Energy Saving Precast Concrete Buildings

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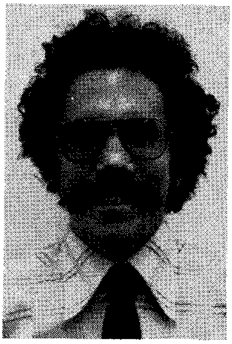

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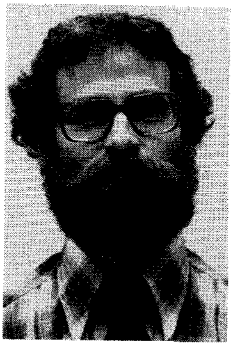

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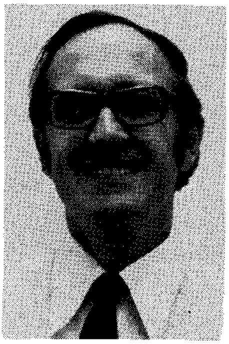

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The era of low cost, abundantly available energy is past, and building design must change so as to become more energy efficient. Fortunately for the precast concrete industry, concrete has properties that make it a desirable element of energy efficient building construction. The development of energy saving precast concrete buildings represents both a challenge and an opportunity to the industry.

The "energy crunch" of the seventies was dramatized in the United States by long lines at the gasoline pumps and the prospects of fuel rationing but especially by the soaring costs of gasoline and heating oil, as shown in Fig. 1. The rapidly escalating cost of oil is not just due to political and economic manipulation, but is also due to the fact that oil is a non-renewable energy source of finite quantity.

The rate of production of a non-renewable energy source increases with time, reaches a maximum and then gradually decreases. In the United States, the rate of production of oil reached a maximum around 1970 and

Rapidly escalating fuel costs are making the use of solar energy and earth sheltered buildings increasingly attractive. Precast concrete, due to its thermal properties, is well suited to the various types of passively solar heated and cooled buildings described here.

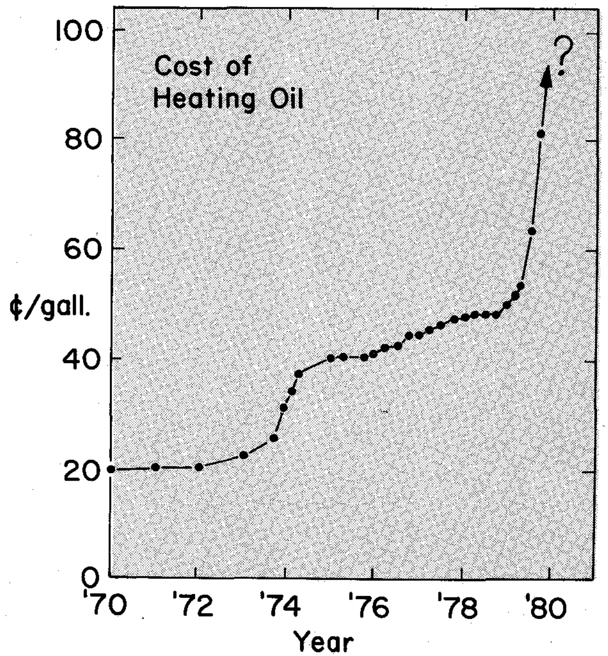

Fig. 1. Increase in the cost of heating oil (1970-1979).

is now declining. The world-wide production of oil is expected to peak soon and to commence declining in the not too distant future.* Similar variations in the production rates of other non-renewable energy sources are predicted. Against this background it is not difficult to foretell continually increasing energy costs in the future.

The considerable increase in the cost of energy in the last decade and the certainty of further increases in

*Atlantic Richfield Chairman R. O. Anderson, quoted by *Newsweek*, August 20, 1979, "There is every likelihood that the world has reached the maximum practical limits of (oil) production. We can expect the decline in production to begin in the next couple of years."

the future is changing the economics of building construction. It becomes increasingly worthwhile to invest money in making a building more energy efficient with a view to reducing the cost of energy used in its operation in the future. Precast concrete construction fits well into this scenario. Its superior performance in moderating the cooling load of a building due to the thermal inertia of concrete is well recognized and documented.[1]

Solar Energy

Since our conventional sources of energy are steadily increasing in cost and decreasing in availability, it makes sense to design buildings with a view to lessening their consumption of expensive non-renewable energy sources. This can be done by minimizing energy losses and by taking advantage of naturally available energy, i.e., solar energy. Actually, most of our conventional energy sources supply us with solar energy indirectly. When we use oil and coal, we tap the sun's energy stored millions of years ago by photosynthesis. Hydropower generation is possible because of the circulation of moisture from ocean to mountain top and back to the ocean — powered by the sun's radiant energy.

In the present context, the term "solar energy" refers to the direct collection and utilization of solar radiation, in particular for the heating and cooling of buildings.

It has been suggested that solar energy could be used to alleviate our shortage of energy by using it to power centralized electrical generating plants. Various approaches are under study and development. One[2] would utilize photo-voltaic solar electric cells to generate electricity directly. Another[3] would use concentrating solar collectors to provide heat for an otherwise conventional thermal power plant. A considerable amount of development work is in progress in these areas, but problems still remain to be resolved before these systems can become economically operational.

It does not appear, therefore, that our energy needs for the heating and cooling of buildings will be met in the near future by the use of electricity generated by solar-electric power plants. Fortunately, an alternative exists which can be used now. This alternate is the direct collection and use of solar energy at the site of a building to heat it or cool it and also for the purpose of heating water.

Actually, the on-site collection and use of the sun's radiation to heat buildings is thermodynamically more efficient[4] than the use of solar energy to generate electric power to use in the heating of buildings. This is because of the better match between the energy source and the task.

In the first case, diffuse low temperature radiation (low-grade energy) is used to provide low temperature heat (low grade energy). In the second case, concentrated high temperature radiation (high grade energy) is used to generate electricity, which is subsequently transmitted across the country and reconverted to low temperature heat (low grade energy) with greater losses of usable energy. (The electrical energy is better used where high grade energy is essential.) The difference in "thermodynamic" efficiency would be reflected in a difference in costs.

