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ALTERNATIVE APPROACHES TO SOLAR HEATING OF RURAL BUILDINGS IN AFGHANISTAN

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Summary: Eleven different methods of solar heating are reviewed with regard to their applicability to rural buildings such as health center, subcenters, and primary schools. Indigeneous methods of low-energy climate control are discussed. Conclusions reached suggest that traditional building styles embody some important fundamentals, and could be modified according to modern prinicples to take advantage of solar radiation for low-cost year-round comfort.

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ALTERNATIVE APPROACHES TO SOLAR HEATING OF RURAL BUILDINGS IN AFGHANISTAN

Needs and Favorable Circumstances

Although Afghanistan may not have been affected as seriously as other developing countries by the recent "energy crisis", its initial position may have been worse than most. Energy resources such as gas and coal are moderate in amount but no real distribution system exists for their application in rural areas. Hydroelectric energy sources supply only two major cities. Timber resources are probably being converted into firewood and charcoal faster than their current replacement rate.

The market cost of imported petroleum fuels has so far been held to pre-1974 levels by means of government subsidies and concessionary terms from neighboring suppliers. Although the possibility exists that these favorable terms will be maintained, and/or grants received from petroleum-exporting countries, it is to be expected that Afghanistan will be hurt economically and development activity dependent on foreign currency reserves will be slowed. It is beyond the purposes of this paper to estimate the magnitude of the effect on foreign exchange of developing supplementary local energy sources, but it is reasonable to suggest that it would be positive in direction.

Looking at the need from the point of view of small, isolated buildings in rural areas such as government schools and health centers, the problem of distribution is added onto that of cost. These combine

to make the problems of heating public buildings so great that the usual response is to heat them inadequately or not at all. Instead of paying the cash price of delivering the fuel needed, the government pays the cost in services not supplied or supplied with low efficiency due to an uncomfortable working environment.

Excluding the possibility of an all-out petroleum windfall, it might be economically beneficial for Afghanistan to invest in the development of a technology for utilizing an abundant and free resource, solar energy. The Central Asian plateau is shown on world maps as an area of relatively high incidence of sunny winter days for its latitude, and measurements of incident solar radiation made in Kabul (Reference 1) indicate that solar energy is as abundant here in winter as in, say, the southwestern United States. Several of the more promising experiments in solar heating have been done in regions climatically similar to Afghanistan, and there is reason to believe that a technology appropriate to conditions here can be found to utilize this resource.

Practical Approaches to Solar Heating

Beginning well before the present "energy crisis", far-sighted architects and engineers have succeeded in applying theoretical principles (briefly outlined in Appendix I) to practice for the solar heating and cooling of small buildings. Recent events have pushed these activities into the limelight, and the non-technical press has given solar heating much publicity. One possible unfortunate result may be that a massive influx of research funds will encourage development of systems too costly and sophisticated for developing nations, at the expense of the low-budget R & D prevalent today.

All available publications have been culled for descriptions of useful schemes for solar heating of small buildings. The more complex and costly approaches, or those requiring the use of exotic materials, have been ignored in favor of a more careful examination of the simpler and locally adaptable ones. Dr. Cornelius Zondag, who in 1974 visited some solar energy research centers in the U.S. and Canada, and Mr. Robert MacMakin, have also provided information.

Eleven different experimental schemes, concepts or designs which seemed to be representative of current developments are described in Appendix II to this report. All of the methods used seem to fall into one of two general categories. The first, and perhaps better-known, method involves the use of a flat-plate solar energy collector in which the working fluid is heated. The heated fluid is then distributed to other parts of the building for storage or for immediate heating. The second category takes advantage of both the temporal and spatial patterns of the flow of energy and matter (usually air) through the outer walls of the building, and the properties and configuration of materials to control these flows. This jargon conceals the fact that the latter approach is often the simpler of the two, as will be seen.

Rural Building Design Constraints

Although the functional requirements may vary somewhat, a common set of desirable characteristics exists for health centers, subcenters, and primary schools in rural areas. The basic assumption of this exercise is that the buildings in cold areas should be comfortable in winter while utilizing a minimum of fuel, and buildings in essentially

warm areas should be comfortable year round. The buildings should be functional, inexpensive, and should have a reasonably long life expectancy.

The remote location of many of these buildings imposes another set of requirements. No source of electric power can be assumed at the site, either for use in construction or for actual use in the building. Several proposed sites for health centers and a majority of sites for subcenters are distant from any roads, forcing greater reliance on locally available materials.

Since sunny days predominate during the winter in most parts of Afghanistan the heat storage requirements of a solar heated building could reasonably be reduced to a minimum, but during cloudy periods supplementary heating would be required. If the means of providing supplementary heat can be made economical and if building heat storage is costly, this would seem to be a reasonable compromise, given the low incidence and short duration of overcast periods.

The exact heating and cooling requirements of a building are determined largely by its occupancy pattern. A building which is occupied only during the daytime need not have a system for storing heat overnight provided it is heated rapidly in the morning, whereas overnight heat storage is highly desirable in space used as living quarters.

If thick walls are used as the storage medium, however, during hot summer days these requirements conflict with the necessity of a long thermal time-lag for spaces occupied by day and a short lag in the sleeping spaces. In the former areas the peak heat of the day should not get transmitted to the working space until early evening, while the

temperature of sleeping room walls should be allowed to drop quickly during the cooler evenings. (The resolution of this problem involves the application of Prof. Trombe's principle, described in the next section).

Regional climatic differences are at least partly responsible for the development over centuries of regional styles of architecture in Afghanistan. (Appendix III) This variance in functional requirements has also made it necessary to create two different designs for government Basic Health Centers, for example, one for cold regions and one for hot regions. Considering the marginal ability of the practical solar heating/cooling schemes reviewed here to perform their assigned tasks even under optimum conditions, it is unreasonable to expect to find a single scheme well-suited to both climatic extremes. A minimum of two different approaches is probably needed, and the following evaluation is made with this in mind.

Although transportation of glass to rural building sites presents serious problems, the desirability of adequate window area in schools and health centers cannot be overemphasized. Hygiene and illumination as well as winter heating are such important requirements for these buildings that the production and transportation problems of glass must be thoroughly examined if a satisfactory construction program is contemplated.

Comparison of Eleven Methods

I have attempted to evaluate all eleven schemes by applying several criteria which are related to the applicability of the method to heating (and cooling) small rural buildings such as health centers, subcenters and schools in Afghanistan. It should be borne in mind that this analysis was performed without the benefit of professional knowledge of architecture and structural design, in the hope that the tentative results might stimulate further discussion and inquiry. Clearly, more precise information is needed about the performance of these different approaches and others, about local climatic conditions, and about local construction material and manpower resources, before attempting any experimental designs.

Several of the schemes described can be eliminated from further consideration by examining the limiting factors which affect their applicability. The reader's attention is directed to the summarized evaluation in Table 1. If electric power is assumed unavailable at the sites of rural schools and health centers, the techniques used in the Thomason Solar House, Sunstructures, and the Solterra Home must be removed from further consideration. Not coincidentally, these three are also the most complex schemes and perhaps the most costly - and represent the mainstream approach solar heating research today in the United States. For applications where electric power is available, the Solterra method, although as yet untested, would seem to have several important advantages. Its initial cost may be competitive with other central heating systems, and is especially worthy of consideration for urban buildings requiring a higher initial investment than schools or

TABLE 1 - COMPARISON OF THE 11 SCHEMES FOR SOLAR HEATING

Name of Technique (see Appendix III)	Heat Supplied During Cold Sunny Days	Approximate Heat Storage Capacity	Need for water, electricity	Construction Difficulty	Need for Imported Materials
1. Thomason Solar House	nearly 100%	several days	both	very complex many automatic controls	high-glass, sheet metal, piping, pumps, tanks
2. Sunstructures	would depend on size of collector used	depends on size of hot water tank	both	fairly complex	as above
3. Solterra Home	100%	very high-measured in months	both	complex	as above
4. Jodhpur Solar Room Heater (USAID/A)	depends on size of collector and room insulation	few hours at most	none unless water is drained	simple but must be fabricated off-site	glass, sheet metal for collector
5. Davis Home	would depend on size of collector	several days	neither	as above	as above
6. Trombe-Michel Solar Wall	up to 100% depending on room size	overnight	neither	simple except for transport of glass	glass
7. ABC Group	must be determined	depends on wall thickness	none	simple	low
8. Solarchitecture Houses	100% in a moderate climate	overnight	water for initial filling	new technique but not difficult	sheet metal and plastics
9. Baer House	100%	several days	as above	as above	barrels
10. Biosphere House	depends on wall area and room size	overnight?	water for greenhouse	simple	glass or plastic film
11. St. George's School	100%	several days	minimum	[illegible]	large quantities of glass

Table 1 - Cont.

Maintenance difficulty	Adaptability to existing buildings	Compatibility with traditional building design	Summer Cooling	Other Factors
fairly high	not adaptable	low-requires sloped roof	with extra machinery	a) solves problem of water freezing b) expensive; long payback period
similar to central heating systems	fairly adaptable if well insulated	as above	as above	a) uses existing hot-water central heating system
moderate	possible but difficult	as above	as above	a) air used as working fluid b) unproved design
low if anti-freeze is used	high	high	no	a) problem of water freezing b) slow morning heating
very low	difficult, depends on terrain	building must be elevated or on hillside	no	
very low	possible	possible	forced ventilation	a) substitute adobe for concrete? b) rapid morning heating c) eliminates window space
very low	high	high	passive nighttime cooling	a) requires an economical shutter design
moderate	principle could possibly be applied	high	yes	a) may be most suitable to hot arid areas
very low	difficult	not very compatible	no	a) availability of empty barrels a problem
low	possible	possible	no	a) incorporates still for drinking water b) high demonstration potential in areas of winter food scarcity
window washing	difficult	not very compatible	no	a) shading needed in summer b) best suited to northerly earthquake-free areas

health centers. The Sunstructures approach is suited to adaptation to existing buildings with fuel-fired central heating plants. The application of this technique at the Child Health Institute in Kabul has been suggested as a pilot project (Ref. 6).

