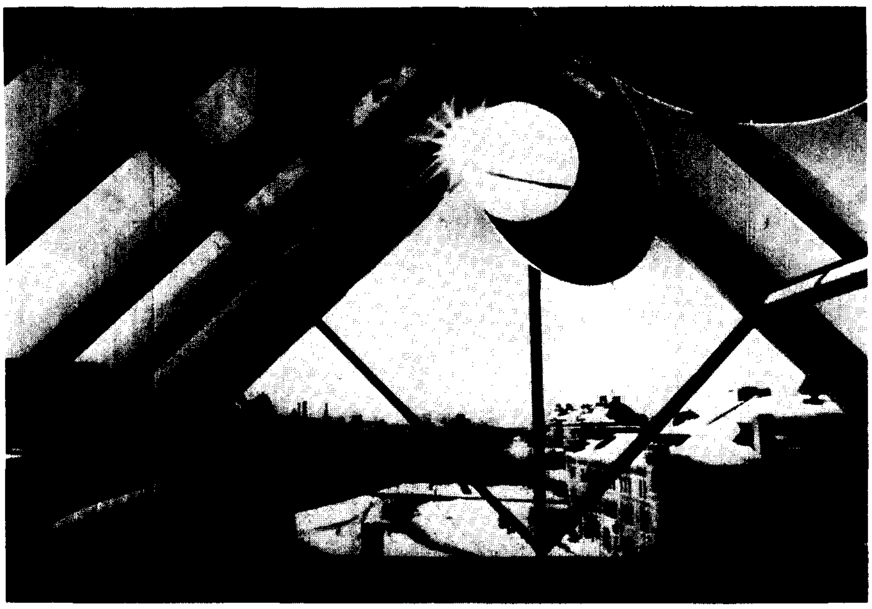

Figure 3. Solar optics system for the CME Building.

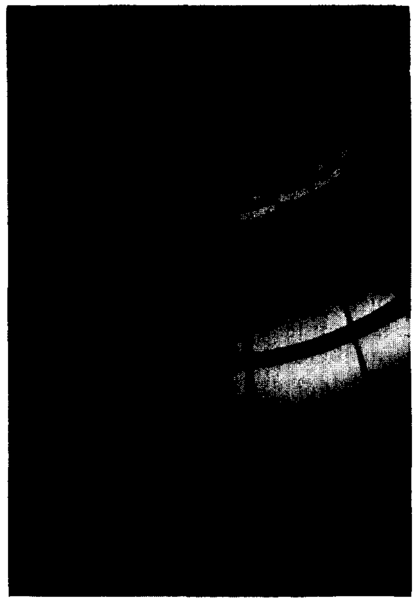

Figure 4. Entrance shaft to mined space in CME Building.

energy systems are used. On the southwest facade of the building, an active water-filled trombe wall system operates in both a warming and a cooling cycle. Passive solar energy is also collected in the area of the faculty offices, which are on the southwest side, exposed to a sunken courtyard. Deciduous forms of vegetation control undesirable heat gain in the summer while allowing desirable heat gain to build up in the winter.

The building uses two basic types of underground space: approx. two-thirds is of the cut-and-cover type of construction, while one-third is in mined-out space. The structural system is fairly consistent throughout the building. Cast-in-place concrete walls, supporting columns, and waffle slab floors are typical. Innovation is not so much in the structural elements themselves as in how they are used.

In conclusion, the CME building consumes approximately one-third less energy than a surface building and provides a stimulating and unique environment for students and faculty. On a crowded campus, it provides desirable open spaces and courtyards in an area that would otherwise be filled with buildings. It demonstrates a unique combination of earth sheltering and active and passive solar systems. The building seems to be meeting the expectations of the University, its faculty and the students. Because of the innovative nature of the building, many studies will be done on its performance over the years. These will be most interesting.

Credits for the CME building are:

- University of Minnesota, owner;
- Department of Civil and Mineral Engineering, developer of mined space technology;
- BRW Architects, Inc., architecture and civil engineering;
- Charles Nelson and Associates, mined space consultant;
- Meyer, Borgman and Johnson, Inc., structural engineering;
- Oftedal, Locke, Broadston and Associates, Inc., mechanical and electrical engineering;
- Dr. Michael Duguay, Bell Labs, optical consultant;
- Glenn Rehbein Excavating, Inc., earthwork and mined space excavation;
- M.A. Mortenson Company, Inc., building general contractor;
- New Mech Companies, mechanical systems;
- Premier Electric Company, electrical systems.