On-Site Collection and Use of Solar Energy for Heating

The systems used for the on-site collection and use of solar energy are designated as "Active" or "Passive" systems. In the active systems, the solar energy is intercepted by a collector in which circulates a working fluid, usually water or air. The work-

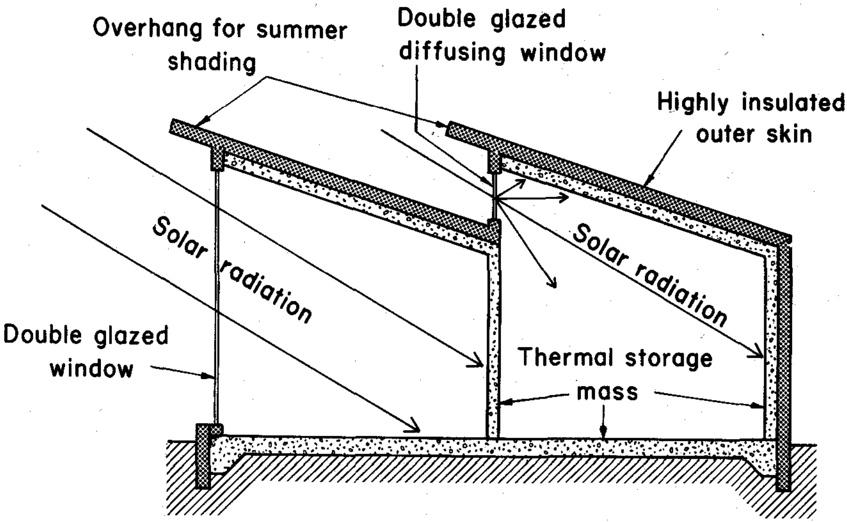

Fig. 2. Direct gain solar heating (day-time operation).

ing fluid is heated in the collector and pumped to the heat storage reservoir, where heat is extracted from it before it is returned to the collector. In passive systems, all or part of the building serves as both collector and heat storage reservoir. Heat transfer is by free convection, conduction and radiation; no pumps or blowers are required.

The active system, with its large collector mounted on the roof or side of the building, still typifies solar heating for the majority of people. However, in recent years it has increasingly been recognized that the passive system, or a hybrid combination of active and passive systems, is the most economical way to utilize solar energy in most new buildings. This is because the building structure is made to do double duty, performing its usual functions and also serving as solar energy collector and store. Appropriately designed precast concrete structures are well suited to this role by virtue of their inherent mass.

The simplest type of passive system is the "direct gain" approach in which the sun is allowed to shine directly into the building through south facing windows (see Fig. 2). These windows are double-glazed to reduce heat loss. To store the heat, the building is designed to include considerable thermal mass. This can take the form of concrete floors and ceilings, and concrete or masonry walls with insulation on the outside. A large part of the solar radiation is absorbed by the internal thermal mass, preventing immediate overheating of the building space.

In a properly designed structure, the floor, walls, and ceiling will reach a maximum temperature of about 85 F (29 C). When the room temperature drops below 65 to 70 F (18 to 21 C), or when people or objects in the room are cooler than this temperature, the floor, walls, and ceilings act as large low temperature radiators (see Fig. 3). Most of the heat is transferred by radiation and a small amount by convection. Radiant heating is the most efficient and comfortable means of heat transfer. The air temperature required for comfort is less with radiant heating than with convection or forced air heating.

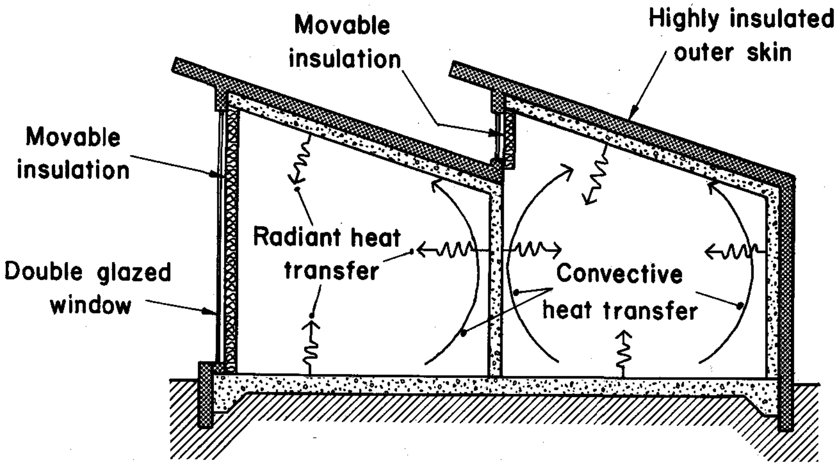

Fig. 3. Direct gain solar heating (night-time operation).

A daily variation in building temperature is inevitable when a passive system of solar heating is used. This variation is necessary for the structure to be able to alternately store and release energy. In a well-designed building, with the correct ratios of window area to floor area and to storage mass, the temperature swing can be held to from 10 to 15 F (6 to 8 C). The ratios will depend upon the type of building, degree of insulation, and other factors. It would also be necessary to provide insulating curtains or shutters over the windows at night to reduce heat losses. In the case of residential buildings, the total area of south-facing glazing would be between 20 and 30 percent of the total floor area, and the surface area of walls, floors, and other elements used as thermal mass should be at least five times the south-facing glazed area. It is advantageous if some of the south-facing glazing can be of a diffusing type so that the incoming sunlight is distributed over as large an area of wall, floor, or other surface, as possible.

Seasonal control of heating can be ensured automatically if an appropriately proportioned shading overhang is provided above the windows. This is because the south face is exposed to a maximum amount of solar energy in the cold winter months when the sun is low in the sky at mid-day and a minimum in the summer when the sun is up to 47 deg higher in the sky. In the winter the sun reaches deep into the building, while in the summer the roof overhang can be proportioned so as to keep all or most of the sun's rays out of the building.

The underlying principles of direct-gain systems have been known and used for hundreds of years. About 400 B.C., Socrates is reported[4] to have written, "In houses with a southern aspect, the sun's rays penetrate into the porticos in winter, but in summer the path of the sun is right over our heads and above the roofs so that there is shade."

In the southwestern United States, the Pre-Columbian Indians put this same knowledge to work in the planning and construction of their pueblos. They also used thermal mass to control building temperatures by using massive adobe walls.

Contemporary designers and builders are rediscovering these same prin-

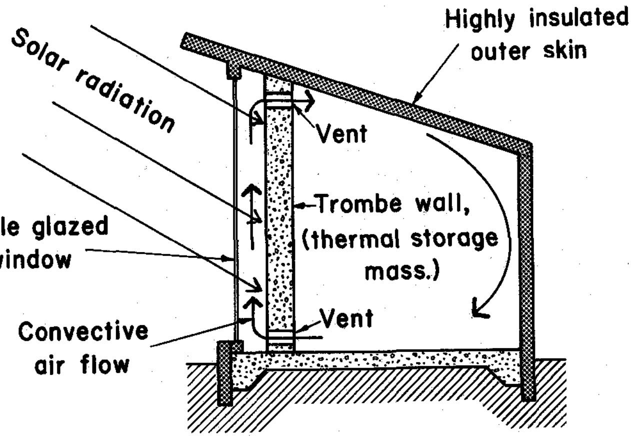

Fig. 4. Indirect gain solar heating using a Trombe wall (day-time operation).

ciples and putting them to work to help solve our energy problems. Because of concrete's thermal storage capabilities, this presents the precast concrete industry with an opportunity for an expanding market. Many common types of precast wall and floor units are suitable for the internal structural elements of a direct-gain heated building. However, for the outer walls, it is necessary to develop sandwich panels with as much of the mass as possible concentrated in the inner wythe and a much higher thermal resistance than has been customary—up to about R = 25 (RSI = 4.4).*

The minimization of thermal bridging across the insulation is extremely important. Appropriately developed plastic tie connectors between the wythes appear to be preferable to steel ties on this score. The inner wythe of the non-composite panel would be loadbearing and the outer wythe would provide mechanical protection to the insulation and provide the external appearance of the building. To reduce panel weight for handling, it might be desirable to replace the outer concrete wythe with a thin skin of glass-fiber reinforced cement or other lighter weight cladding material.