The Davis Home (Appendix II-5) is an ingenious attempt to take advantage of the non-leaking and non-freezing properties of air by using it as a working fluid. At the same time the use of pumps or fans to circulate the air has been avoided by the use of natural convection, but the apparent requirement that the building be elevated or built on a south slope must be regarded as a serious limitation.

The Jodhpur Solar room-heater (Appendix II-4) may represent a practical solution to the heating of well-insulated, existing buildings having fairly small individual rooms. Whether or not its characteristically slow morning heating poses a limitation depends on the occupancy pattern of the building. The problems of water freezing and of limited heat storage should be overcome by making the indoor storage tank-cum-radiator high in volume and draining at sundown only the small amount of water held in the collector. Although this method, already under development at USAID/A, could be used in new structures, it is not evident that it would be the most appropriate, given its limitation and other available options.

Having given low marks to the five approaches using flat-plate collectors, we must turn to the second basic scheme to find a better method for the solar heating of new buildings. Examination of the summary comparison chart shows that no single approach is the perfect one, but several are not far from the mark.

One advantage shared to a greater or lesser degree by the schemes that use the outer skin of the building to control the internal climate is that the basic principles and forms involved are well known and found in many types of indigeneous architecture. (Appendix III) Five of them require southern exposure, implying either an oblong single-storey or multi-storey layout to get a sufficient number of rooms. The sixth method uses the roof to modulate heat flows, and may represent the most radical departure from traditional construction even though though the building layout is the most flexible. The requirement of a major southern exposure is not as limiting as it may seem, and does not rule out a courtyard layout, for example.

Trombe-Michel (Appendix II-6) - The Trombe-Michel solar wall has many of the desired characteristics. Rapid morning heating ability tends to offset limited heat storage capacity, but there is apparently room for improvement there as well. The 35-cm. (14-inch) thick wall, which is said to provide a circulation of warm air until after midnight, is thin by Afghan standards.

In summer it might not be necessary to shade the wall. A coat of whitewash (removable with water in the fall) over the glass would suffice to reduce the sun's intensity but still maintain a thermo-circulation of cool outside air through the building.

The basic simplicity and efficiency of the Trombe-Michel scheme is offset by two disadvantages. The fact that the area occupied by the solar wall is unavailable for ordinary windows is a serious drawback where direct sunlight is needed for hygiene and illumination. Windows could be added high on the south wall, resulting in a dual system of

solar heating, or else on other exposed walls. The second and more serious problem is the need for a double-glazed outer wall. Although no mention is made in the reference of the possibility of substituting plastic film for one or both layers of glass, this might be worthy of investigation.

A word about plate glass is in order. Glass is fragile, difficult to transport, but useful in solar heating systems because of its radiation-selective properties. Every scheme described here with the exception of the Solarchitecture House calls for glass in fairly large amounts. Plastic sheet is unbreakable but it is degraded by sunlight and is not as efficient as glass, and since it is petroleum-based its cost is rising faster than glass. Thicker sheets of glass are less fragile but cost more to buy and transport. Fortunately, the plate glass used need not be of high quality, and the ultimate solution might be to stimulate a domestic window-glass industry (using solar furnaces!) An interim solution might be to equip a vehicle especially for transporting glass to rural construction sites.

ABC Group (Appendix II-7)

While the methods for controlling the flow of heat through a wall suggested by the ABC Group do not present a formula for a solar heated building, they are appealing because of the ease with which they can be applied to conventional buildings. In winter, a south wall painted black and equipped with a system of whitewashed or reflective shutters would act as an absorber and store of heat during the day. At night when the shutters are closed, most of the heat stored in the walls would radiate inwardly, provided the shutters formed a tight

seal to trap warm air and act as a convection and radiation barrier. If a conventional or double-glazed window were built into part of the wall, the room would receive direct solar radiation during the day but the heat stored in the floor and internal walls would not be re-radiated outward at night if the shutters also covered the window.

In the summer, the shutters could be left partially open to admit indirect light during the day and allow heated air to escape from the walls. At night the shutters would be opened to allow the wall to cool by radiation.

Solarchitecture House (Appendix II-8)

This design seems best suited to hot, arid southerly regions where winter temperatures can also drop below a comfortable level. If the execution of the design proves impractical for Afghanistan because of the rather unusual requirements of water-filled plastic bags on the roof, the concept can be easily employed in a somewhat different form. The traditional thick mud roof could be topped with black bitumen or tar, and a wooden "eggcrate" framework built into it to provide dead air space under the removable cover. The cover could be the wood-straw sandwich suggested in Appendix II, or some kind of impregnated white tent canvas which would be rolled up during the day in winter. The basic principle would then be similar to the ABC approach, but the rapid morning heating at the black film interface of the original design would be lost. This could be compensated for in rooms with a southern exposure by conventional windows, which could be effectively shaded from the high summer sun by a small fixed roof overhang.

Summer cooling results when the black roof is uncovered at night and loses its heat to the sky. If water is available it can be sprinkled on the roof at dusk, increasing cooling by evaporation.

Baer House (Appendix II-9)

Basically a variation on the ABC theme, this scheme obtains a large heat storage capacity by making a wall out of water, and can also be regarded as a vertical application of the Solarchitecture principle. Although the use of barrels seems impractical on a large scale in Afghanistan, the large heat capacity of water could be utilized by filling the hollows in concrete block walls with water-filled plastic tubes.

Biosphere House (Appendix II-10)

The application of the Biosphere concept in full would seem at present to be a rather ambitious endeavour for rural buildings. Nevertheless, the basic configuration of a slanted glass wall and thermal barrier and an internal vertical south heat storage wall could add flexibility to other designs. This layout has in fact been used in another of Baer's houses, and is yet another variation on the ABC concept.

The specialized application of this arrangement to a greenhouse could have valuable demonstration potential at health centers and rural schools in areas where fresh vegetables are unavailable in winter. In combination with a simple composting latrine, a complete water-conserving, sanitary ecological system could be demonstrated and the produce grown could be given to the school or health center staff.

A steeply inclined glass or plastic cover in conjunction with a tall black-surfaced wall would unite the two advantages of a large heat storage

area and freedom from snow overload. The nighttime cover could be made from inexpensive local materials such as reed matting and felt, with a renewable coat of whitewash to improve the reflectivity of the covering. This might be especially well suited to the south wall of sleeping rooms of living quarters, especially if an east window is available for early morning heating and illumination.

St. George's School (Appendix II-11)

The vast double-glazed area of the south wall precludes the use of this approach in rural Afghanistan, but the principles demonstrated are useful. Enough heat can be trapped and stored by massive interior walls and floors to maintain comfortable temperatures without supplemental heating, even under rigorous winter conditions. At the more southerly latitude of Afghanistan it would probably be necessary to make extensive use of skylights because of the high winter sun, but this in turn produces the need for shading devices in the summer.

Indigeneous Architecture (Appendix III)

Many of the innovations proven over centuries of building in Afghanistan are based on sound principles and are relevant to low-energy climate control, and with some modification could be used as a basis for new designs. Certainly the proportioning and orientation of buildings so the major axis runs ENE-WSW optimizes both winter heating and summer cooling. Thick walls and roof are also desirable, but by themselves are not an optimal arrangement for thermal control.

Prof. Trombe (Ref. 10) has expressed an important principle of building fabric control as follows: "It is absolutely necessary to avoid using the same mass both as a heat store and as a thermal barrier."

All six schemes in this category described here have recognized this requirement, and four have accomplished the separation of functions by a system of movable shutters. When covered the wall or mass is a heat barrier, and when exposed it is a heat store.

In addition, the principle of adjusting the thickness of walls of different exposures to provide different thermal lag periods, as described by Olgyay (Ref. 3) can be applied to provide balanced winter heating and minimize summer exposure.

Traditional building materials are usually inexpensive and locally available. Advanced techniques for adobe and compacted earth construction have been developed under USAID auspices. Preservative treatments could be added on-site to inexpensive and useful local materials such as reed matting, felt, poplar poles and dry brush, at far less expense than importing structural elements and insulation. Stone walls have thermal properties similar to concrete, and put money into the pockets of local laborers that would otherwise go into the purchase and transportation of cement. Far less water is also consumed.

Incorporation of traditional methods of supplementary heating and cooling which are energy-conserving also seems desirable. The "tabakhana" system of underground radiant heating widely used in mosques and houses would also find application in schools, clinic waiting rooms, and staff living quarters. The use of shading verandas and overhangs for summer protection from the high sun must be retained, and of course the surrounding greenery and strategic placement of deciduous trees must be considered as an integral part of the building plan. Scientific principles of ventilation and air circulation are readily applied to

most kinds of traditional buildings.

Recommendations

Before undertaking the design of a prototype solar heated rural building, three preliminary steps appear necessary. It would first be necessary to have more information about some of the described schemes, both in terms of their execution and performance. The need for economy and simplicity would suggest that more should be known about the work of the ABC Group in France, and the encouraging results obtained with the Trombe-Michel Solar Wall in the same country also are worthy of further inquiry. If a design for the hot region is contemplated, the Solarchitecture Houses in Arizona and California would seem to contain ideas worth exploring. If there have been any practical developments of Chahroudi's Biosphere concept, it would be of value to know more about them.

The second step would be to refine and adapt the most applicable approaches to the particular problem of rural buildings in Afghanistan. Enough engineering and architectural talent exists in Kabul to make a good start on this, and outside consultants could be brought in as required. If there is some interest in this problem at Kabul University, that might be the logical locus for such a group.

The third step would be to construct an experimental structure in which several alternative or complementary approaches could be evaluated over one year. The design might be an approximation of a multi-room school or health center, and the separate rooms would be heated and cooled by different methods. Information could then be

obtained under controlled conditions on temperatures achieved, building costs, maintenance costs, and costs of supplementary heating. The best method or methods could then be selected. If the experimental building were built in the in-between climate of Kabul, reasonably good extrapolations could be made for both colder and warmer areas.