Central Pre-Mix Concrete Company Corporate Headquarters — Spokane, Washington

The Central Pre-Mix Concrete Company is a large manufacturer of concrete building materials that serves the northwest portion of the United States. The earth-sheltered corporate headquarters was completed in 1980. The building was designed to: (1) exhibit architectural innovation using concrete; (2) establish a design oriented corporate image; and (3) demonstrate corporate concern for energy conservation.

The 1476-m^2 horizontal office building houses executive and management personnel dealing with sales, administration, accounting and data

Figure 5. The Central Pre-Mix Office Building-view from the entrance drive.

processing for the entire corporate operation. An open office system is used to maintain flexibility for potential expansion and to create a pleasing environment for the office workers. The earth-covered exterior walls are cast-in-place concrete with 5 cm of exterior rigid insulation. The total project construction cost was $896 000, or $607 per m^2.

The earth is used effectively in this project to achieve energy conservation. Heat transfer by means of infiltration is virtually eliminated by the monolithic earth covering. Also, heat transfer by conduction is reduced due to the insulating properties of the soil and the tendency of the surrounding earth mass to dampen fluctuations in seasonal temperatures. In Spokane, air temperatures vary between —23 and 48°C. Temperatures in the earth at a depth of 2 m vary from 5 to 16°C. According to the architects:

> "... special consideration was given to the placement of planted soil on the roof. In such an application, the value of the earth covering does not lie in its insulating properties. The amount of soil necessary that in a conventional roofing system also requires an unwarranted costly increase in structural support. The value of the earth covering lies in its relatively high mass and in its planted surface. As stated above, the mass of the earth covering dampens temperature fluctuations at the outside surface of the building. The lawn covering yields several benefits. It shades the surface of the soil on the roof and entraps a thin insulating layer of air. Furthermore, solar heat gain is eliminated by the release of moisture from the grass. (This phenomenon is graphically demonstrated in a comparison of surface temperatures on adjacent areas of unshaded grass and asphalt during a hot summer day.)"

Figure 7. "Open" office interior of the Central Pre-Mix Office Building.

This building successfully employs all of the energy conservation methods discussed in the opening section of this paper. The result has been a 50% reduction in the amount of energy consumed, compared to a conventionally constructed surface building of the same size and function.

Credits for the corporate headquarters are:

- Walker McGough Foltz Lyerla, architects;
- Riley Engineering, mechanical and electrical consultants;
- Lydig Construction Incorporated, general contractor.

University of Michigan's Legal Research Building — Ann Arbor, Michigan

The new Legal Research Building for the University of Michigan was designed to protect the existing gothic revival buildings and courtyards, which were designed in the 1920s. The new building had a space requirement of 5500 m^2. If it were built aboveground in a contemporary style, it would destroy the gothic feeling of the campus and the precious few remaining open spaces. Consequently, the decision was made to locate the building below ground for aesthetic reasons.