For roofs, also, a much higher thermal resistance than has been customary is desirable—up to about R = 35 (RSI = 6.2).* This could be provided using current methods of roof construction but incorporating a much thicker layer of insulation. Conventional precast roofing elements would be used.

The second type of passive solar heating system is the "indirect gain" approach. Typically a thermal mass is located immediately behind south-facing windows (see Fig. 4). This mass is heated by the sun's radiation and subsequently heats the inside of the building by radiation and convection. The thermal mass is usually water either contained in metal drums or vertical tubes, or a thick concrete wall. The latter is generally referred to as a Trombe wall, after Dr. Felix Trombe, Director of the French National Solar Energy Laboratory at Odeillo in the Pyrenees, who developed and publicized this idea† in the late sixties.

*The precise value will depend on building size and occupancy, and climatic conditions.

†A similar scheme, but incorporating a sheet of slate close to the glass was used by E. S. Morse in two buildings in Massachusetts in the 1880's.[5]

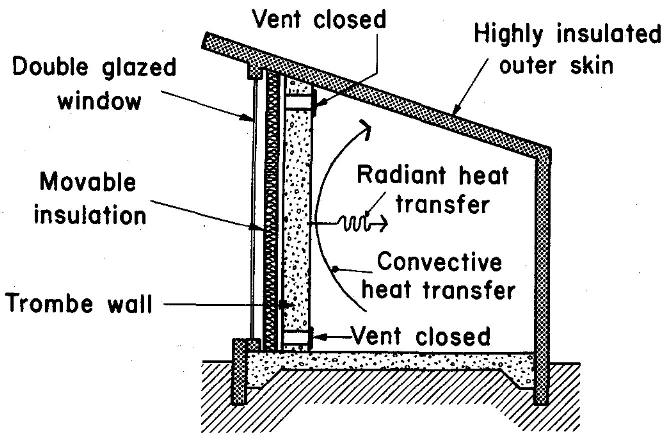

Fig. 5. Indirect gain solar heating using a Trombe wall (night-time operation).

In the Trombe wall system, closable vents are provided near the top and bottom of the wall, which is usually painted some dark, heat-absorbing color. On a cold sunny day the dark concrete surface absorbs the solar radiation and heats up to about 150 F (66 C). The glass in front of the wall reduces heat loss by low temperature radiation (the "green-house effect") and by suppressing convective losses to the outside air, and so the majority of the heat passes into the wall. The air between the glazing and the wall is also heated, rises, and passes into the interior of the building through the top vents. At the same time, cool air is drawn out of the building through the bottom vents, subsequently to be heated and returned to the building. Daytime heating is therefore achieved primarily by natural convection and to a minor extent by radiation from the wall.

At night, the Trombe wall vents are closed and an insulating curtain or shutter is put between the glazing and the wall (see Fig. 5). Heat is then transferred from the wall to the interior of the building by radiation and by convection currents caused by the heating of the air adjacent to the wall.

An advantage of the concrete storage wall is that it provides a time delay between the absorption of solar energy on the outside of the wall and the delivery of that energy to the interior of the building, due to the thermal inertia of the mass of concrete. This time delay is typically from 6 to 12 hours, depending on the thickness of the wall. Thus, the maximum availability of heat by radiation occurs at night when the convection heating is not available. This time delay is illustrated in Fig. 6, which shows the variation of temperature with time at increasing distances from the outside face of a 12-in. (30 cm) thick concrete wall. It can also be seen that the temperature range decreases as the distance from the outside face increases.

The storage wall thickness appropriate to particular usages will vary. Trombe used 60 cm (2 ft) in his first house in the Pyrenees. With the building temperature controlled at 68 F (20 C) the wall provided about 70 percent of the total thermal energy required to heat the building over a one-year period. Subsequently, thinner walls were tested and Trombe and his associates concluded that about 40 to 45 cm (16 to 18 in.) would be an

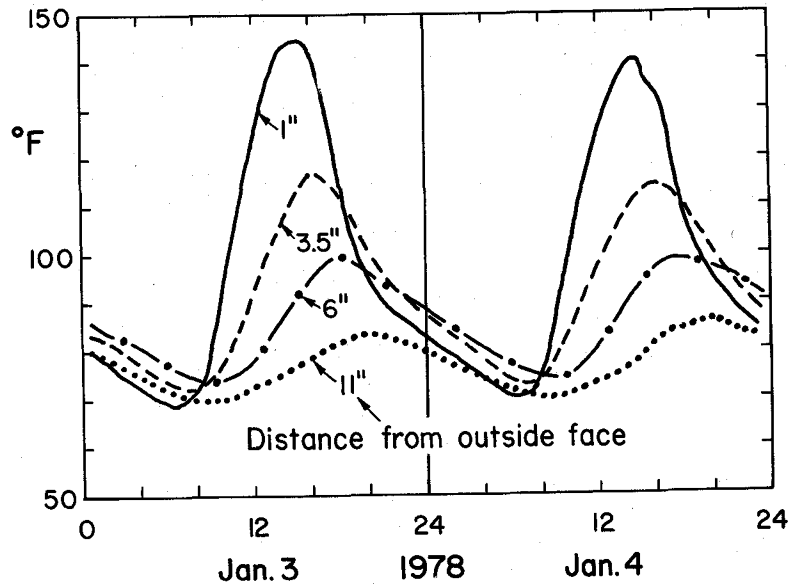

Fig. 6. Variation of temperature at different distances from the outer face of a Trombe wall (after Balcomb[6]). Note: 1 in. = 2.54 cm; C = (5/9) (F − 32).

optimum thickness.[4] Computer simulation studies by Balcomb et al.,[7] for various locations in the United States, indicated that if the building temperature can vary between 65 and 75 F (18 and 24 C), then a 12-in. (30 cm) thick concrete wall gives the highest contribution to total thermal energy required per year. This thickness corresponds to a thermal storage capacity of 30 BTU/deg F per sq ft (613 kJ/deg C per m^2) of glazing.

The Trombe walls that have so far been built have generally been cast-in-place concrete or reinforced concrete masonry in which all the voids in the blocks were filled with normal weight concrete or mortar. While a solid Trombe wall of 12 in. (30 cm) or more thickness might be too heavy to make precasting attractive, a hollow-core slab section could perhaps be used as permanent formwork for such a wall. The voids in the section would then be filled with low-slump concrete so as to minimize the moisture content of the wall.* Alternatively, two 6-in. (15 cm) thick slabs could be precast and be attached to one another, face to face. If this were done it would be necessary to ensure intimate contact between the faces. This could be achieved by casting one slab on top of the other (as in lift-slab construction), or by leaving a small space between the slabs to be filled with an expansive grout.