The experimental building might follow the plan layout shown in Fig. 9. Room 1, having both south and west exposures would be used for the Trombe-Michel solar wall. In room 2, a three-quarter version of the solar wall would be constructed and conventional double-glazed windows installed in the upper part. Room 3 would be a demonstration of the ABC Group shuttered heat-storage wall combined with a large single-glazed window, which would also be shuttered. Room 4, with an additional eastern exposure, would be used to test the effectiveness of a plain shuttered wall.

Room 5 has a northern and western exposure and could be used to evaluate both the heating and cooling effectiveness of the Solarchitecture roof-pond system. Windows in the west wall would simulate the heat load of a square house with east, south and west walls of normal thickness. Room 6 could demonstrate a simplified scheme for a thermal-control roof with an ordinary south window as described earlier.

Attached to the south wall of room 7 is a Biosphere greenhouse. This could be divided by an internal wall to test the relative effectiveness of plastic and glass or different covering materials.

The experimental structure would also incorporate features that are desirable in the future prototype building regardless of the methods specified for heating. The long axis would be oriented so it faces about

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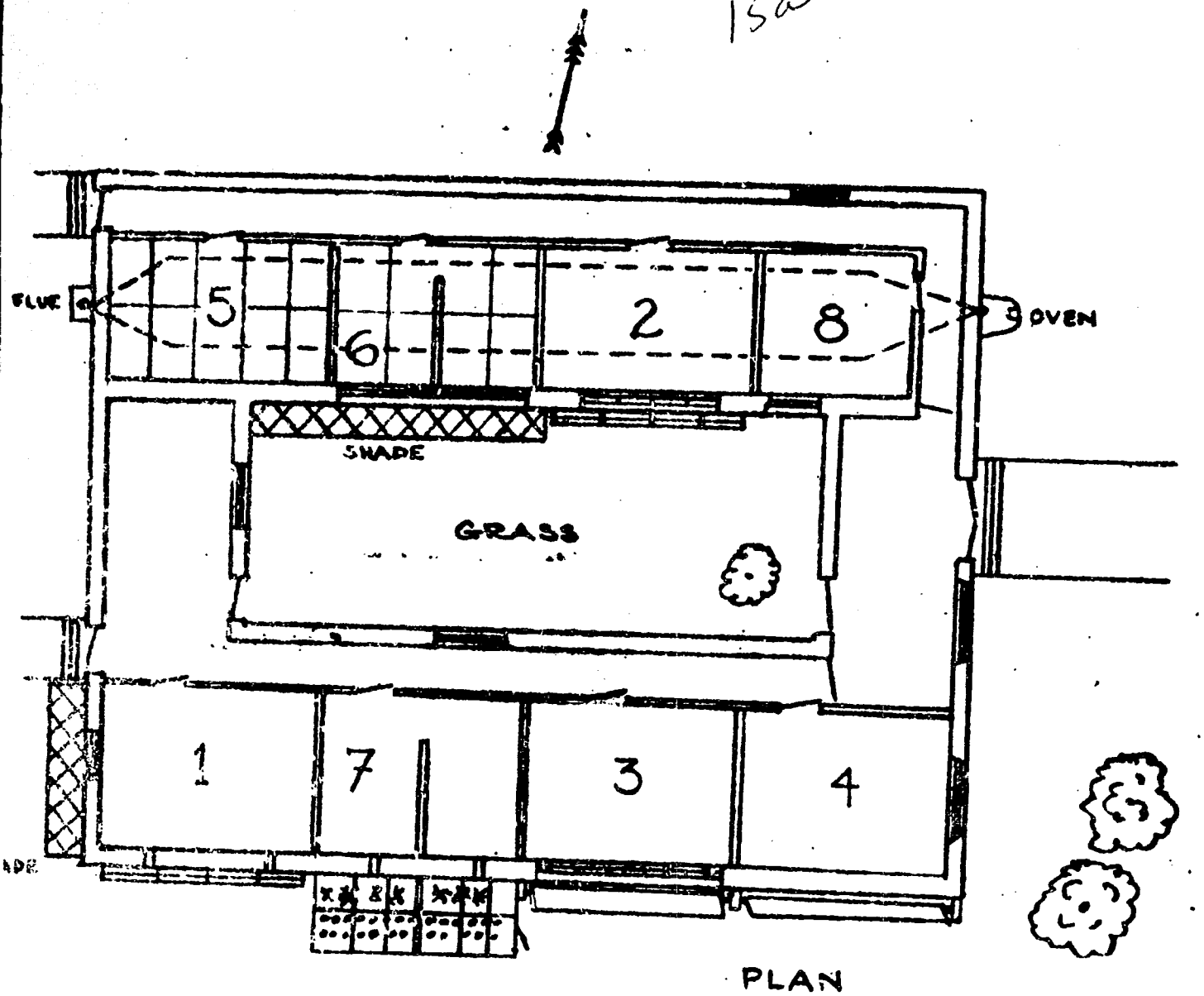

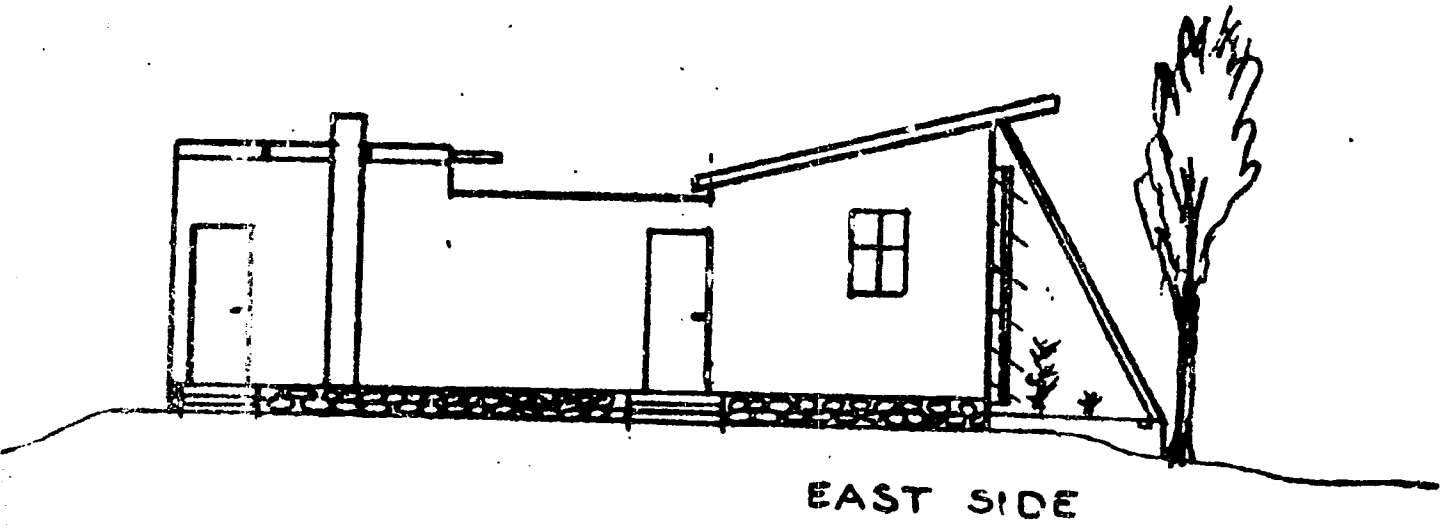

Figure 9

17 degrees east of south according to Olgyay's principles. A vestibule and internal circulation corridors would minimize heat loss through opened doors. Heat generated by the occupants and an east window exposure would be adequate for a vestibule-cum-waiting room.

The year-round effect on internal temperatures of a light-colored versus dark mud roof could be evaluated by dividing one of the test rooms internally. The effectiveness of dark colored internal floors and walls as heat absorbers could also be differentially compared in room 6.

A supplemental heating scheme such as the "tabakhana" could be evaluated by building the system into several of the rooms and comparing its performance with standard wood-burning stoves or kerosene heaters. Each system would be used on alternate winter days and the room temperatures obtained and the amount of fuel consumed would be recorded. Variations in solar heating effects would average out over the winter period so reliable efficiency data would be obtained. It would be useful to also conduct this experiment in a conventional room such as Room 8. Information gained from this experimental building over the course of a year should be sufficient to proceed with the design of a prototype rural building.

In addition, experimentation with methods suitable for use in existing buildings should be continued. The Jodhpur-USAID solar room heater has potential for this application, and the shuttered ABC wall may also prove to be useful and inexpensive "add-on" approach. Three prototype phases could potentially arise from an experimental phase: a new design for rural buildings, an "add-on" technique for existing buildings, and a specialized "add-on" unit for existing buildings with central heating systems.

Acknowledgements

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APPENDIX I

Principles of Solar Heating

Studies of the physiological basis of comfort have shown that the achievement of thermal equilibrium (constant normal body temperature) with a minimum of thermoregulation (muscle respiration, shivering, perspiring, etc.), usually corresponds to the sensory feeling of comfort. Thermal equilibrium is achieved when the heat produced by the body's metabolic processes is balanced by losses or gains of heat by radiative, conductive-convective, and evaporative processes. Radiation is believed to account for 40-45% of body heat loss to (or gain from) surroundings, and conduction-convection for 35-40% (Ref. 2). In practical terms, this means that the major factors in the comfort of a building are the temperature (and to a lesser extent the velocity) of the air inside the building, and the temperature of the interior building surfaces. Because of the extraordinarily high emissivity of human skin, a great deal of heat may be lost by radiation to surrounding solid objects whose temperature is lower than that of the body.