The architect skillfully designed the building so that each major space

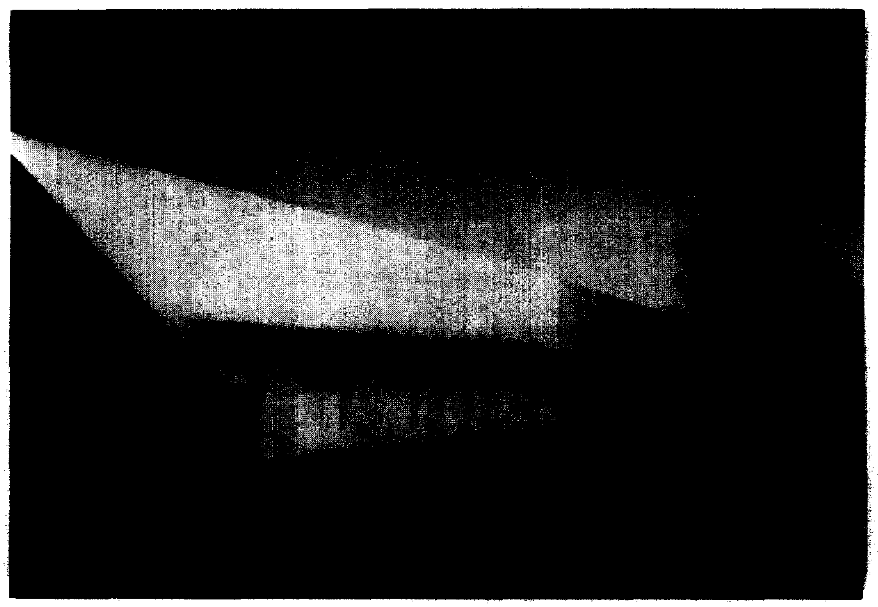

Figure 6. South elevation of the Central Pre-Mix Office Building.

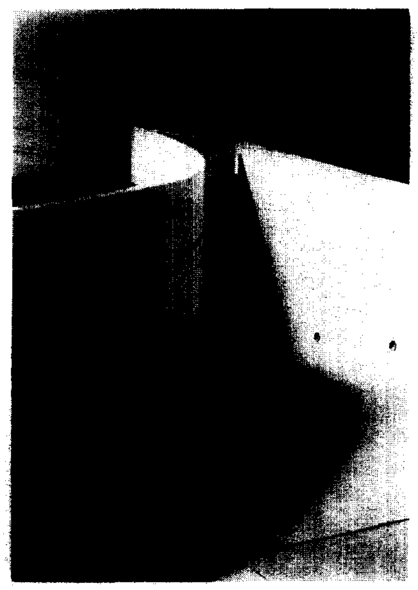

Figure 8. Entrance to the Central Pre-Mix Office Building.