As mentioned previously, water filled steel tanks or tubes are sometimes used as the thermal storage mass. Their advantages compared with a cast-in-place Trombe wall are lower first cost, greater thermal storage capacity for a given volume, and, by use of greater volumes, the possibility of increasing the percentage of the annual thermal energy requirement provided by solar energy.[7] Their disadvantages are higher maintenance costs and little delay in transmitting

*This is desirable so that the amount of solar energy diverted to drying out the wall in its early life is minimized.

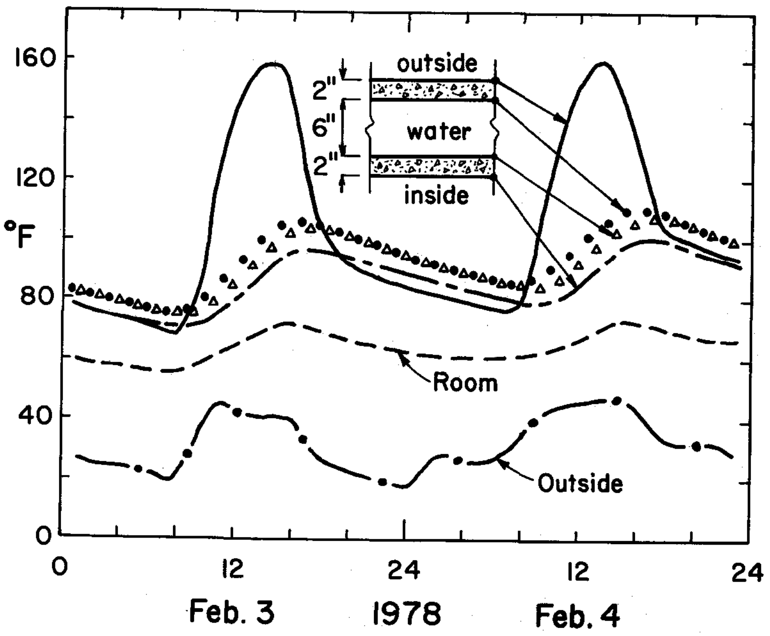

Fig. 7. Variation of temperature in a "water-loaded" Trombe wall (after Balcomb[6]). Note: 1 in. = 2.54 cm; C = (5/9) (F − 32).

heat to the inside of a building due to the effect of convection currents in the water, resulting in greater variation in room temperature than for a solid wall.

In an attempt to obtain the advantages of both the solid concrete wall and the water wall, a trial has been made using 4 x 8 ft. x 10 in. (1.2 x 2.4 m x 25 cm) overall dimension concrete water tanks with a wall thickness of 2 in. (5 cm).[6] The water was contained in a sealed plastic bag placed in the cavity. This is called a water-loaded Trombe wall. The typical behavior of such a system is shown in Fig. 7. The designer, W. Nichols, concluded that future walls of this type should be made thicker to provide greater thermal storage capacity, so as to maintain the wall warmer during long cloudy periods.

A possible adaptation of this idea to precast concrete would be to use a hollow-core slab as a water-loaded Trombe wall containing the water in thin plastic tubes placed within the voids. In a typical 12-in. (30 cm) thick slab with 10-in. (25 cm) diameter voids, approximately one-half the volume of the wall would be water. This would result in an increase in thermal storage capacity of about 50 percent, as compared to a solid concrete wall.

Also, compared to filling the voids with concrete, the cost may be less. Since 50 percent of the cross section is concrete, there should be a greater time delay in transmitting heat through the wall and lesser inside temperature fluctuation than in the case of the metal tube water wall. The greater thermal storage capacity would possibly increase the percentage of required thermal energy obtained from the sun.

This idea requires further study, from both a technical and economic viewpoint. A possible concrete technology problem may lie in the

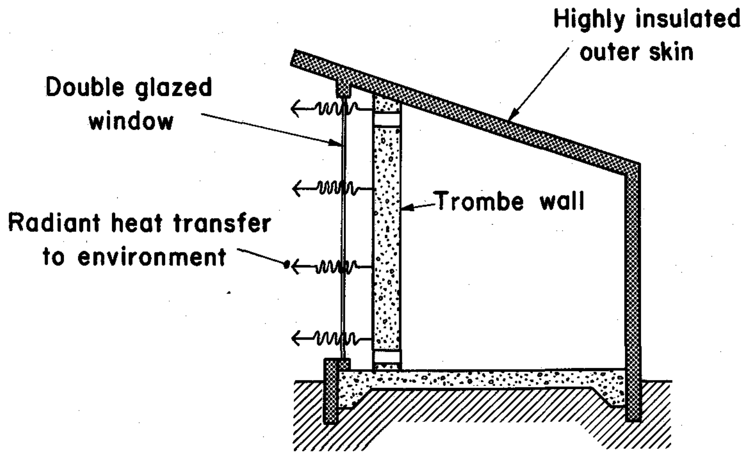

Fig. 8. Night-time operation of an indirect gain system used for cooling.

cyclically occurring steep temperature gradient between the outside face and the concrete-water interface near to it. A maximum temperature difference of 60 F (33 C) is probable. However, the idea does merit further study.

If a Trombe wall is used, thermal mass is not essential in the other walls of the building, but they must be heavily insulated as in the case of the direct gain system. Lighter weight cladding panels incorporating insulation up to about $R = 25$ (RSI = 4.4) would appear to be a suitable precast concrete product.

Other variations of the "indirect gain" passive system include the attachment of an extensively glazed "sun room" or greenhouse to the south face of the building with a thermal mass storage wall separating it from the rest of the building. The opportunities for utilizing precast concrete in such structures are similar to those already described.

On-Site Collection and Use of Solar Energy for Cooling

Both "Active" and "Passive" systems can be used for the cooling of buildings. In the active system, water heated by a concentrating solar collector is used to heat the refrigerant solution in an absorption refrigeration cooling system.

In the passive system, the same elements used for indirect gain solar heating are used in a different way to cool the building. At night, in the cooling mode, the movable insulation is retracted and the Trombe wall cools by radiating heat to the outside, as seen in Fig. 8.

During the day, two alternate modes of operation are possible. In the first, the insulating curtain or shutters are put in place between the Trombe wall and the glazing, in which vents are opened at both top and bottom (see Fig. 9). The light colored or aluminized outer face of the insulation reflects the solar radiation. The air between the glazing and the insulation rises as it is warmed by the solar radiation, passes out of the top vent, and draws cooler air in at the bottom, helping to keep the insulation and the wall cool. The wall, cool after radiating heat to the outside during the night, absorbs heat from the interior of the building.