Most conventional heating systems depend on the achievement of relatively high temperatures by operating fluids to heat air by convection, which in turn warms the surrounding solid surfaces. Several types of low-temperature radiant heating are also in widespread use. They can be generally described as requiring the conversion of energy at high temperatures (burning fuels or electrical resistance elements) to lower temperatures (hot water or air). The same can be said for solar heating. Most of the sensible heat from the sun arrives on the earth's surface in the form of short-wavelength infrared radiation produced by high temperatures on the

sun's surface. The interaction of this high-energy radiation with matter results in its conversion to low-temperature heat. Solids, gases, or liquids thus heated by the absorption of short-wavelength infrared radiation then re-radiate long-wavelength infrared in the form of sensible heat. Direct conversion can also occur at the skin-air boundary when direct solar radiation falls on the body surface, resulting in warming of the body.

Many common materials have properties which make them useful in solar heating systems. Ordinary window glass is transparent to short-wavelength infrared radiation but is relatively opaque to long-wavelength radiation. This means it can allow solar energy in to heat up a solid or fluid mass, but will not allow the warm mass to lose heat by rapidly re-radiating it to colder objects. Certain materials such as water, concrete and damp soil have a high thermal capacity, and can be used to store large quantities of heat in small volumes. Other materials, notably metals, are good conductors of heat and can transmit heat rapidly from one interface to another. Insulating materials such as still air, rock wool, polyurethane foam, asbestos, foamed concrete or dry sand can be used to block the flow of heat where or when it is not desired. In addition, the surface properties of any object drastically affect its ability to absorb, radiate and reflect radiant energy. Dark and rough surfaces are good absorbers of energy, and are also good radiators when the object is hot. Light or shiny surfaces are good reflectors of radiant energy, and are as a result poor absorbers or radiators.

A fundamental property of all liquids is sometimes applied to the problem solar heating and cooling. When a liquid turns into a gas by evaporation, or a gas under pressure expands through a nozzle, heat is absorbed by the substance from its surroundings. This property of heat absorption can be used to cool buildings in hot climates, but its application generally entails some degree of complication of the building.

Fluids (gases and liquids are physically both fluids) are lower in density when warm than when cold, so warm water, for example, rises to the top of a closed tank and cold water settles on the bottom. This density gradient can be used in certain circumstances to move the fluid where desired without the use of pumps or fans.

The condition of the sky is another important factor. Solar radiation, especially the short infrared which produces heating, is reduced and diffused on cloudy days, but can still be useful. A warm building loses far more heat energy by radiation to the sky on a clear night than on a cloudy night, helping to offset the lower gain of heat during cloudy spells.

Perhaps the single most important factor affecting year-round climatic adaptation to the solar energy input is the orientation of the vertical surfaces of a building. Olgyay (Ref. 3) has found that, at the latitude of Phoenix, Arizona, maximum radiation during winter is received by a vertical surface oriented 32 degrees east of due south, while maximum summertime radiation is received 68 degrees west of due south. He has determined the optimum orientation for maximizing winter heating and minimizing summer heating to be 25 degrees east of south. The latitude

of Phoenix is near to that of Kabul, and Dr. Albert Szabo and his colleagues at Kabul University have found that the predominant orientation of houses in four villages studied near Kabul is in fact very close to this theoretical optimum.

The tilt of the earth's axis results in the seasonal change in the sun's apparent daily course through the sky. Above the Tropic of Capricorn the sun is low in winter, and most radiation falls on south-facing vertical surfaces. In the summer the high sun falls mostly on horizontal surfaces, and south walls can be easily shaded from its intensity. West walls remain vulnerable to the low afternoon summer sun.

Three Different Approaches to Solar Heating of Small Buildings

1. The Thomason Solar Home (Ref. 4)

Fifteen years ago Dr. Harry E. Thomason, patent attorney, built a solar heated house in a Washington D.C. suburb, using a relatively simple, reliable, and inexpensive heat-collecting and storage system he invented. The house worked, and a second and third model were built. The third house also proved successful and has received substantial publicity. Last year his home-heating cost until February 1 was only $15, in a period of rapidly rising gas, fuel oil, and electricity costs.

Most of the steeply-sloping south roof is covered with blackened corrugated aluminum sheets, and a small trickle of water runs down each of the valleys. The space the water travels in is covered by a layer of glass which insulates it from cold air and reduces heat loss from long-wave infrared radiation. (This is the basic principle of the flat-plate collector used in the USAID/A experimental model and most other designs). A gutter collects the solar-heated water that drips from the lower ends of the channels and directs it to a large basement water tank that is surrounded by coarse crushed rock. After several sunny days of operation, the tank and the crushed rock become hot, and contain enough heat to keep the house warm for several sunless days. When the rooms need heat, a thermostat turns on a fan that blows the hot air from the crushed rock into the rooms. At the end of the day, the pump that sends water from the tank to the top of the collector is turned off and all the water on the roof returns to

the tank. Thus practically no heat is lost from the collector at night and there is no danger from freezing temperatures. An efficient air-conditioning system has been designed into the latest model, so during the warm seasons some solar energy is utilized, reducing electricity consumption for cooling.

2. Sunstructures (Ref. 5)

A small group of ecological activists in Michigan has modified several existing structures for solar heating, with "moderate" success to date. The group, which operates under the corporate name of "Sunstructures", has used essentially the approach employed by Thomason, but transfers the heat in solar-heated water to heat air in an already-existing heat-exchange system. This is identical in principle to the system proposed (Ref. 6) for the Child Health Institute in Kabul.

They also suggest simple techniques for achieving low-energy designs for small buildings, such as the use of a sod roof, earth mound insulation of north walls, and ventilation by natural convection. (Fig. 1) The major contribution of this group has been to show that existing houses can be adapted to solar heating by means of flat-plate collectors. "Moderate" success in Michigan can probably be translated into a much higher level in sunnier regions.

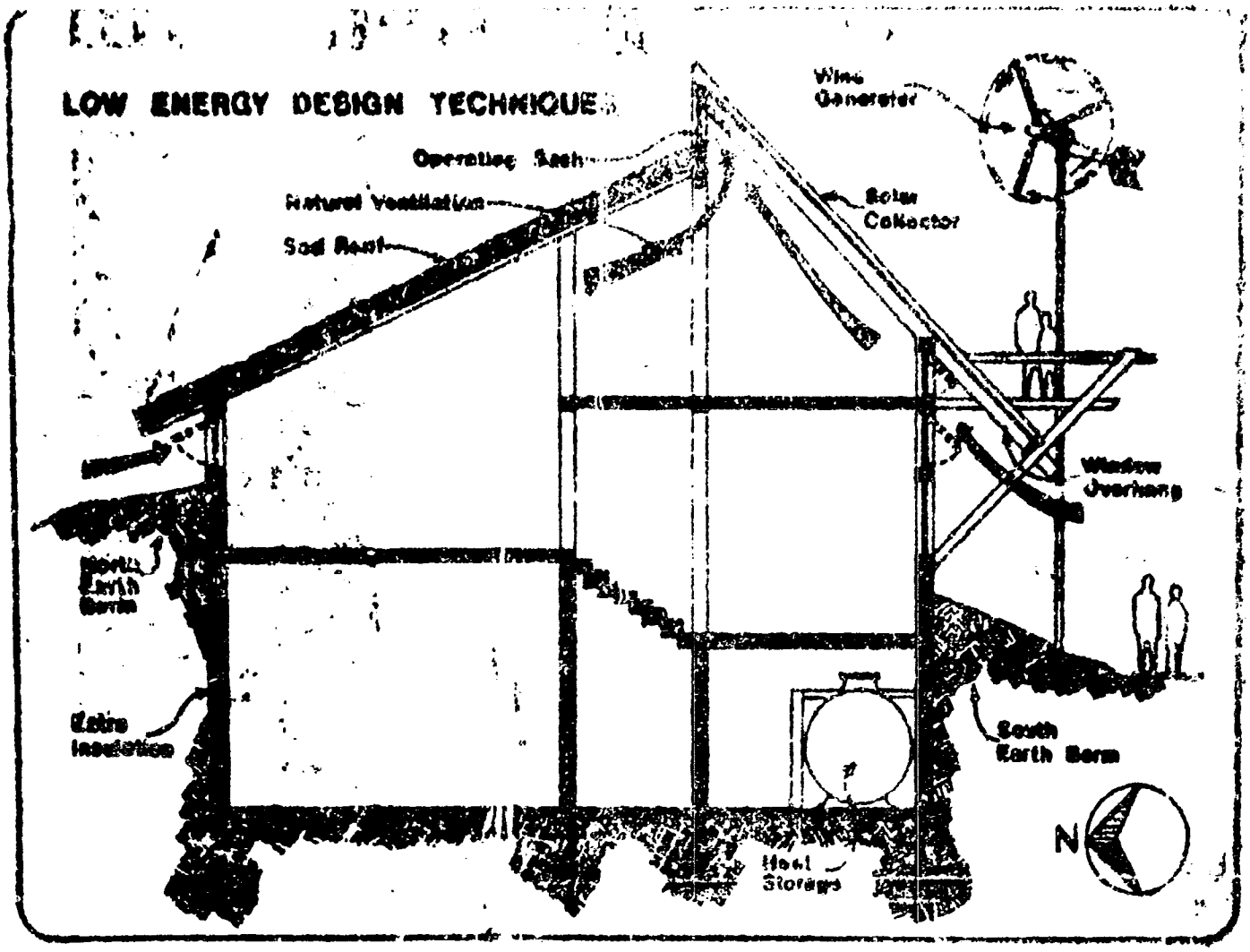
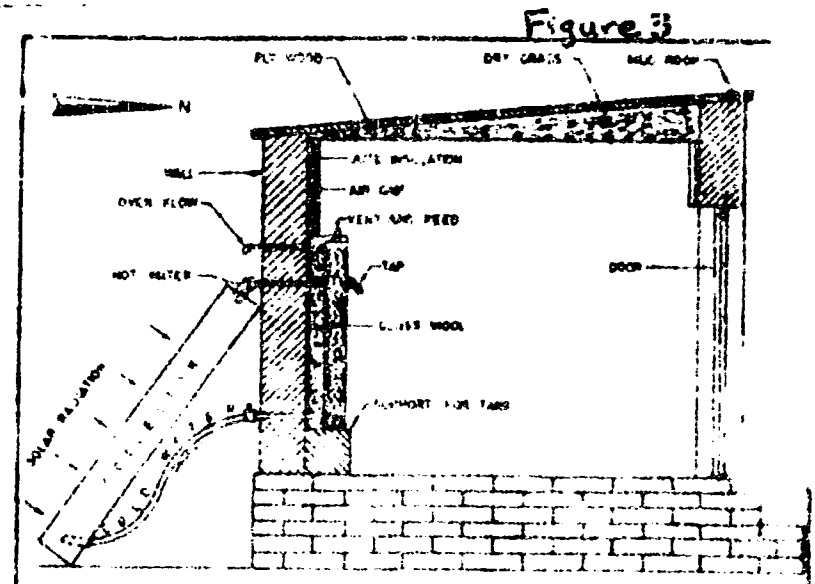


Figure 1

TECHNIQUES: The Sonstructures drawing, above illustrates some of the techniques that can minimize a building's energy demands and utilize alternative sources to fill them.