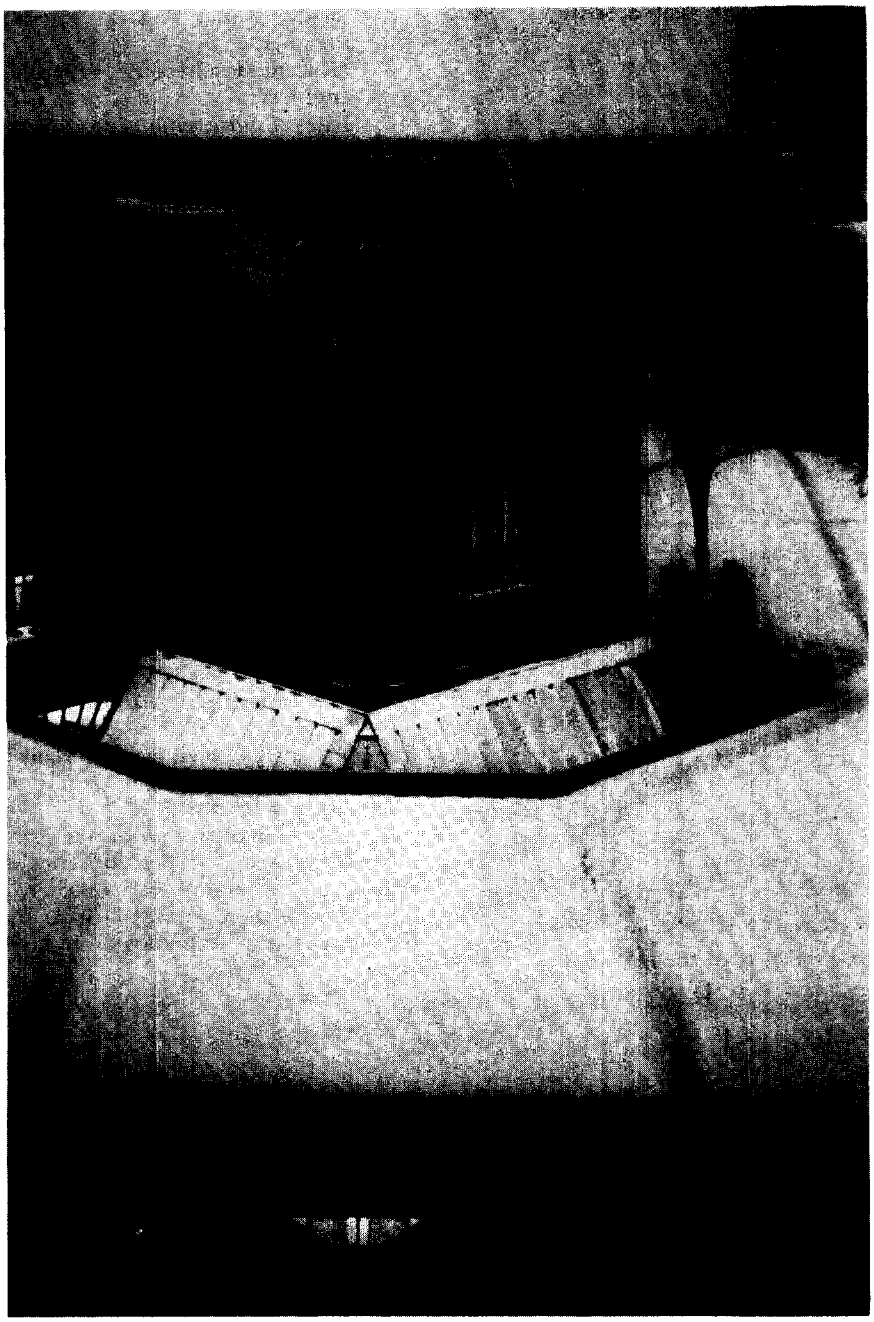

Figure 9. Bird's-eye view of the University of Michigan Legal Research (UMLR) Building showing the original law library, built in gothic revival style.

benefits from natural light. In most areas, two natural light sources are visible. As a consequence there is no sense of being buried while in the structure.

According to the *AIA Journal*:

> "The principal requirement for the library was to add space to the overcrowded gothic style Legal Research Building, and bring students, books, and staff into a close working relationship. The old building is a series of warrens where the library's 30 to 40 staff members were scattered horizontally and vertically in stacks and alcoves. The new $9.5 million building is L-shaped and designed as a single open space with tray-like floors arranged as balconies overlooking the window area. In front of the window is a grand stairway, which together with the glazed wall, serves as the chief interior design element. The stair angles up and down, with its landings as though suspended at the crook of the L between the limestone wall and balconies formed by the edge of each level."

Interestingly, the energy performance of this building has not been superior to above-grade structures of the same size built for the same purpose. The University administration is seeking ways to reduce the energy consumption of this building to exploit its potential energy advantages. The reason that this building is included in this paper is to show that all subsurface structures do not necessarily save energy. The large amounts of glazed areas in the building, as well as an excessive introduction of outside air, are the probable causes for the disappointing energy performance.

The users of the buildings, both students and staff, are delighted with the environment. The floor plan is highly functional, the lighting is excellent, and the view out towards the surface gothic structures is dramatic. Therefore, it can be said that the building is a successful design even though it does not save appreciable energy.

Credits for the Legal Research Building are:

- Gunnar Birkert, architect;
- Webber Darvas & Associates, structural consulting engineers;
- Joseph R. Loring & Associates, mechanical and electrical engineers;
- Wolf & Company, cost consultant.

Washington Jefferson Elementary School — Walla Walla, Washington

The Washington/Jefferson Elementary School is a dramatic design and engineering response to contemporary educational programming. In addition, the earth-sheltered design protects the historic significance of Ft Walla Walla and minimizes the consumption of energy. The total cost of the 6523-m^2, two-story building was $5 057 720, or $775 per m^2.

The school is located in Walla Walla, Washington, in the northwest corner of the United States. The site is adjacent to the historic Ft Walla Walla, which is on the National Register of Historic Places. When the 13-acre site was made available by the Veterans Administration, a requirement was placed on the design to minimize the visual presence of the school so as to protect the historic significance of the site. The earth covering and earth berming admirably achieved this objective.

The basic construction is poured-in-place concrete. Somewhat unusual is the fact that it is a two-story building with earth berming and earth covering. This requires a somewhat massive concrete structure. The floors are typically precast "double T's" with concrete topping at the upper level, and precast "single T's" at the roof, supported by cast-in-place reinforced concrete columns. Exterior walls are 10-in. thick with 5 cm of rigid insulation. Waterproofing is by rubberized asphalt sheet membrane. The roof is covered by 36 cm of topsoil, 10 cm of drainage gravel, a protection board, 10 cm of rigid insulation and the waterproof membrane.