The second mode of operation is appropriate when cool air is available outside on the north side of the building. In this case, vents are

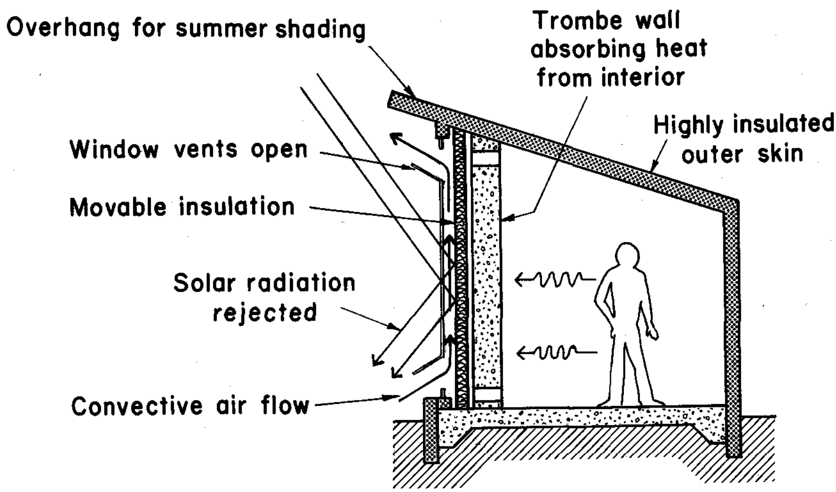

Fig. 9. Day-time operation of an indirect gain system used for cooling.

opened in the north wall of the building, at the bottom of the Trombe wall, and in the top of the glazing, as seen in Fig. 10. The movable insulation is retracted to expose the Trombe wall to the sun's radiation. The air space between the glazing and the Trombe wall heats up, causing air to flow out of the vents at the top of the glazing and to be drawn out of the building through the bottom vents in the Trombe wall. In turn, cool air is drawn into the building through vents in the north wall.

Examples of Use of Passive Solar Energy Systems

The most extensive use of passive solar energy systems to date has been in single family residences. However, other types of application more suited to the use of precast concrete will be discussed here. Although these buildings did not use precast concrete, they are presented as representative building types, suited to the use of precast concrete in the future.

1. **School Classroom Building—A**

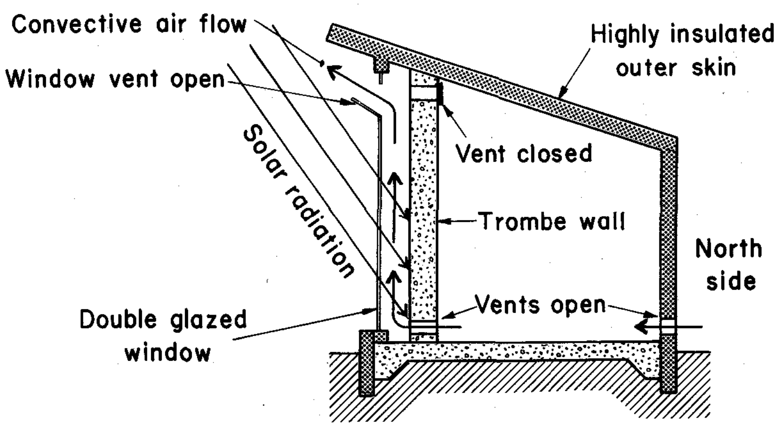

Fig. 10. Alternate day-time operation of an indirect gain system used for cooling.

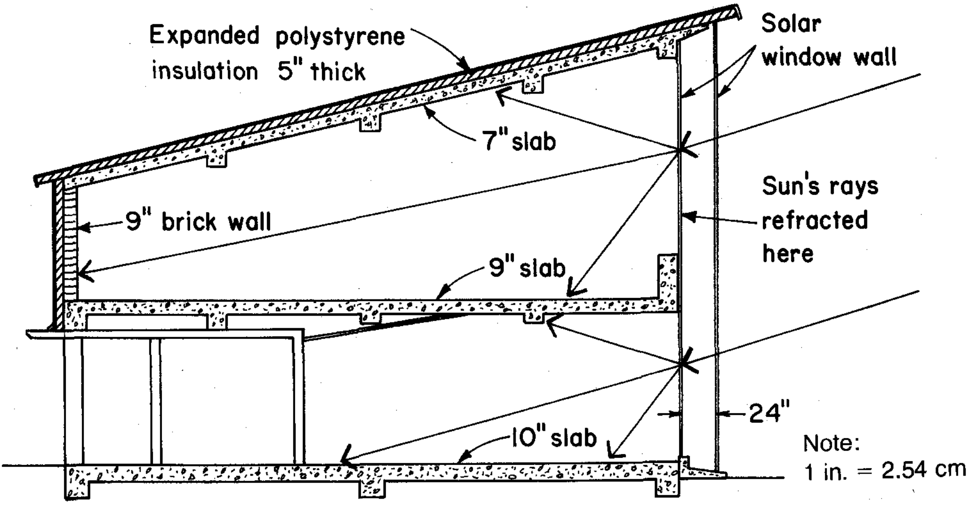

Fig. 11. Section through St. George's School, England (Architect: E. A. Morgan).

good example of a direct gain system is the St. George's School Building at Wallasey in the north of England (latitude 53.4 deg N). A section through the building is shown in Fig. 11. The south wall, 230 ft (70 m) long and 27 ft (8 m) high, is entirely double glazed. The outer layer of glass is clear. The inner layer is of diffusing glass with a rippled surface and is located 2 ft (60 cm) behind the clear glass. The diffusing glass scatters the sun's rays so that they reach a larger area of the roof and floor slabs and rear wall than would otherwise be the case. Horizontal sun breaks are provided between the two layers of glass to furnish summer shade and a means of access for maintenance.

The thermal storage mass is provided by the reinforced concrete roof slab [7 in. (18 cm) thick], upper floor slab [9 in. (23 cm thick)], and ground floor slab [10 in. (25 cm thick)] together with the 9-in. (23 cm) thick brick walls. The roof slab and north wall are provided with an exterior layer of expanded polystyrene insulation, 5 in. (13 cm) thick.

The operation of this building was monitored intensively from January 1969 through July 1970. The data recorded indicated that annually the building obtained about 70 percent of its heat from the sun, about 22 percent from lighting, and about 8 percent from the occupants. The auxiliary heating system installed at the time of construction in 1962 has not been needed. The success of this building is particularly interesting in view of the few hours of direct sunlight available at this location in winter. Diffuse sunlight evidently contributes substantially to its heating.