Figure 3



A simple solar room heater

J P Gupta and R K Chopra of the Defence Laboratory, Jodhpur, India have developed a very simple storage heater for use in high altitude conditions (ie cold air but clear skies). It consists of a flat-plate collector through which warm water thermo-syphons. It passes through the external wall to a tall thin rectangular storage tank on the inside of the wall. The back of the tank is carefully insulated. Heat radiates from the front in the room. It was tested at an altitude of 3,[illegible] under sub-zero conditions for [illegible] down to - 20°C! Antifreeze was put in the water. It heated a living room 3.75m by 2.[illegible]m by 2.4m as satisfactorily as comparable rooms heated by electricity or fuel (kerosene).

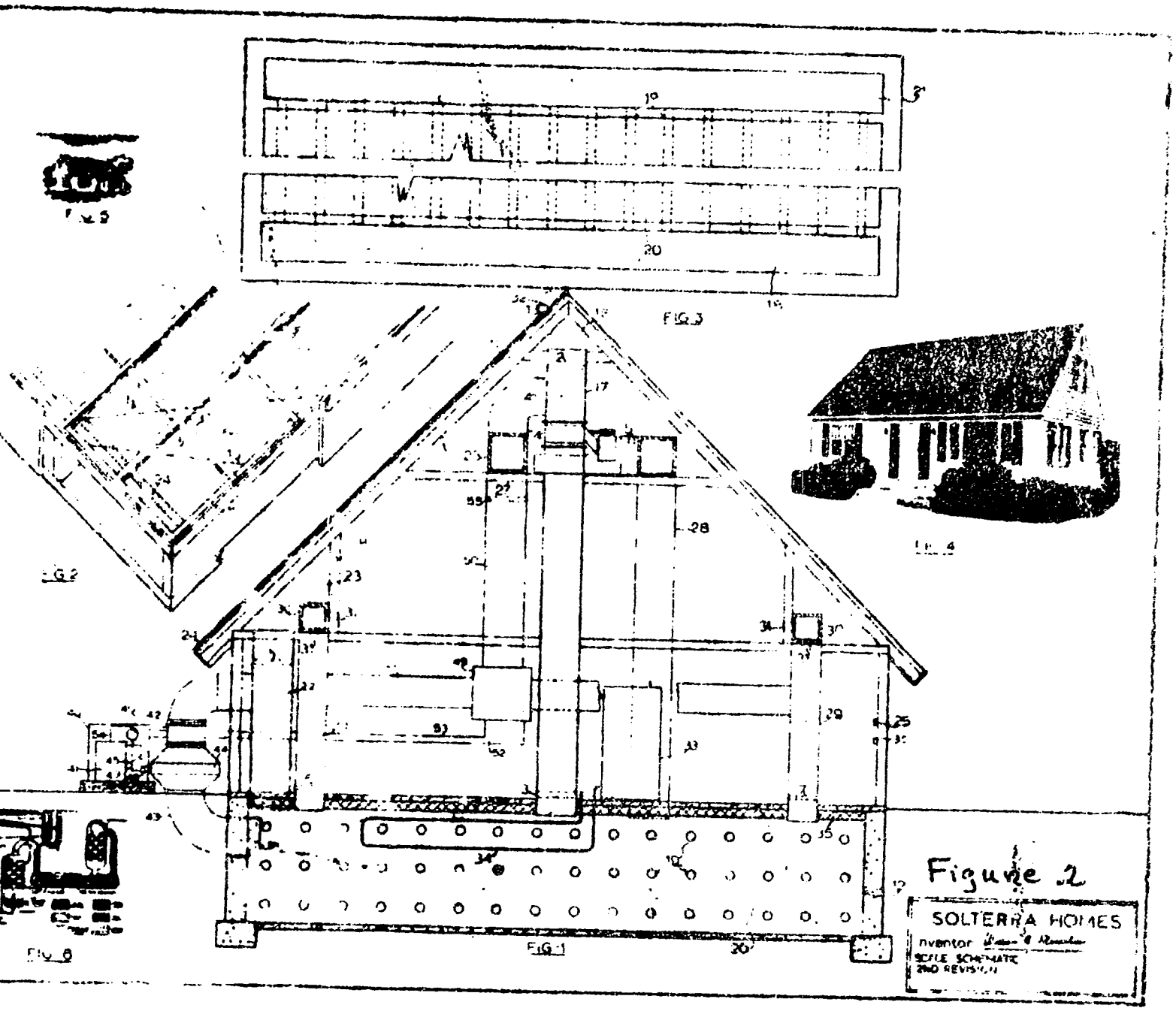


FIG.3
FIG.4
FIG.2
FIG.1
FIG.5
FIG.6
SOLTERRA HOMES
Inventor
SCALE SCHEMATIC
2ND REVISION

Figure 2

3. The Solterra Home (Ref. 7)

William B. Edmondson of San Diego, California has described an as-yet unproven design for a low-cost solar-heated and cooled home that can be built without a backup heating system and has offered detailed plans for sale. Air, instead of water, is heated in a glass-covered flat plate solar collector which also forms the south side of an otherwise normal-looking sloped roof. (Fig. 2) The heated air is circulated through a closed system which includes a heat storage bin contained in the normal basement area of the hosue. Thermostatic controls direct the flow of warm air from the collector into the storage bin during the summer. The bin consists of thousands of cubic feet of damp earth criss-crossed with clay soil pipe, which forms a high surface area heat exchanger. The designer claims that some two months worth of heat at 130 degrees F. can be stored for late fall and early winter heating in a bin of the size that could be located under a typical small house. Hot air produced during sunny winter days is circulated through the house, and any excess or deficit for heating the house is added to or withdrawn from the storage bin. At night all required heat is withdrawn from the bin.

Heat accumulated during the summer can be used to operate an absorption type air conditioner but requires the use of some fairly complex machinery.

4. Jodhpur Solar Room- Heater (Ref. 8)

J.D. Gupta and R.K. Chopra of the Defence Laboratory, Jodhpur, India have developed a very simple storage heater for use in high altitude conditions (i.e. cold air but clear skies). It consists of a flat-plate collector through which warm water moves by means of natural convection. (Fig. 3) It passes through the outer wall to a tall thin rectangular storage tank on the inside of the wall. The back of the tank is carefully insulated, and heat from the warm water radiates from the front of the room. It was tested at an altitude of 3,500 meters under sub-zero conditions. Anti-freeze was put into the water. It heated a living room 3.75 m. by 2.40 m. by 2.40 m. (760 cubic feet) as satisfactorily as comparable rooms heated by electricity or fuel.

This is similar to the system now being tested at USAID/A. The dimensions of the solar collector used by Chopra and Gupta were not given, but if the output of the USAID unit is about 4,000 BTU/hr. during winter days (Ref. 8), a single unit might be sufficient for a room of this size.

5. The Davis Home, Albuquerque, New Mexico (Ref. 9)

Although construction details were not given, this house is heated by naturally-convected warm air from a large flat-plate collector. The house itself is built on the south slope of a hill, so that the first floor appears to be elevated on posts. A heat reservoir of crushed rock under the house stores heat

from the collector. No information about ducts or controls was given, but supplementary heat is needed during prolonged cloudy weather. No pumps or fans are used.

6. The Trombe-Michel Solar Wall (Ref. 10)

Since 1956, the Solar Energy Laboratory of the CNRS (French equivalent of our NSF has been studying the application of solar energy to domestic climate control. The principles of this method were developed by Prof. Trombe (of solar-furnace reknown and director of the laboratory) and their application has involved an architect, Jacques Michel. Michel has this to say about previous "solar houses":

" The absence of success of previously constructed prototypes of houses heated by solar energy is a result of their technical complications. It is for this reason that the designs we propose are as simple as possible. . . ."

The principles upon which the design are based are:

* the use of vertical south-facing walls as collectors of solar energy.
* the use of the greenhouse effect to trap solar energy.
* the natural thermocirculation of air heated this way.
* the storage of heat using the high thermal capacity of concrete or water.

A prototype house built in the Pyrenees (Lat. 42° 37') applies these principles as follows. The south wall consists of a concrete slab which is structural as well as being a heat store. The outside surface of the wall is rough cast and is painted black. The area of the wall intended to collect solar energy is sheathed in an air space covered by glass, two layers of glass being the economical break-even point. (Fig. 4)

Short-wave solar radiation penetrates the glass and is absorbed by the wall, which heats up and emits long-wavelength infrared radiation. This radiation does not penetrate the first sheet of glass encountered, but is absorbed by it and heats it, so that it in turn emits radiation. About half of this is directed externally and half internally. The second sheet is placed to further intercept the externally directed component, so only about one quarter of the long-wave radiation finally reaches the outside. Three-quarters stays inside and heats the air between the panes of glass and the wall, as well as heating the glass and the walls themselves.