Approximately 40% of the energy consumed in the operation of a school building is for artificial illumination. This not only requires electrical energy to produce a light, but also additional cooling capacity to neutralize the heat

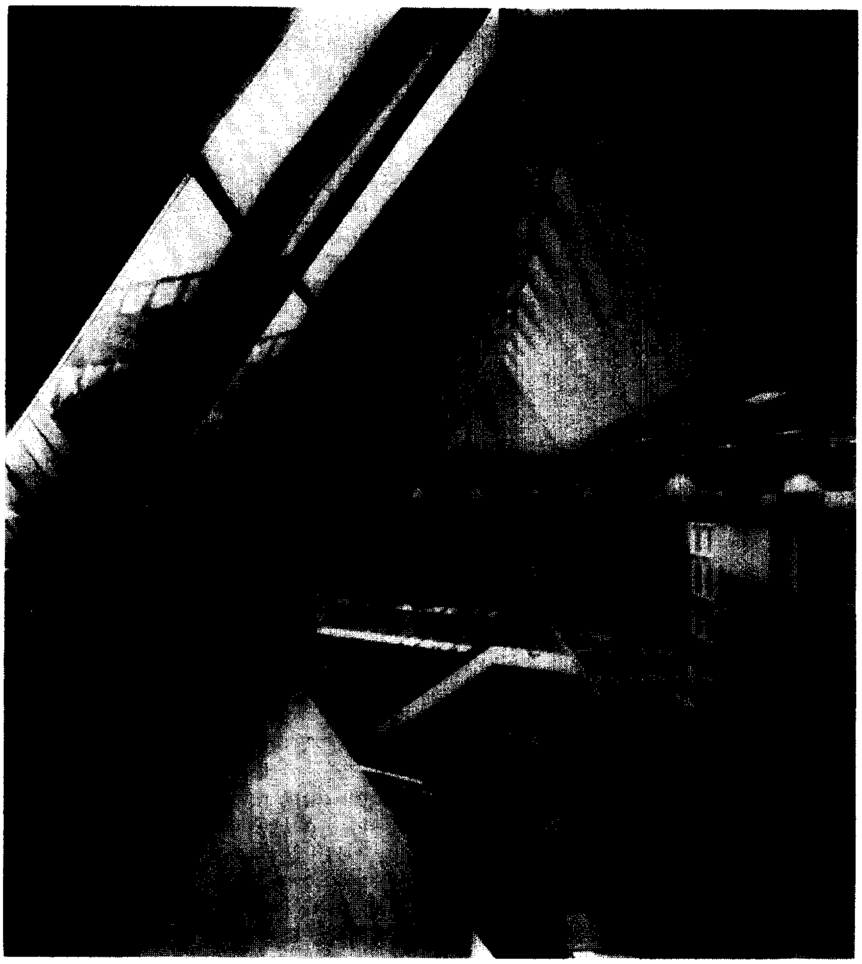

Figure 10. Interior view of the glazed wall and stairway of the UMLR Building.

gained in the operation of the lighting fixtures. Consequently, it is a great advantage to provide natural illumination wherever possible. This design admirably achieves this through bold exposures on the south elevation and imaginative skylighting.

During the winter, passive solar features will provide sufficient heat in combination with heat generated by lighting and occupants. Ninety-five per cent of the glass area is on the south side. During the summer the glass areas will be totally shaded, thus reducing the cooling loads by more than 30%.

The Washington/Jefferson school will require only 70% of the energy required by a conventionally constructed school building of the same size and quality above grade. Fifty-five per cent of the energy will be used for heating and air conditioning, 35% will be used for lighting and 10% will be used for all other needs, including hot water. Again, all of the techniques for conserving energy discussed in the opening section of this paper are utilized in the Washington/Jefferson Elementary School.

Credits for the school are:
- — Walker McGough Foltz Lyerla, P.S., architects and engineers;
- — Eric C. Benson, ASLA, lanscape architect;
- — Sandy Butler, ASID, interior designer;
- — Howard Mondress, PE, structural engineer;
- — Riley Engineering, Inc., mechanical and electrical consultants;
- — Towne, Richards & Chaudiere, Inc., general contractor;
- — Sceva Construction Company, Inc., general contractor.