2. Eight-Unit Townhouse Building[9]—This recently constructed building in Vancouver, British Columbia, utilizes both direct-gain and indirect-gain solar heating. A typical section through the building is shown in Fig. 12. Reinforced masonry cross walls [8 in. (20 cm) thick] are provided at 13 ft 8 in. (4 m) centers. Wood framed cladding, providing $R = 20$ (RSI = 3.4 m) insulation, covers the outside faces of the end cross walls. The floors are 6 in. (15 cm) reinforced concrete slabs. (Precast slabs were priced, but were slightly more expensive, so were not used.) The remaining walls and the roof are timber

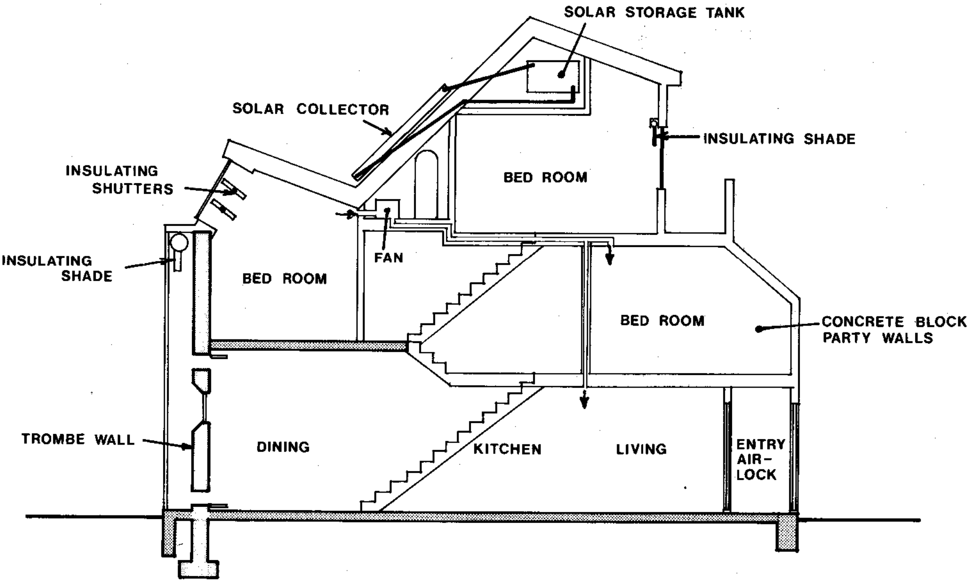

Fig. 12. Section through townhouse building, Vancouver, British Columbia. (Architect: Klaus Schmid; Solar Design: Solar Applications & Research Ltd., both of Vancouver, British Columbia.)

framed, the insulation levels being R = 20 (RSI = 3.5) and R = 35 (RSI = 6.2), respectively.

Cast-in-place Trombe walls [12 in. (30 cm) thick] are provided on the south side of the building. The wall of each unit is painted a different dark shade. Double glazing is provided in front of the walls, as may be seen in Fig. 13. These walls heat or cool the ground floor by convection and radiation and the second floor south bed-

Fig. 13. South side of Vancouver townhouse building (see section above).

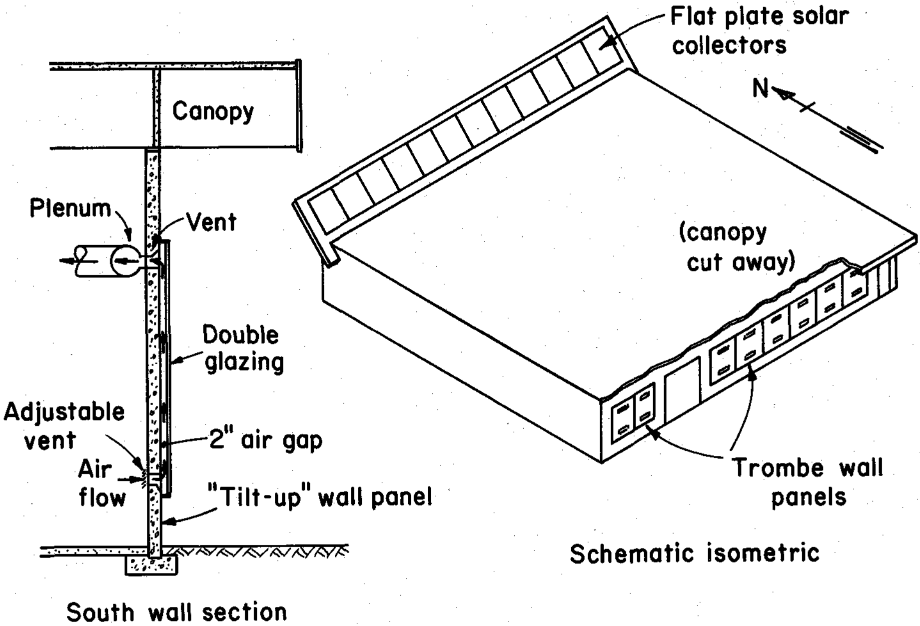

Fig. 14. A solar-heated industrial building, Santa Clara, California. (Designer: Pacific Sun, Inc., Menlo Park, California.)

room by radiation. The air circulates by way of closable vents at first floor ceiling and floor levels. A movable insulating shade is provided between the Trombe wall and the double glazing. It consists of four layers of aluminized nylon which are separated by air spaces when in use and provides $R = 16$ (RSI = 2.8) insulation. The shade rolls up into a case above the wall when not in use. It can either operate automatically in response to heating conditions or can be manually operated. The Trombe walls also insulate the townhouses from traffic noise from the adjacent busy road.

Direct-gain heating is obtained through south-facing skylights in the second-floor south bedroom and also through a window provided in the Trombe wall. Thermal storage is provided by the concrete walls and floors. The skylights are inclined at 60 deg to the horizontal. They are provided with insulating shutters which pivot about a horizontal axis, either automatically in response to heating conditions or manually. A small fan draws warm air from this bedroom and circulates it to the north side of the house. A thermosyphon solar water-heating system is also provided, with flat plate collectors on the south slope of the roof.

The performance of this building is being extensively monitored. It is anticipated that about 70 percent of both space heating and domestic hot water heating will be provided by solar energy.

3. Industrial Buildings[10]—Twin 48,000 sq ft (4460 m^2) single-story industrial buildings incorporating both active and passive solar heating systems have been constructed at Santa Clara, California (see Fig. 14). The solar heating systems were designed to provide perimeter heating for the building, the central core areas requiring little, if any, heating. Although the tilt-up method of construction was used for these buildings, they are of a