The heated air expands, becomes less dense and rises. If there are ducts at the top and bottom of the collecting areas connecting the heated air mass in the collector to the cooler air mass inside the building, the heated air will naturally flow out of the top and cooler air will flow in at the bottom - establishing a circulation of air throughout the building. If the thermal capacity of the collector wall is sufficient it will continue to reradiate heat for most or all the night. Experience

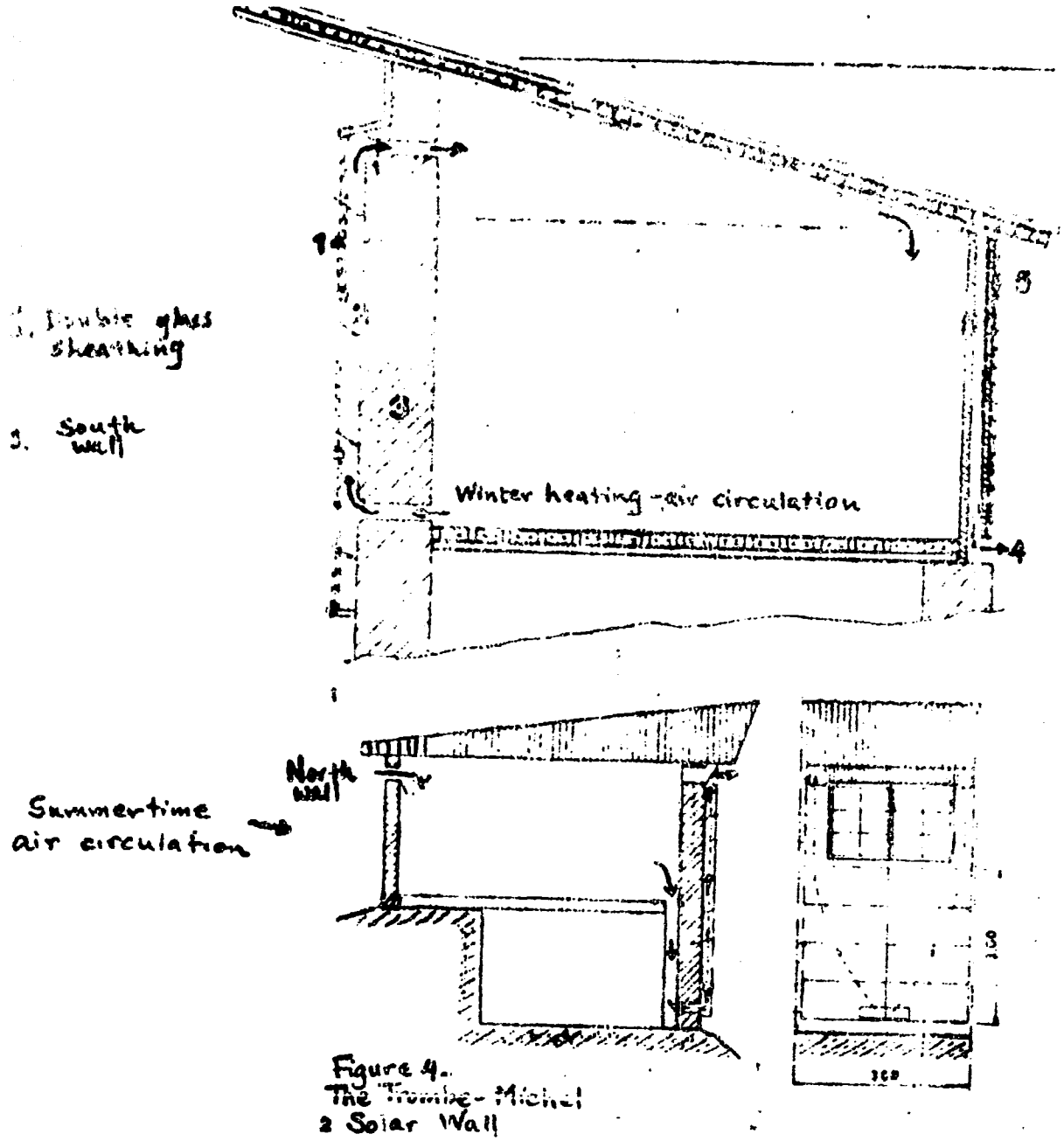


Figure 4.
The Trombe-Michel
2 Solar Wall

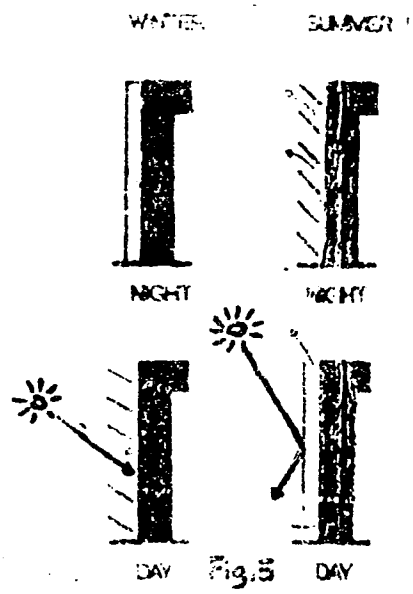


Figure 5.
ABC Group recommends this method of modulating heat flow through walls.

Fig. 5

with the prototype houses in the Pyrenees shows that for a concrete wall 35 cm. thick about half the heat absorbed by the wall is stored by it and is sufficient to maintain a warm air current until the early hours of the morning.

During the summer the pattern of air flow can be modified to cool the house by sucking air through it. The collector acts as a thermal chimney and air from ducts in the shaded north wall is sucked in. (Even with no roof overhang, during the summer months, a south wall at the latitude of Kabul receives only a fraction of the amount of radiation received during the winter. From the beginning of August until the onset of cool weather, it might however be necessary to provide some shading of the south and west walls.)

Michel indicates that for a well-insulated building, one square meter of glazed wall can heat ten cubic meters of interior space. The two prototype houses in the Pyrenees were able to gain two-thirds to three-quarters of the energy required for winter heating (while external air temperatures frequently fell below zero Centigrade).

7. The ABC Group Approach (Ref. 11)

ABC, a multidisciplinary group based in Marseilles, France, have been working on the climatological adaptation of existing buildings, paying particular attention to solar radiation. Their project is in no way attempting to build a 'solar house', nor to develop costly add-on devices, but rather to develop low-cost

housing, "paying great attention to economic constraints and existing social realities." The group summarizes its aims as follows:

* to concentrate on modular housing adapted to (Mediterranean) climatic conditions.
* to ensure that this adaptation improves comfort conditions and does not involve any additions to the cost of construction.
* to ensure a noticeable reduction in running costs and in energy expenditure by increasing the solar heat gain.

Their approach has been to select materials according to their radiant and thermal properties from freely available existing materials. The basis of their system is, as is that of Trombe and Michel, structural. They use the thermal properties of the south wall to absorb, store, and transmit heat in both directions (i.e., from the outside inwards when heating is required, and from the inside outwards when cooling is required). They have chosen to use the wall as the sole means of heat transfer, there is no glass cover heating up a column of air. One of the group, F. M. Camia, has made extensive studies of heat transfer across walls in fluctuating climatic conditions. His approach has been to examine the effect of walls on internal temperature curves. Not surprisingly, he found that the greater the thermal capacity of the wall (usually closely related to thickness and conductance) the smaller the variations in the internal temperature curve over a twenty-four hour period, and the more comfortable the internal climate is likely to be, relative to the external climate. This principle

is not unknown in Afghanistan; thick mud walls having a high thermal capacity contribute much to the year-round comfort of buildings.

Camia also observed that a high capacity wall which reduces the peak amplitude of the internal temperature curve will also put the internal curve very much out of phase with the external curve. (i.e., if the peak external radiation occurs about 2 p.m., the peak internal temperature may not occur until some time later.) The intended use of the building (daytime only or twenty-four hour use) should therefore be taken into consideration when designing the south wall.

Further control of heat transfer across the south wall would be effected by a system of adjustable shutters. (Fig. 5) In the summer these can be used to partially or totally block incoming solar radiation; in the winter they can be opened so that they do not block incoming solar radiation, but when it is cloudy and at night they can be closed up to reduce losses of heat both by long-wave radiation and by convection.

The north wall would be particularly well insulated, while the east and west walls are shaded and treated as being non-absorbing.

The ABC group believes these techniques to be economically viable and hopes that it will be possible to test them in the near future by applying them to actual buildings. Clearly, much of the resulting information will be applicable to local problems.

8. The Phoenix and Atascadero Solarchitecture Houses (Ref. 12)

At lower latitudes in winter a higher proportion of incident solar radiation falls on a flat roof than in northerly locations. Harold Hay has built one of the most successful solar heated and cooled houses near Phoenix, Arizona (approximately the same latitude as Kabul), and another has recently been completed in California at a latitude of 35° N. The concept employed is modulation of heat flow through the roof.

The choice of materials for achieving control over heat flow is as unique as the concept itself. Hay describes his Phoenix prototype himself:

"Corrugated metal sheets form the ceiling supported between upward extending roof-beam supports. Black plastic sheet above the metal sheets was crossed over the beams to waterproof the structure. Six to seven inches (15-18 cm) of water in transparent plastic bags was laid on the lining between the beams. (Fig. 6) This amount of water provided the heat capacity effect of a foot (30 cm) of concrete with a weight equivalent of a three inch (8 cm) slab. Extruded aluminum trackways mounted atop the beams permitted insulation panels to be alternately positioned above the ponds, or stacked two or three deep over a carport.