Conclusion

The descriptions and illustrations of four recently completed earth-sheltered buildings in the United States constitute the third and final presentation I will make on the subject before the working group on subsurface planning, for two reasons. First, I believe that it has now been amply demonstrated that using the subsurface has become an important architectural response to energy conservation, protection of the environment and other problems of building design. Second, the working group on subsurface planning now needs to turn away from its concentration on energy savings to broader concerns: for example, the design of urban systems in cities.

Perhaps in another four or five years it would be useful to repeat the series of papers on important earth-sheltered buildings for the purpose of exploring the developing technology. In the

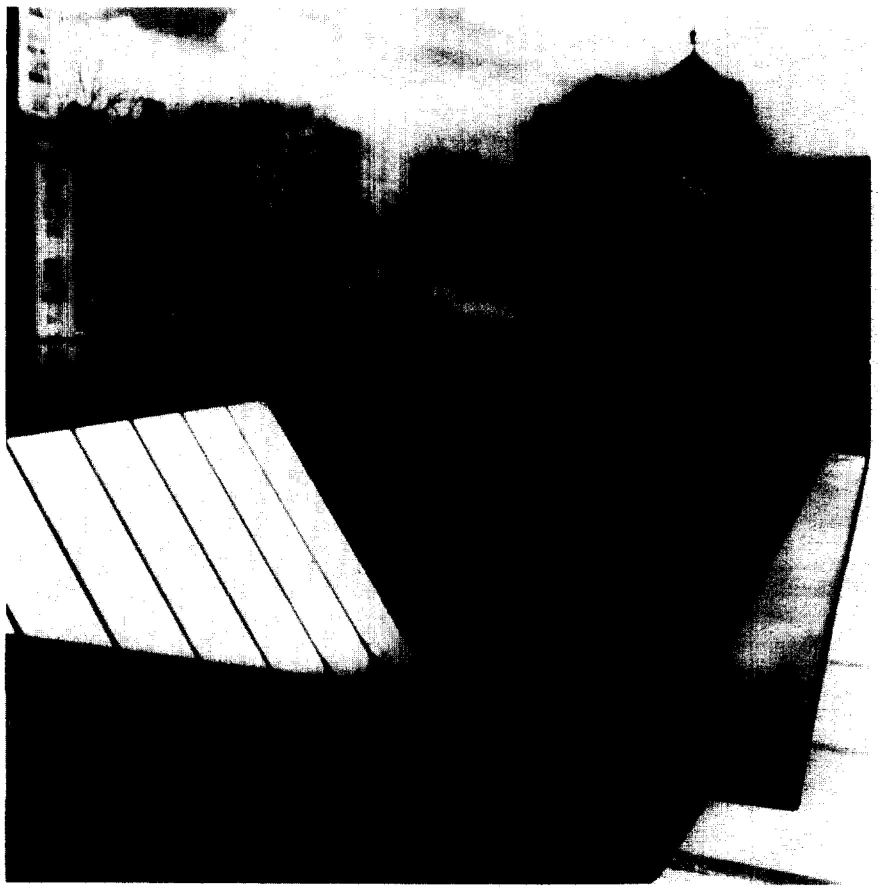

Figure 11. Exterior view of the UMLR Building's glazed wall, which abuts the gothic revival original law building.

Figure 12. View through the UMLR Building's glazed wall of the gothic revival original law building.

Figure 15. Interior view of the gymnasium of the WJES.

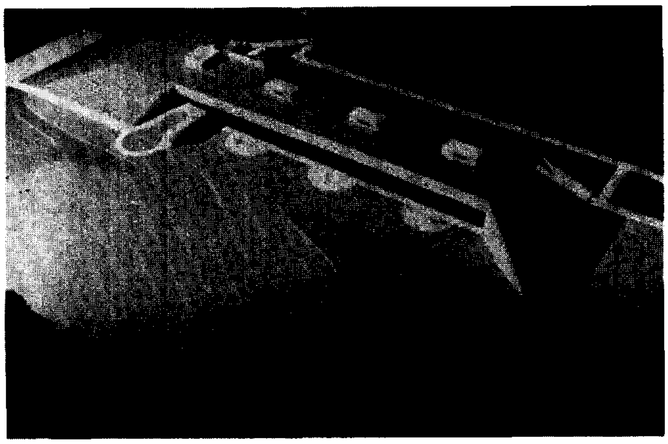

Figure 13. Model of the Washington/Jefferson Elementary School (WJES) showing earth covering.