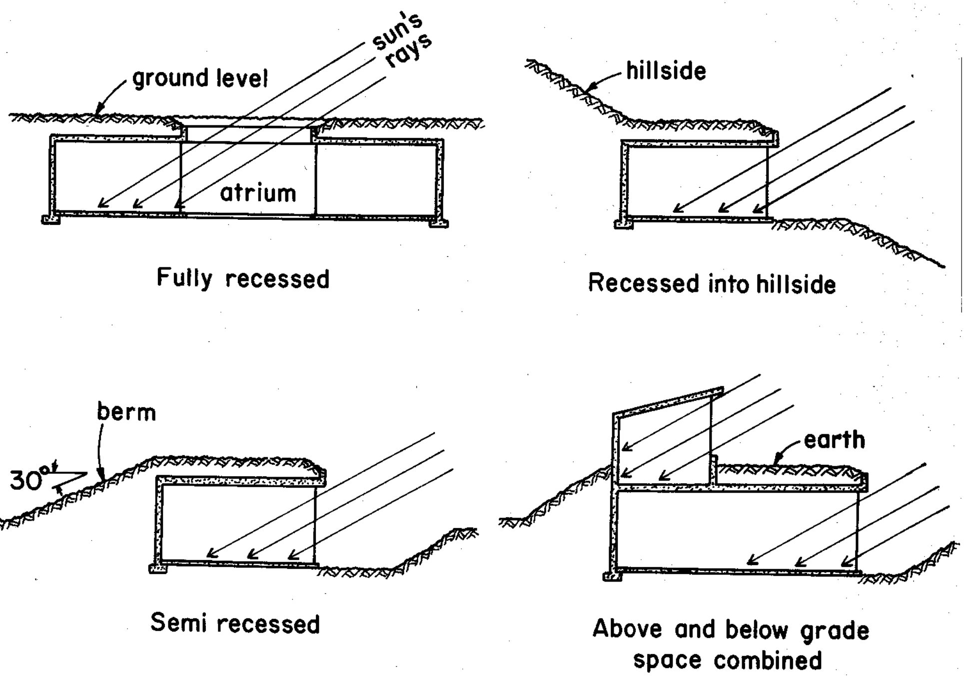

Fig. 15. Typical configurations for various types of earth sheltered buildings.

type well suited to precast concrete construction.

A sloping canopy at the north end of each building carries an array of high performance, flat plate collectors. Hot water coils fed by these collectors heat air for the perimeter heating system.

Of more interest from the point of view of the possible application of precast concrete, is the Trombe wall type of passive system incorporated in the panels of the south wall. The projected use of the building stressed day-time, not evening operation. It was therefore appropriate to use a thin Trombe wall which would not delay the transmission of heat through the wall for several hours. A wall thickness of 5½ in. (14 cm) was therefore used, the same as for the other walls of the building.

Panels [11 ft (3.4 m) high] of double glazing are attached to the outer face of the wall panels as shown in Fig. 14. That part of the outer face of the wall covered by the glazing is painted a dark color to improve heat absorption. The roof overhangs the wall by 6 ft (2 m) in order to shade the glazed panels in summer.

Adjustable vents through the wall are provided near the top and bottom of the glazed panels. The upper vent is connected directly to the collection plenum of the perimeter heating system. The temperature of the air entering the plenum reaches a maximum of 113 F (45 C) shortly after solar noon. The building is also heated directly by radiation from the inner surface of the wall panels. This appears to be a very promising approach to the incorporation of solar heating in precast concrete industrial buildings. Thicker wall panels could be used if retention of heat for longer periods was desired.

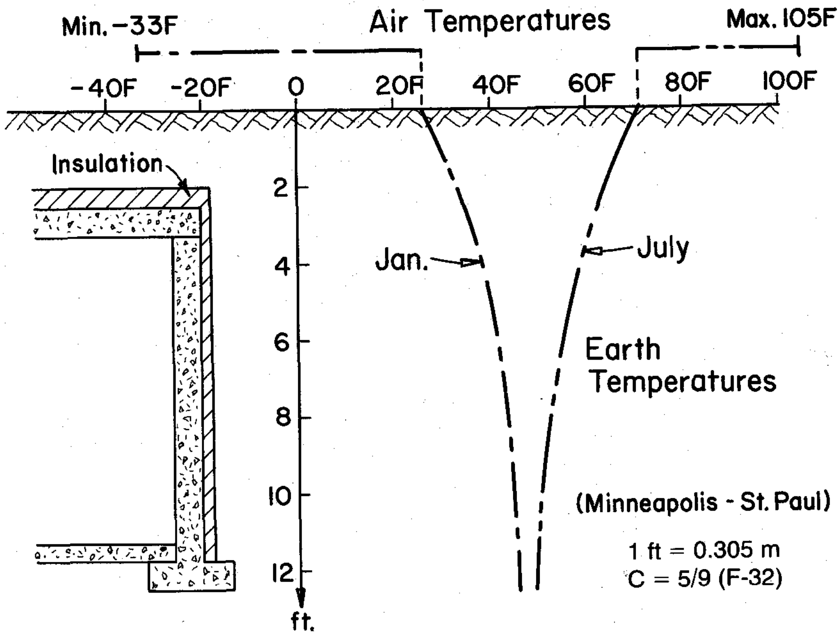

Fig. 16. Typical variation of maximum and minimum temperatures with distance below the surface of the earth (Minneapolis-St. Paul).

Earth Sheltered Buildings

There is increasing interest in earth sheltered buildings from the viewpoint of energy conservation. This includes both completely underground buildings and also buildings partly or wholly covered by earth mounded above the natural ground level, as shown in Fig. 15.

The energy savings accrue primarily from a reduction in the range of temperature to which the outside of the building is subjected. This is due to the thermal mass of the earth surrounding the building and is illustrated in Fig. 16 for the case of the Minneapolis-St. Paul area.[11] It can be seen that the energy required both for heating and cooling an earth sheltered structure would be greatly reduced. In addition, infiltration losses are also greatly reduced. Even when the building is not below the natural ground level, comparable savings will occur if the building is covered with earth to the same depth and is surrounded by berms with 30-deg slope.

Most earth sheltered residential buildings are also designed to utilize solar energy. All or part of the south side of the building is exposed so as to allow the use of passive or active solar heating. Windows on this south side also make the buildings more pleasantly livable.

A market exists for precast concrete in earth sheltered building construction, even in the case of single family homes. This is because the loads to be carried by the roof and walls of the structure are much greater than in the case of an above-grade building. Typically, the roof is covered by 1 to 2 ft (30 to 60 cm) of earth, i.e., it must carry a super-load of 160 to 280 lb per sq ft (7.66 to 13.41 kPa) plus its own weight and that of waterproofing and insulation. Precast concrete roof-