"Operating procedures for the Phoenix building expose the ceiling ponds to solar radiation in winter. Heat conversion takes place at the black liner under the water and tends to heat the room in the mornings faster than it does the water, which may eventually attain a temperature of 85° F (29.4° C) before the insulation is

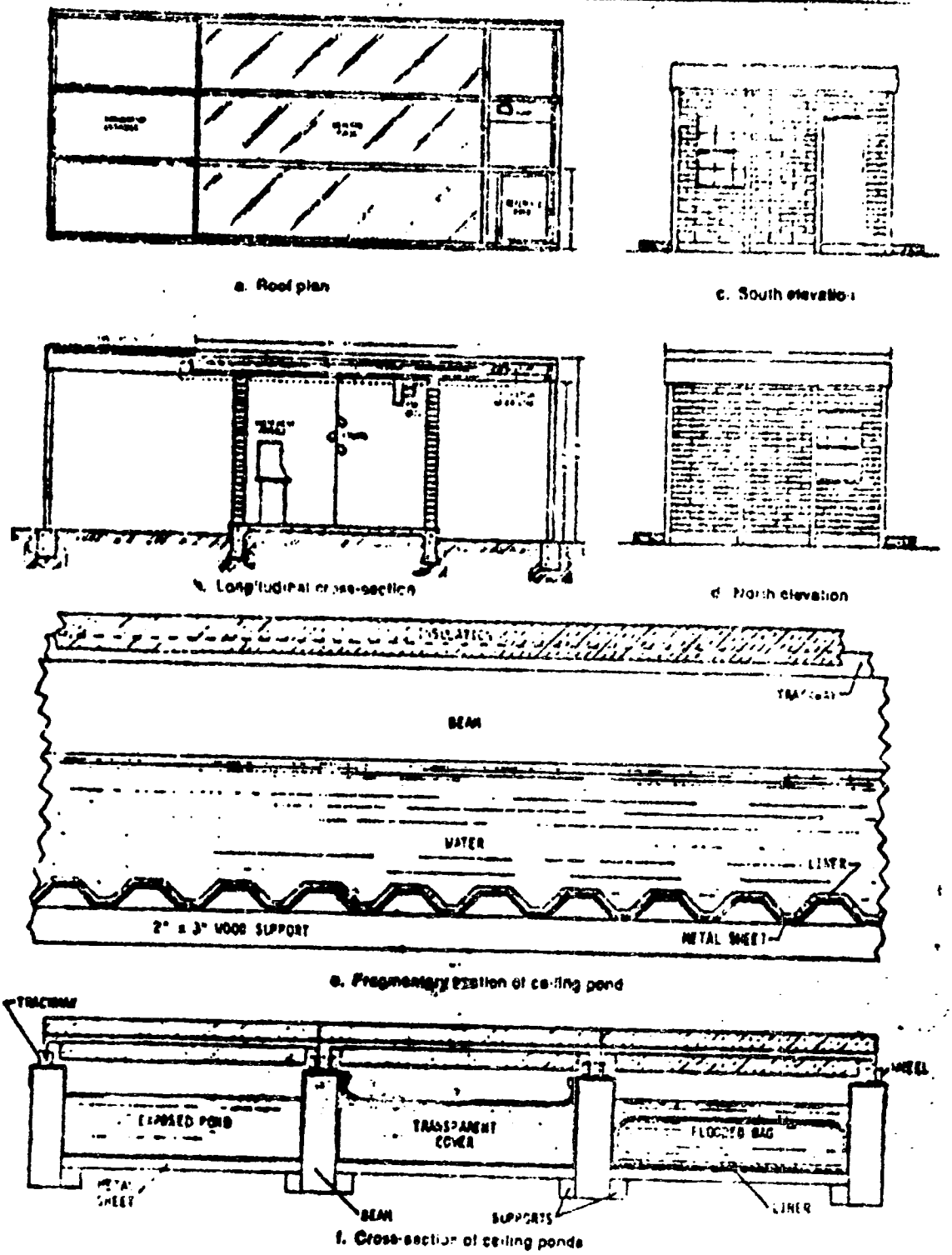


Figure 6 -
The Solarchitecture
Houses

moved over the pond to prevent night-time heat loss to the sky. Downward radiation from the ceiling kept the room in the 66-73° F (19-23° C) range when outside temperatures reached 100° F (38° C) and the 24-hour average was 84° F (29° C). With maxima of about 108° F (42° C) and an average of 87° F (31° C), room temperatures between 77 and 82° F (25-28° C) were obtained by flooding the plastic-enclosed ponds with a thin layer of water. Night-time evaporation of 1/8 to 1/4 inch (.3 to .6 cm) of water cooled the ponds below the minimum morning air temperature. The loss of only 1.37 gallons (5.5 litres) of water can produce the effect of a ton of refrigerant . . . . the problems of humidity restrict roof pond cooling without forced evaporation to dry, clear areas. In these areas natural radiation and evaporation can provide all the cooling most people feel comfortable with - even in the hottest deserts- for winter heating the system is limited to snow-free regions with strong solar radiation.

"Operational skill for this natural air conditioning is minimal. A rope is pulled an hour after sunrise and an hour before sunset. On cloudy winter days there is enough solar radiation to heat the ponds if a weak shadow can be produced by one's hand. The system can be installed and maintained by an illiterate person properly trained. During summer the shaded plastic bags do not deteriorate, algae do not grow, and mosquitoes cannot breed in the enclosed ponds."

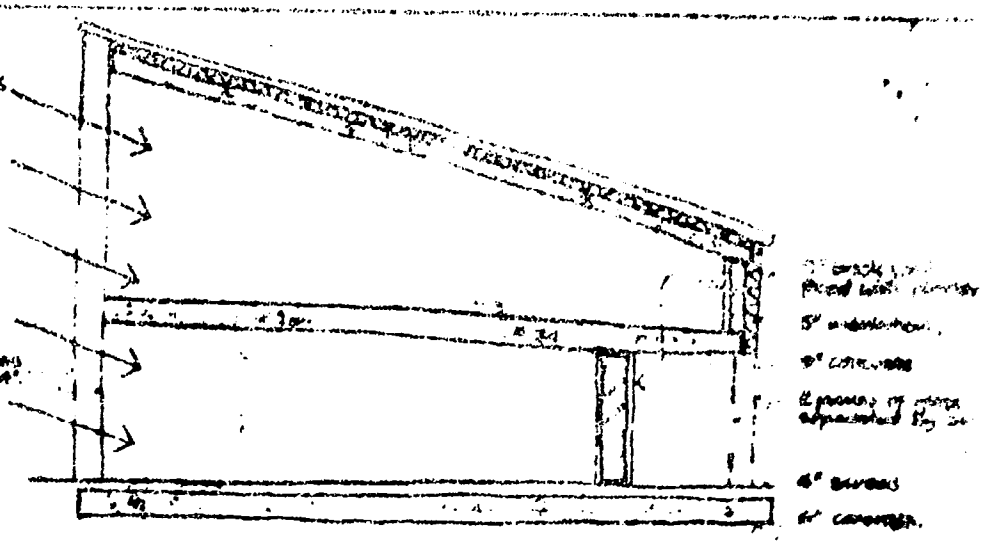
Hay's use of cellular polyurethane panels, a material not readily available in Afghanistan for insulation should not be regarded as an obstacle to local application of the principles described. A possible substitute might be locally-made sandwiches of white-painted composition board filled with dry straw. These would then be compatible with common practice of shoveling snow from roofs, and would overcome the climatic limitation proposed by Hay. A less sophisticated system for covering and uncovering the ceiling ponds requiring some manual labor could be easily devised, perhaps employing hinged panels as used in the Baer house described next. If roof ponds are found to be impractical for Afghanistan, the traditional adobe roof could be used, blackened by mixing crushed charcoal with the top layer of mud. The rapid morning room-heating effect mentioned would be sacrificed, but overall results should be similar if enough thermal capacity exists.

9. The Baer House (Ref. 13)

Steve Baer, architect and ecology activist, has constructed a home near Albuquerque, New Mexico heated by a vertical application of Harold Hay's selective roof. The heat store consists of racks of 55 gallon (200 liter) drums filled with water and stacked vertically on south-facing wall sections behind a single sheet of glass. Movable exterior panels of styrofoam insulation can be raised or lowered to cover or expose the black-painted outside ends of the drums. When heat is needed, the panels are lowered,

Figure 8

St. George's School



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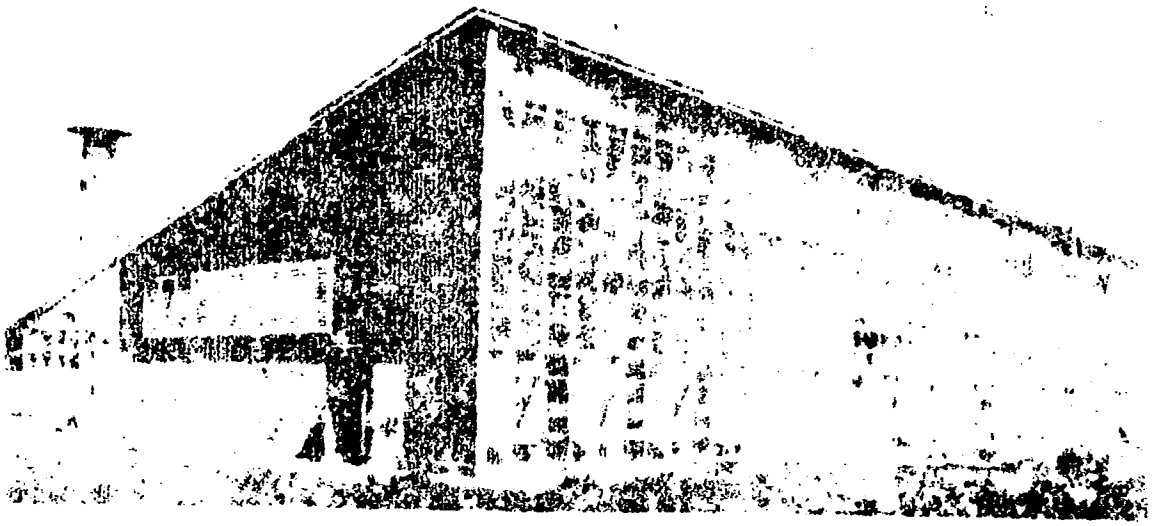