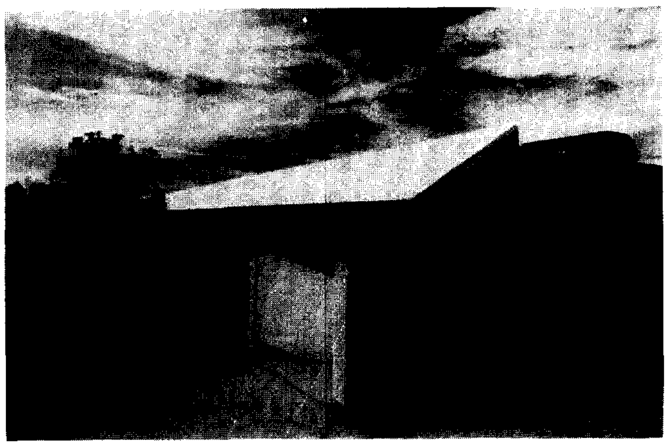

Figure 16. South elevation of the WJES.

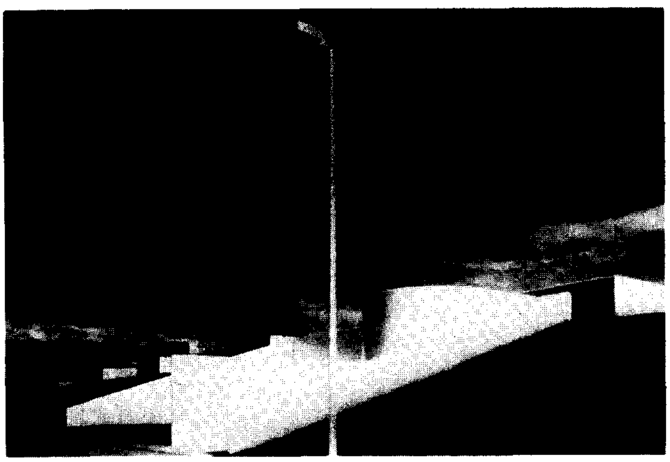

Figure 14. Entrance elevation of the WJES.

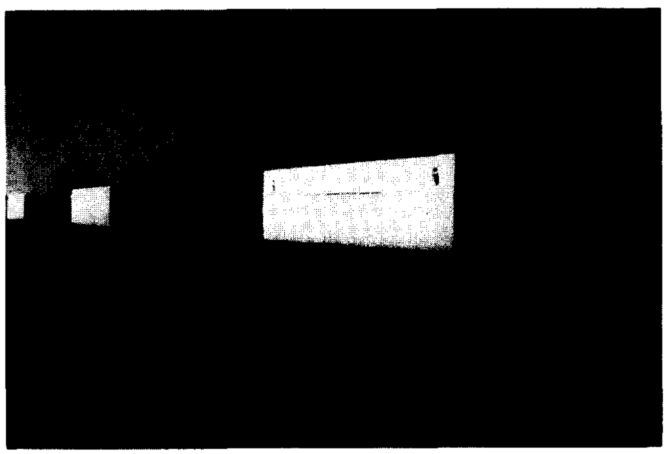

Figure 17. WJES roofscape, showing light wells and ventilators.

meantime, the working group has before it the interesting challenge of documenting the successful uses of the subsurface that have led to an improved quality of human life in urban environments.

The working group needs to examine underground pedestrian linkages, underground urban transportation spines, utility and service systems, and other potentially successful applications of the use of the subsurface. The working group should also pay attention to the institutional questions of planning for the successful use of the subsurface. Too frequently, institutional issues are overlooked until major problems result.

The sharing of ideas among our diverse countries ultimately will lead to a sounder application of design and engineering principles in our quest for improving the human condition. □