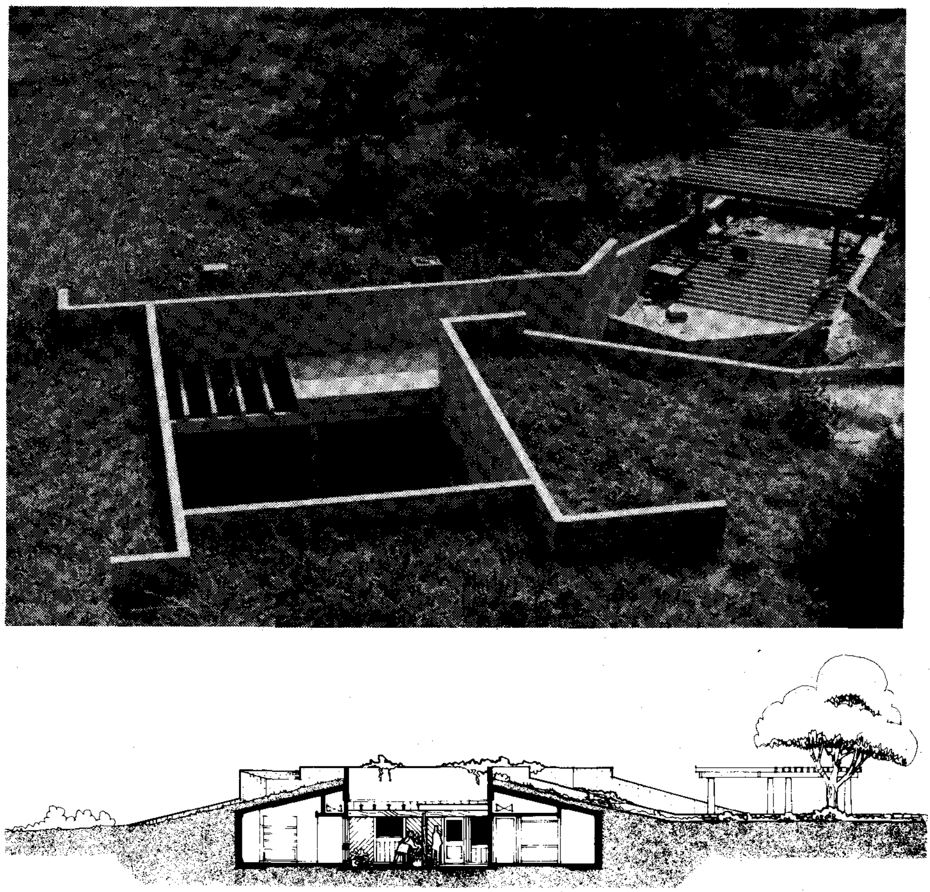

Fig. 17. Fully recessed single family home, Round Rock, Texas. (Architect: Coffee and Crier, Austin, Texas.)

ing units are well able to support these loads and also provide additional thermal mass to further moderate temperature variation in the building.

The walls of earth sheltered buildings have to serve as retaining walls resisting earth pressure. They have usually been of reinforced concrete but precast concrete has been used in some cases.

An example of the utilization of precast concrete in a fully recessed single family home is shown in Fig. 17. The John Bordie house in Round Rock, Texas, used 6-in. (15 cm) thick precast, prestressed concrete hollow-core slabs to carry the 2 ft (60 cm) covering of earth. Solar heating is provided by sunshine entering windows bordering the central atrium, in the manner indicated in Fig. 15.

Precast prestressed concrete double-tees, 3 ft deep, 8 ft wide (92 x 244 cm) and with a 3-in. (8 cm) cast-in-place topping were used for the roof of the Amity School Building[12] in Boise, Idaho, shown in Fig. 18. The double-tees span up to 55 ft 6 in. (17 m) and are supported on cast-in-place concrete walls at the perimeter and concrete masonry walls in the interior

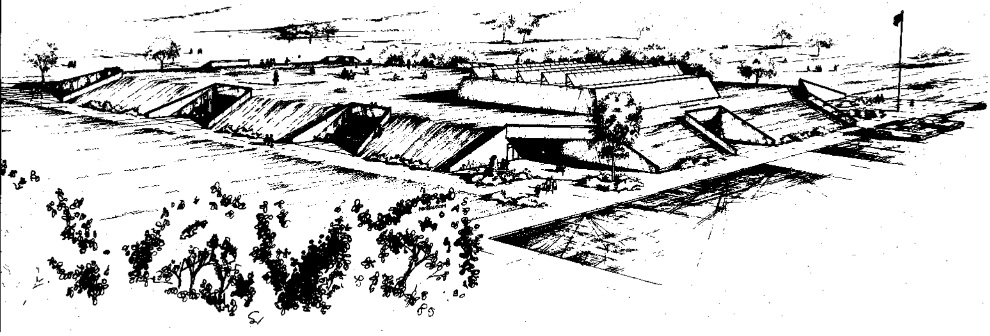

Fig. 18. Amity School, Boise, Idaho. (Architect: Cline, Smull, Hamill, Quintieri Associates, Boise, Idaho.)

of the structure. This building has 2 ft (60 cm) of earth on its roof and a 2:1 slope earth berm around it, as may be seen in Fig. 18. Styrofoam insulation [4 in. (10 cm) thick] is provided on the outside of the concrete walls and roof. A 6-in. (15 cm) drainage layer of gravel is provided between the styrofoam and the earth.

The electric boiler heating system is supplemented by selective surface, flat plate solar collectors, mounted on top of the building, as may be seen in Fig. 18. This building is expected to require only about 30 percent of the energy used annually by a conventional school building of the same size.

A general discussion of earth sheltered building construction with the accent on large-scale buildings was recently provided by Bartos.[12] Several interesting examples of this type of building are cited in the article.

Example of a Hybrid System

Hybrid combinations of active and passive solar heating and cooling systems are the most cost-effective in some cases. An example of the use of precast concrete in a building utilizing a hybrid system, is the North Campus Building of the Denver Community College shown in Fig. 19. This 282,000 sq ft (26200 m^2) building, which is more fully described in Reference 13, is entirely precast concrete. Heating is provided by a combination of 35,000 sq ft (3250 m^2) of double glazed flat plate solar collectors and a heat pump.

The building incorporates such passive design features as the use of heavy thermal mass construction (precast concrete), minimally glazed exterior north wall, and the placement of all major entrances and over-head doors facing south. In addition, the two lower floors of the building are recessed into the hillside to take advantage of the thermal inertia of the adjacent earth.

A spine roof of 24-in. (60 cm) double-tees supported at the ends by 10-in. (25 cm) thick precast panels, is angled at 53 deg to the horizontal to support one bank of solar collectors running the length of the building. A second bank of solar collectors rest on frames supported by double-tees with 5-in. (13 cm) thick flanges.

In addition to the ability of the precast prestressed structure to accommodate the solar oriented requirements, this structural system was ideal for the "exposed-systems aesthetic" of the building. By exposing the structural and the mechanical systems, both initial and life cycle costs were minimized.

Fig. 19. North Campus, Denver Community College. (Architect: J. D. Anderson & Associates, Denver, Colorado; Solar Design: Bridgers & Paxton, Engineers, Lakewood, Colorado). This building, in which precast concrete was used extensively, is a good example of a structure utilizing both active and passive solar heating and cooling systems. For further details see Reference 13.

Concluding Remarks

The on-site collection and storage of solar energy and the use of earth sheltered buildings are two means of conserving our rapidly diminishing supplies of energy and of reducing future building operation costs. In both these fields, the thermal and structural properties of precast concrete make it a very suitable construction material for reasons that have been discussed in this paper.

Although many existing precast products are readily applicable, and some have already been used, the precast concrete industry should also develop new products or modify existing ones to fit the special thermal and structural needs of these fields. This is a challenge and an opportunity presented to the entire precast concrete industry by this newly emerging market.

Acknowledgment

Figs. 2, 3, 4, 5, 8, 9, and 10 are reproduced by courtesy of the British Columbia Energy Commission. They are drawn from "The Potential for Solar Energy Heating in British Columbia," prepared for the Commission by Solar Applications and Research Ltd., and Acres Consulting Services.

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Discussion of this paper is invited. Please forward your comments to PCI Headquarters by Nov. 1, 1980.