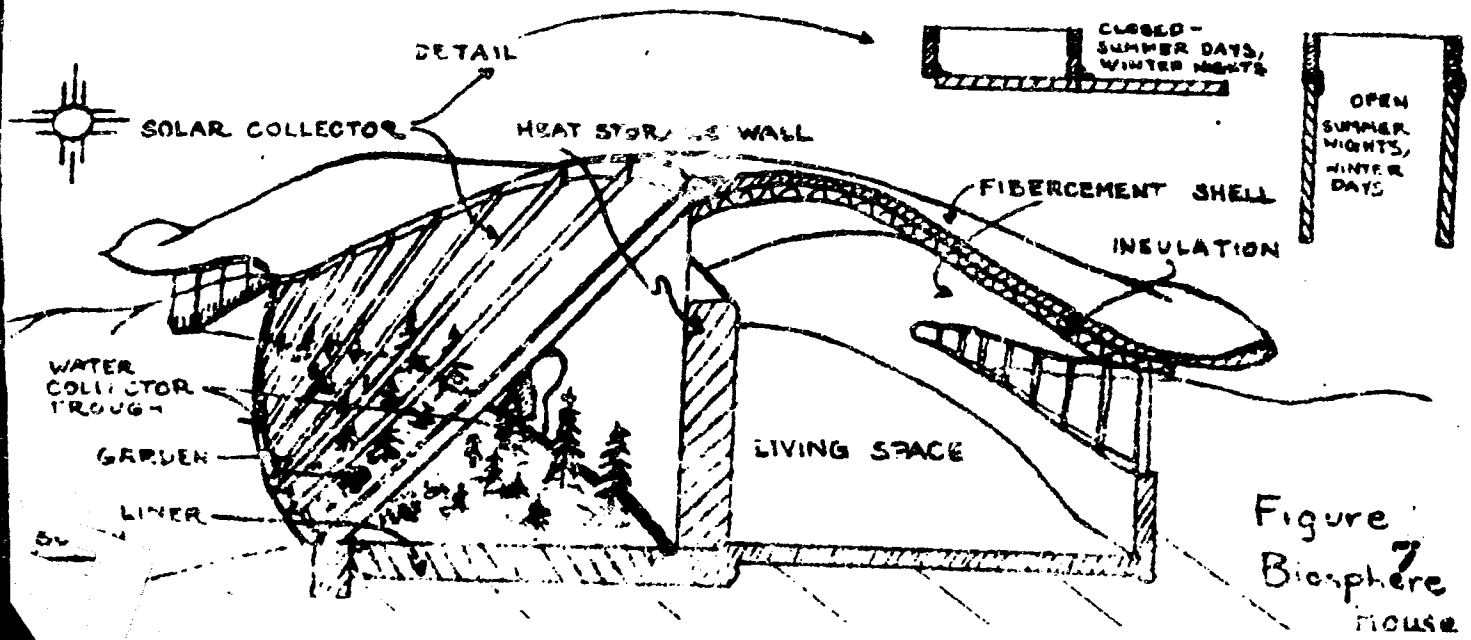

Figure 7
Biosphere House

solar radiation warms the drums and the water inside. The glass reduces external heat loss by long-wavelength radiation and by convection, and the house is heated by inward radiation and convection from the warm barrels. When the sun goes down or heavy clouds come over, the panels are raised to prevent heat from being lost, but the barrels continue to radiate inside. Enough heat can be stored in one day to last through two days of cloudy weather.

10. Biosphere House (Ref. 14)

Day Chahroudi's Biosphere concept applies several of the principles already described in an integration of a house, greenhouse, solar heater, and a solar still. Although it has not been proven in practice, it represents a possible demonstration of advanced ecological principles and could in addition encourage the production of fresh vegetables during winter.

A greenhouse covered by an angled glass or plastic roof is erected on the south side of a long, well-insulated building. (Fig. 7) The south wall of the building is the north wall of the greenhouse and is constructed as a high-capacity heat store. Solar radiation heats the wall and the soil of the greenhouse. At night, insulated panels are swung into place over the glass or plastic to prevent heat loss. The wall radiates heat into the living space and into the greenhouse and ducts allow circulation of air warmed by the soil and the wall from the greenhouse into the living space.

Fresh drinking water condenses on the cold glass or plastic and trickles down into collecting troughs. In summer the shutters are partly closed during the day and opened to allow the wall and soil to cool by radiating heat to the night sky.

11. St. George's School (Ref. 15)

An annex to St. George's School in Wallasey, England was built in 1961 for the use of 300 students. It was designed to gain, directly, as much heat as possible from solar radiation, to be sufficiently massive in construction so thermal inertia would prevent rapid or extreme fluctuations in internal air temperature, and to be insulated so that internally trapped and stored heat stays inside. In winter, solar radiation is the principal form of heating, the only other sources being the occupants and the lighting. It is situated at a latitude of 53° N, and in a harsh, windy, cloudy climate. If it is possible to use unassisted solar energy to heat a building in winter in that part of England, it should be possible to do so in most temperature climates.

The building is a long, thin two story structure running east-west. (Fig. 8) The ground floor, intermediate floor and roof are concrete slabs 4, 9, and 7 inches (10, 23 and 18 cm.) thick, and the latter is insulated by a 5 inch layer of plastic foam. The internal walls and east and west walls are of 9-inch brick, while the low north wall is of 9-inch brick with foam insulation.

The south wall is 27 feet (8.6 meters) high by 230 feet (59 m.) long and consists mostly of double glazing with a 24 inch (62 cm) separation between panes. Each classroom is provided with two or three openable windows, which are single glazed.

The purpose of the tall south wall and the north-sloping roof is to permit the low winter sun to illuminate a maximum of floor and rear wall area. Heat is stored by the massive floor slab and walls, so that external temperature fluctuations are smoothed out and the inside is maintained about 20° C (36° F) warmer than the outside air temperature through night and day, sunny and cloudy weather. Floor-to-ceiling temperature differences, an important indicator of comfort, are quite small.

The St. George's School has demonstrated the possibilities of the simplest possible form of solar heating. Many Afghan houses have a "gulkhana" (flower room) warmed in the winter by sun streaming in through tall windows. Clearly, double glazing is almost a necessity to reduce heat loss, and some kind of shading and ventilation would be required to adapt such a building for summertime use in Afghanistan.

APPENDIX III

Energy Conservation and Climate Control in Indigenous Architecture

The thick mud brick walls used in most buildings in Afghanistan are not only functional in terms of protecting the lives and property of the inhabitants, but also reduce the uncomfortable effects of harsh winter and summer climates. When built to a thickness commensurate with high strength, mud walls also afford a useful (but not ideal) combination of insulation and heat storage properties. As used in traditional designs, they tend to reduce outward heat flow during cold periods while part of the heat trapped in the south wall during the day slowly radiates into the house at night. In the summer, thick east and west walls tend to reduce the effect of peak morning and afternoon solar radiation by absorbing its impact and then slowly releasing the heat throughout the day and evening. High ceilings and thick mud roofs also aid in conserving heat in winter and assist summer time ventilation.

The orientation of buildings and major apertures has been found to follow a formula optimal for natural heating and cooling. The long side of rectangular buildings and the large majority of windows face in the preferred south-to-southeast direction, maximizing solar heat flow into the building in winter but minimizing it in summer by means of small east and west wall areas. South-facing overhangs block the high summer sun.

The use of plate glass is a relatively new innovation and, perhaps due to its high cost in rural areas, a method of making the light admitted by a small pane equivalent to that of a larger piece has evolved. The window opening inside the thick wall is splayed outward so that light is

not blocked when the sun is high or at an acute angle to the wall. The effective window area is increased, while heat losses are kept small.

For hot, arid areas in the south of Afghanistan, specialized styles have evolved which keep daytime interior temperatures low during the summer. A high, domed brick roof is a prominent feature of the Kandahar "gumbazi" building. The dome may promote the circulation of cool air from the floor and exterior courtyards, which are cooled by evaporation of the water sprinkled regularly throughout the day. Small windows in the north and south walls can be opened to take advantage of cooling breezes.

Flat-roofed buildings in hot areas can also be comfortable in summer if the roofs are thick enough to delay the interior heating effect of the noon sun until late afternoon. In the evening the population moves upward to enjoy the coolness, and sleeps warmly on the roof while it and the interior cool down until sunrise.

The dreadful prevailing summer "120-day" winds in the Herat region are harnessed by rooftop wind-towers, which create a partial vacuum inside the building, sucking in cool, relatively dustless air from the courtyard.

Clearly, Afghan builders have accepted the fact that the structure by itself is inadequate to protect its inhabitants from temperature extremes. If natural ventilation and evaporative cooling represent the local form of low-energy supplemental cooling for hot climates, then the ancient innovation known as the "toba-khana" or "takhta sang" must be the local answer to low-energy supplemental winter heating. This system is also known in modern China and Korea, and is reputed to be a highly

economical way of heating an enclosed space. Basically, the floor of the room is heated by hot gases passing through an underground network of channels which serve as the flue of a small oven. Warm air and radiant energy rise from the floor, producing a pleasant warm environment (especially for those sitting on the floor), while the oven itself serves in the kitchen or other room. A large part of the heat normally dissipated to the open air through the chimney is instead put to use, and a relatively small amount of fuel provides even and long-lasting heat where it is most wanted. The oven is fired initially with dry brush for a large fire and quick heating, and then fed slow-burning fuel, often dung cakes.

Further documentation of these methods and their performance would be desirable, but they have been described with such enthusiasm that there is little doubt of their effectiveness. Houses in Ghazni (one of the coldest regions in Afghanistan) built according to these principles are reported to remain comfortably warm all winter while consuming small amounts of fuel, and are said to be cool during the hot arid summer as well.

As elaborated in the text, many of these indigeneous techniques could be embodied in a new, optimized design. The resultant building would then have the advantage of being familiar in terms of construction and operation.

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